Smart Innovation, Systems and Technologies 223

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Design for Tomorrow—Volume 3

Proceedings of ICoRD 2021

Springer

Smart Innovation, Systems and Technologies

Volume 223

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ISSN 2190-3018 ISSN 2190-3026 (electronic)
Smart Innovation, Systems and Technologies
ISBN 978-981-16-0083-8 ISBN 978-981-16-0084-5 (eBook)
https://doi.org/10.1007/978-981-16-0084-5

This Springer imprint is published by the registered company Springer Nature Singapore Pte Ltd.
The registered company address is: 152 Beach Road, #21-01/04 Gateway East, Singapore 189721, Singapore

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Design is ubiquitous; it pervades all spheres of life and has been around as long as life has taken up the task of purposefully changing the world around it. Research into design and the emergence of a research community in this area have been relatively new. Its development has been influenced by the multiple facets of design (human, artefact, process, organisation, the micro- and macro-economy and the ecology by which design is shaped) and the associated diversification of the community depending on the facets of focus or that of their applications. Design is complex, balancing the needs of multiple stakeholders and requiring a multitude of areas of knowledge to be utilised, with resources spread across space and time.

ICoRD'21 is the eighth in a series of conferences intended to be held every two years in India to bring together the international community from diverse areas of design practice, education and research. It aims to showcase cutting-edge research about design to the stakeholders; aid the ongoing process of developing and extending the collective vision through emerging research challenges and questions; and provide a platform for interaction, collaboration and development of the community in order for it to take up the challenges to realise the vision. The conference is intended for all stakeholders of design and, in particular, for its practitioners, researchers, pupils and educators.

The collection of papers in these two book volumes constitutes the Proceedings of the Eighth International Conference on Research into Design (ICoRD'21) held on virtual platform during 7 to 10 January 2021 at the IDC School of Design, IIT Bombay, Powai, Mumbai.

ICoRD series was initiated by Centre for Product Design and Manufacturing (CPDM) at Indian Institute of Science (IISc), Bengaluru, in 2006. Since then, it has been hosted in 2009 and 2011 (both at IISc), 2013 (at IIT Madras), 2015 (IISc), 2017 (IIT Guwahati) and 2019 (IISc). CPDM has pioneered design research in India for the last two decades. IISc is one of India's leading science and technology institutions and is one of the Institutes of Eminence decreed by MHRD, Government of India.

ICoRD'21 has been organised jointly by IDC, IIT Bombay, and CPDM, IISc Bengaluru. ICoRD'21 has been hosted on virtual platform by IDC School of Design, Indian Institute of Technology Bombay, Mumbai, India. IDC School of Design has overseen the inception of design in a free India for the past 50 years. IIT Bombay is one of India's leading technological institutions and is decreed by the Government of India as an Institute of National Importance. As a city, Mumbai serves as a home to a variety of technological and service sectors.

The theme of ICoRD'21 has been 'Design for Tomorrow'. The world as we know it in our times is increasingly becoming connected. In this interconnected world, design has to address new challenges of merging the cyber and the physical, the smart and the mundane, and the technology and the human. As a result, there is an increasing need for strategising and thinking about design for a better tomorrow. Our theme for ICoRD'21 serves as a provocation for the design community to think about rapid changes in the near future to usher in a better tomorrow.

The conference contained:

- Keynote presentations from eminent (inter)national experts and practitioners
- Presentations of refereed papers as podium presentations
- Panel discussions to present perspectives on topics of general interest
- A series of workshops on topics of special interest
- Networking sessions for young researchers.

Preface

Design is ubiquitous; it pervades all spheres of life and has been around ever since life has been engaged in purposefully changing the world around it. While some designs have transcended time, most designs are in a perpetual process of being evolved. Research into design and the emergence of a research community in this area have been relatively new. Its development has been influenced by the multiple facets of design (human, artefact, process, organisation, ecology, micro- and macro-economy by which design is shaped and which it shapes in turn) and the associated diversification of the community depending on the facets of focus or that of their applications. Design is complex, balancing the needs of multiple stakeholders and requiring a multitude of areas of knowledge to be utilised, with resources spread across space and time.

The collection of papers in these two book volumes constitutes the Proceedings of the Eighth International Conference on Research into Design (ICoRD'21) held at Indian Institute of Technology Bombay, India (this time on virtual platform), during 7–10 January 2021. ICoRD'21 is the eight in a series of biennial conferences held in India to bring together the international community from diverse areas of design practice, teaching and research. The goals are to share cutting-edge research about design among its stakeholders; aid the ongoing process of developing a collective vision through emerging research challenges and questions; and provide a platform for interaction, collaboration and development of the community in order for it to address the global and local challenges by forming and realising the collective vision. The conference is intended for all stakeholders of design and, in particular, for its practitioners, researchers, teachers and students.

Five hundred and fifty-four abstracts were submitted to ICoRD'21, from which 529 were accepted for full paper submission. A total of 295 full papers were submitted, which were reviewed by experts from the ICoRD'21 International Programme Committee comprising 238 members from over 149 institutions or organisations from 27 countries spanning five continents. Finally, 234 full papers, authored by 460 researchers (460 unique authors, actually 606 authors' entries in 236 papers) from 21 countries spanning five continents, were selected for presentation at the conference and for publication as chapters in this book. ICoRD has steadily grown over the last seven editions, from a humble beginning in 2006 with 30 papers and

60 participants, through 75 papers and 100 participants in ICoRD'09, 100 papers and 150 participants in ICoRD'11, 114 papers and 170 participants in ICoRD'13, 118 papers and 200 participants in ICoRD'15, 178 papers and 230 participants in ICoRD'17 and 169 papers and 352 participants in ICoRD'19.

All papers were presented in ICoRD'21 in the podium mode. It had keynotes from prominent researchers and practitioners from around the world such as Steve Eppinger, MIT, USA; Punya Mishra, Arizona State University, USA; Armand Hatchuel, Mines ParisTech, France; Tetsuo Tomiyama, International Professional University, Tokyo, Japan; Paul Hekkert, TU Delft, The Netherlands; Tomas Ramos, Nova University, Lisbon, Portugal; Dibakar Sen, Indian Institute of Science, Bengaluru, India, etc.

The chapters in the three book volumes together cover all three major areas of products and processes: functionality, form and human factors. The spectrum of topics ranges from those focusing on early stages such as creativity and synthesis, through those that are primarily considered in later stages of the product life cycle, such as safety, reliability or manufacturability, to those that are relevant across the whole product life cycle, such as collaboration, communication, design management, knowledge management, cost, environment and product life cycle management. Issues of delivery of research into design, in terms of its two major arms: design education and practice, are both highlighted in the chapters of the book volumes. Foundational topics such as the nature of design theory and research methodology are also major areas of focus. It is particularly encouraging to see in the chapters the variety of areas of application of research into design—aerospace, health care, automotive, biomedical and so on.

The theme of ICoRD'21 is 'Design for Tomorrow'. The world as we know it in our times is increasingly becoming connected. In this interconnected world, design has to address new challenges of merging the cyber and the physical, the smart and the mundane, and the technology and the human. As a result, there is an increasing need for strategising and thinking about design for a better tomorrow. Our theme for ICoRD'21 serves as a provocation for the design community to think about rapid changes in the near future to usher in a better tomorrow. ICoRD'21 is organised jointly by IDC, IIT Bombay, and CPDM, IISc Bengaluru. IDC School of Design has overseen the inception of design in a free India for the past 50 years. IIT Bombay is one of India's leading technological institutions and is decreed by the Government of India as an Institute of National Importance. As a city, Mumbai serves as a home to a variety of technological and service sectors.

On behalf of the Steering Committee, Advisory Committee, Organising Committees and Co-Chairs, we thank all the authors, delegates, institutions and organisations that participated in the conference. We also thank the members of the International Programme Committee for their support in reviewing the papers for ICoRD'21, which is essential for maintaining the quality of the conference, and for their support in putting this book together.

We are thankful to the Design Society and Design Research Society for their kind endorsement of ICoRD'21. We thank Indian Institute of Technology (IIT) Bombay and its IDC School of Design, and Indian Institute of Science (IISc), Bengaluru, and its Centre for Product Design and Manufacturing (CPDM), for their support of this event. We also wish to place on record and acknowledge the enormous support provided by the Student Organising Committee in managing the review process, in preparation of the conference programme and this book and the conference as a whole. In particular, we wish to thank Mr. Apoorv Bhatt, Mr. Roopa Narayan Sahoo and Ms. Nishath Salma for their valuable contributions. We also thank the large and dedicated group of student volunteers of IIT Bombay, IISc Bengaluru, IIT Guwahati and other institutions in the organisation of the conference. Finally, we thank Springer, especially its Editor Ms. Swati Meherishi and its editorial support team, for their wonderful support, including their sponsoring of Springer book vouchers for the Winners of Distinguished Paper Awards at ICoRD'21.

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Part I
Design Ideation, Creativity and Synthesis

Chapter 1
Developing the P.O.L.E Framework for User Subjective Experience

Chaitanya Solanki

Abstract Thomas Nagel in his paper, 'What is it like to be a bat?' highlights the problem of subjective experience. He talks about the problem of subjectivity, of how an observer, if not a bat, can never fully understand what it is like to be a bat. This paper takes on the above problem and attempts to utilize it to theoretically deduce that the problem of user subjectivity can be logically dismantled and the information gained can help in the domain of design processes. The P.O.L.E framework tries to utilize on the social and biological aspect of the user's subjectivity and attempts to break it down by engaging in the pre-design stage of task-clarification. It aims at providing a more holistic perception of the user, by piecing together the various influences that might affect an individual's subjectivity. The proposed framework is in its adolescence, but shows the potential to establish a base of information before the design process takes place. The research concludes with tentative future plans of how this framework will be further deployed and tested.

1.1 Introduction

Even though research in new product development (NPD) has been going on for many years, the failure-rate for new products has remained a constant problem [1]. The success of a new product relies mainly on the product development process [2], which includes the effective retention of knowledge and its usage as a part of the design process [3]. Understanding the user, also, is a key part of the developmental process, where the knowledge, if retained, helps in creating a guidance database that a designer/design researcher can refer, whenever trying to gauge preferences, both conscious and unconscious [4]. Even though widely accepted, the application of user-centered principles has still not been able to eliminate the frustration with the designing of modern products. The reason could be that though many organizations preach the importance of practicing user-centered concepts, a lot of them fail to

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A. Chakrabarti et al. (eds.), *Design for Tomorrow–Volume 3*,
Smart Innovation, Systems and Technologies 223,
https://doi.org/10.1007/978-981-16-0084-5_1

consider the consumer needs as the cornerstone of their design processes [5]. It then becomes increasingly important to emphasize the importance of perception from the viewpoint of the user, and though many researchers have tried to address the various nuances regarding it [4]. Although there still lies a need to come up with an approach in design research [6] which can help understand the user's subjective perception holistically, which in turn, can attempt to improve the design process itself.

Since the framework proposed here is still under development, the methods of evaluation have only been suggested in this paper.

1.2 Developing a Framework

Conformity experiments like that of Asch [7] and Milgram [8] show that human perception, subjective experience, and choice making are susceptible to various influences. In this context, influences refer to anything that can alter an individual's subjectivity; which mainly arises from the individual's past experiences [9]. Diminutive discussion of the nature-nurture topic has been found in literature, mainly due to the difficulties of the problem itself and the complexities of collecting objective evidence, but it remains accepted that the nature-nurture dispositions weigh heavily on individuality [9, 10]. The research by Asch [7], Milgram [8], and Leahy [11] demonstrates that social and biological influences can impact choice making in an individual; and because biological and social influences most closely resemble the nature and nurture aspects of an individual, this paper therefore has tried to focus on them to be utilized as a tool for the development of the following framework. The abbreviation 'P.O.L.E' will refer to an expansion which is **P**hysiological dependency, **O**ntogeny, **L**imits of the individual, and **E**nvironmental limitations, respectively. The 'pre-design stage' mentioned hereafter will refer to the task-clarification phase of a design process which comes before conceptualization.

1.2.1 Physiological Dependency

Thomas Nagel, in his paper [12], describes the generally known facts about bats such as that they perceive the external world primarily by SONAR or echolocation while detecting the audio reflections, from whatever is within range and interactive with sound waves which they emit in the form of rapid, high-frequency shrieks. He describes to the reader that the brain of the bat is wired to project the receiving data into information that can help them navigate in the physical world, which mostly relates to the visual interactions in humans. After this, Nagel rightly highlights that though we have read and understood the bat navigation mechanism, it is next to impossible for a human to experience what it would be like to *be* a bat. He says that though SONAR is a sense of perception for bats, it is clearly different from any of the senses that humans harbor and that there is no reason to presuppose that it may even remotely be subjectively understood (experienced in this case) by a human. This appears to create difficulties for the notion of imagining what it is like to be a bat. Along with consciousness and subjective experience, Nagel here also reiterates how the physiological constraints and facilities are salient features of subjective experience. This can be a key for the design process in understanding the user too; the physiological faculties of the user will always dominate the usability of the product/design.

User Dimensions—In this case, the researcher suggests taking into consideration the physical dimensions of the user to design the most ergonomic product suitable for the subject and for the function [13].

Sensory Inputs—Designing a blue/red cup for a user without eyesight might not be the best innovation unless the color is being used as a symbol for other people to recognize. The designer therefore should keep in mind the types of sensory inputs that the designed product might emit toward the user. Research shall be taken into consideration to cater to the design of all senses as products are perceived by subjects through various senses throughout the life of a product [14].

1.2.2 Ontogeny

For this paper, the terms in relation to ontogeny would refer to the experiences that the user had since the time they gained declarative memory and knowledge [15]. Simply put, they will refer to the experiences of the subject since their childhood. The researcher presents the following thought experiment to analyze this part of user interpretation:

> Imagine a child who has been told to draw a rectangle. There are many steps involved in the process, but if the child is uninitiated in the activity, they can end up being clueless. If the child does not know what a pencil is, they might try to pick up a stone to do the deed. Unless the child is informed or has previously observed someone using the pencil to draw, he or she will probably not guess it right. The second step involves using the tool in a correct manner, where the child needs to know the relation between pencil and paper. The final step to draw a rectangle itself is something that the child can never do unless they are familiar with the shape.

Ontogenetic experiences then become key to the behavior of the user/participant. Like in the case of physiological dependency, ontogenetic experiences help the subject to familiarize themselves with whatever stimulus is presented and build upon the experience [9]. Ontogenetic experiences can be regarding the environment that the subject was brought up in, the social trends that the subject might have experienced during their lifetime, geographic influences (living in a humid/cold/hot place changes perception), or the economic range that the subject might have lived within, etc.

Trends During Lifetime—Refers to the comfort level of the subject with respect to the new product being designed. If they have observed trends throughout their lives that make the newer product design not seem completely alien, then their familiarity might help them engage with the newer design quicker [16]. For example, a housewife from the lower middle class in India might be quicker to understand the functions of a washing machine than the functions of a new dishwasher. This is because the usage of a dishwasher is not a common practice in that demographic (engagement also depends on the sophistication of instructions provided along with the product).

Geographic Influences—Ontogeny is heavily influenced by where the person has grown up geographically. It is not difficult to imagine that a person from the upper northern hemisphere who occasionally interacts with sunlight would be more used to the idea of sunscreen, than a person who has grown up near the equator and is more dependent on the presence of melanin in their body [17]. Similarly, the experience of traveling by boat would generally be more familiar to someone from Kerala than that of someone from Rajasthan, and hence, the interpretation toward a product regarding boats might greatly vary among these two demographics.

Economic Comfort—The economic comfort mentioned here is not referring to the spending power that the user might have. Rather it is referring to the range of economic transactions that the user might have engaged or witnessed throughout their lives. To take an example, the child of a well to do businessman would not find it difficult to imagine transactions that involve lakhs of rupees, whereas the child of a small tea shop owner may not have ever witnessed a transaction as big. This can radically influence the perception of the user toward any economic transaction and should be kept in mind [18].

Emotional Status—Though the use of a product is emotionally engaging to the user throughout its life, the moment of purchase is highly influenced by the emotional state of the consumer [19]. The designer might be unaware of that information, as it might be instance based and/or store related, but they should try to research the accurate state of emotion that a consumer might generally have while purchasing a particular product. It can be argued that emotional status should not be categorized under ontogenetic experiences, but we need to remember that even though the emotion experienced during the purchase is momentary in nature, there are a myriad of emotions that have brought the user to the purchase point. Considering the emotional status at the moment of purchase will only help with the efficiency.

1.2.3 Laws of Nature|Limitation of the Individual

Carl Sagan, in one of his famous videos, is trying to explain what a four-dimensional spatial object, a 'tesseract,' he calls it, would look like [20]. Even though he does an apt job of explaining it, his final explanation is limited to 3D imagery. A part of the reason for this is that the human mind cannot comprehend more than the four dimensions of time and space [21]. A more important reason is that human cognition cannot think of shapes/visuals that they have not seen previously either in their entirety or a part of it [22]. This is similar to the analogy highlighted above of Flatland, where the author provides for a setting in which the creatures can only move in two dimensions. He clearly provides for examples that show the inability of the two-dimensional creatures to imagine a three-dimensional object. Though the above example illustrates observational disparity, it can suggest to designers that the subject can only comprehend in ranges that are available to them. Carl Sagan was referring to physical dimensions, whereas here we can refer to other dimensions in which a subject could move.

Economic Capabilities—This directly relates to the range within which a user might be comfortable in making purchases [23].

Functional Design Preferences—In the case of making a choice which is for functional aspects and not for only esthetics, the decisions are made mostly toward conventional experiences. For example, in the case of a villager trying to choose between fossil fuel or solar panels to cook their food, the user would first consider the economic resource available and then consider the comfort level of choices made by their social circle up until now. Solar panels in this case might be an uncomfortable choice for them initially as they represent a non-conventional choice [24].

Knowledge Limitation—Taking the above example of adopting a three-wheeled car, knowledge limitation refers to the degree of awareness among the user regarding the product. If the user has no knowledge about why a three-wheeled vehicle might be beneficial in their case over a four-wheeled vehicle, or the user lacks the capability of understanding it, then trying to design a three-wheeled vehicle could be a futile endeavor. To precisely gauge the knowledge pool of the demographic, the designer/researcher would need to understand and research all the outlets of information that the user might have access to [25].

1.2.4 Environmental Limitation

The work of Nagel is also reminiscent of the famous thought experiment/story by Abbott, which he staged in the world of 'Flatland' [26]. The author provides a setting in which the creatures can only move in two dimensions. He urges the reader to imagine a vast sheet of paper on which straight lines, squares, heptagons, pentagons, and other figures, instead of remaining fixed in their places, move freely about, within or on the surface, but lacking in the ability to rise above or to sink below it, very much like shadows. The shapes axiomatically perceive each other just as a straight line, unlike what an onlooker from our world would perceive. In the latter part of the story, one of the shapes supernaturally granted the ability to rise above their setting and view their own world from the perspective of a higher dimension, where shapes like spheres and cubes live. Though Abbott's story was a comment on the intellectual disparity of the Victorian times, it is also highlighting a key aspect of observation and perception of creatures belonging to any universe. The work, like

Nagel's, points out that a creature is limited in its perception and subsequently the observations made from that perception by the capabilities of its physiology and the physical liberty that is provided to it by the laws of nature of that world. He clearly provides for examples that show the inability of the two-dimensional creatures to imagine a three-dimensional object.

When addressing the challenges of design, the metaphor of flatland resonates with the part of the process which connects to the user. If the product that is being designed has attributes that are out of the limited perspective of the user, it might affect his/her perception radically, making the interaction more volatile. To understand this, the reader can imagine giving a touch screen phone to an Indian farmer in the 1960s and observing the hypothetical situation. The farmer would have absolutely no idea what to do with it in terms of functionality as the concept of wireless communication would not have permeated the society yet and the technological jump will not bring the farmer any benefit if the society is not allowing him/her to utilize this discovery. This illustrates the fact that though designs can be radical for experimentation, they would best work only if the user society has some idea of what the design is indicating. For example, in the development of the first iPhone, though the design might have been substantially different from other phones in terms of interaction and esthetics, the user base had some working understanding of what a wireless phone is and does and what it means when a phone is touch operated [27]. Although the analogy of flatland teaches one to empathize with the limited perspective of the user, it also highlights how an observer, if observing from a specific distance, can identify problems that the participant/user themselves could not, similarly to how shapes observed each other as lines while the observer could see their complete forms.

Social Facilities—Refer to the range of tools that society offers to the user to understand a product. To take an example, the laws in the USA make gun ownership common, whereas a common person holding a firearm may come as a shock to anyone in India [28]. This disparity in perception is caused by the rules and framework set by society at large and should be taken into consideration while designing a product.

Social Acceptance—Arising from the facilities provided by society, social acceptance can have many contributors to influence the thinking of a user [29]. For example, the probability of adopting a garment that resembles a burqa might change with the religious inclination of the user and their social and cultural circle. Another example would be of a company trying to sell a three-wheeler economy car in a country where four-wheeler family cars are the norm. The acceptance of the society (or the lack of it) might turn out to be disadvantageous for the company. Therefore, the designer/researcher is advised to consider and research the acceptance level of the society toward whatever is to be designed.

Option Availability—The user choice would rely heavily on the number and types of options that are presented before them. This range limits the circle within which a user can explore. The circle is increased by the presence of the Internet, but it still varies from region to region. Other than understanding the competition, researching the other options will also provide insight into the social facilities and acceptance of the group.

It needs to be noted that for the purposes of definition, 'physiological dependency' (2.1) is a biological category while the rest (2.2-2.4) encompass social aspects; however, the product will finally dictate what each category will reflects with respect to the user. For example, even though 'knowledge limitation' (2.3) is dictated by the outlets of information around the user, it can very well be altered by the individual's own capacity if the product being designed is for a neurologically/physiologically atypical user. The designer/researcher will then have to club this subcategory as a biological influence. The paper therefore suggests that the categories and subcategories are to be considered as oscillatory in their definitions.

1.3 P.O.L.E Framework Applied

To further highlight what each of the subcategory should ideally represent during an independent case, the researcher tries to work through the framework with a hypothetical product for reference. It is to be noted that the categories (and subcategories) might or might not be exhaustive at this stage of development, but that will be scrutinized in further research where P.O.L.E might be tested with actual products; after which the framework will be modified to accommodate the new findings. The product we have selected for this is 'face protection equipment' (F.P.E). We have made this selection because the product is in great demand during the contemporary times of the COVID-19. The product has a very specific function to provide for the user, and it can be used both in private and in public across many parts of the world, but for this instance, the research will specifically focus the design to cater to the needs of the lower-earning class of India. The physical and functional inputs for this product have been taken from the review on face shields by Roberge [30].

Hypothetical Design Brief: 'Design a 'face protection equipment' (F.P.E) for the low-income class of India.'

1.3.1 Physiological Dependency

The F.P.E, for its functionality, relies heavily on the initial moment of the application by the user and then has to sustain prolonged use.

User Dimensions—The designer/researcher would need to take into consideration the average physiological dimensions of the hands and face of the average user. The fastening mechanism would need to cater to the size of the hands, whereas the wearable dimensions would need to be accommodating for the average size of the head of the user. The protective part should also be considered to cover the entire face of the subject and not just partially.

Sensory Inputs—The main senses that an F.P.E will stimulate would be touch, sight, and occasionally smell. For touch, prolonged use can result in chafing and damage to the skin over long periods of time. Thus, the material selection and tightening mechanism should be designed with that in mind. Sight needs to be unhindered for the user, which would again emphasize on the correct material selection and the angle of view permitted by the design. The close proximity of the product to the nose of the user makes it important to take the smell into consideration. Smell would be key initially as the new equipment could harbor the smell of chemicals used to produce the materials. It will also be important to make sure that none of the materials produce odor by reacting with the occasional splashes of water.

1.3.2 Ontogeny

The use of F.P.E is not a common occurrence around the world for the lay population. It is especially rare for the lower-earning class of India.

Trends During Lifetime—Many consumers making a choice to purchase an F.P.E would do so out of necessity or prevention. It could be inferred that the users from the lower-earning of India would not have had a chance to engage with the use of a mask for their daily activities. In India, the use of masks is a part of many communities for ritualistic purposes during festivities and as toys for children to play. There have not been many trends regarding masks for the common people other than the ones where superheroes wear them in movies and on television. This information can indicate to the designer/researcher that for a mask to be accepted by the user, it needs to be functional while being the least noticeable. One more thing to observe would be that up until now, an F.P.E has been a nonessential trend and would be perceived by a lot of people similarly. It would be the duty of the authorities as well as the designer/researcher to counter this.

Geographic Influences—As stated above, the use of F.P.E has not been a regular part of the Indian population, but it could be slightly different for the demographic of the areas around Delhi, where the rise in air pollution levels has forced the population to adopt face masks and respiratory aides. The lower income demographic from this particular region might be more comfortable in accepting the use of masks. There could even be potential to push some radical designs in this area. Other than that, the designer needs to keep in mind how the material would interact with the user in a humid place like Kerala, a hot dry place like Rajasthan and cold and wet place like Meghalaya. The design should be engineered to reduce the disparity between the usages of various geographies.

Economic Comfort—As we have selected the demographic of the lower-earning population in India, it is key to realize that transactions of two to three digit numbers might be frequent for them, whereas transactions regarding thousand and lakhs of rupees could be out of their conventions and comfort. The design has to be accommodating toward the purchasing power of the selected demographic.

Emotional Status—As the need for the product that we have chosen, arises from a state of emergency, we can infer that the emotional state of the purchase would generally not be happy, excited, relaxed, content, etc. Rather the emotional states might lean toward surprise, hurry, worry, tension, etc.

1.3.3 *Laws of (Design) Nature\Limitation of the Individual*

The fact that F.P.E purchasing by the common person is a new (hypothetical in this case) phenomenon in India helps the designer understand that there will not be many frontiers where this product will initially be available for the purchasers. This drastically limits the venues for the consumer to go.

Economic Capabilities—For the low-income demographic of our study, anything priced at 500 rupees or above would be an almost impossible purchase for the user when comparing it with the other necessities of life. It is also important to note that the use of F.P.E has been an absolute nonessential up until now for a lot of users and thus, they would not want to invest too much in it initially.

Functional Design Preferences—As mentioned before, there exists no conventional choice for the user, as this is a new product necessary for their daily lifestyle. Therefore the contest of preference would lean toward whatever design is able to make its way into the familiarity of the society for this demographic. For this, the designer could also invest time in thinking about how to familiarize their user into the usage of their product as quickly as possible, for the product to seep into the functional design preference of the masses.

Knowledge Limitation—The passing of information among the users will happen through the word of mouth, advertising, and government instructions. This will severely limit the knowledge of the product toward the user. F.P.Es are products that work best if the user is well aware of the consequences of using them properly/improperly. Though, raising awareness will happen through indirect channels, the designer themselves should consider informing the users about their product. This will also help the user to familiarize themselves with the product which in turn with help with the ‘functional design preference.’

1.3.4 *Environmental Limitation*

Social Facilities—The product being designed will axiomatically only be available at limited venues. Though this would be an unfamiliar product for the common man and the common market, the push by authorities in the times of a pandemic might help expand the range availability.

Social Acceptance—There could be some resistance from various cultural and social elements. The act of wearing an F.P.E itself might be new to the community and thus would take time to be socially accepted. The designer could think about a design which is minimal to reduce the impact of the visual aberration.

Option Availability—The user choice would rely heavily on the number and types of options that are presented before them. This range limits the circle within which a user can explore. The circle is increased by the presence of the Internet, but it still varies from region to region. Other than understanding the competition, researching the other options will also provide insight into the social facilities and acceptance of the group.

1.4 Testing and Validation

After establishing all the specifics from the P.O.L.E framework, the designer is already equipped with preliminary guidance data to initiate the design (see Table 1.1). Though the proposed framework is in its adolescence, the concerns generated from this method could be useful in kick starting the design process. All the categories highlighted in the P.O.L.E framework can be researched in much more detail by various methodologies, for example, researching the user dimensions and sensory input through 'focus group methodology' for ergonomic design [31] and understanding the economic capability through consumer behavior theories [23]. However, the aim of this framework is to provide for a holistic approach in understanding the subjective user experience. It intends to understand the user better, so the evaluation methods should attest if the user is getting more satisfaction using a product designed by this framework. Methodologies of varying processes can be applied to evaluate the user expectations, product performance, functional satisfaction, emotional satisfaction, and user behavior after purchase [32], to analyze the effectiveness of P.O.L.E.

The researcher plans to test this methodology by implementing it in modules for the graduate and postgraduate design schools over the course of next few years. The students will be guided through the framework, and then, their final designs will be evaluated. Another plan is to use the P.O.L.E framework to try to create a market ready product and try to test it in the field with performance comparative analysis of similar products already available.

1.5 Conclusion

It needs to be emphasized that the variables will change significantly with the type of product that needs to be designed. For example, if the product to be designed is a digital application, then the sensory inputs would mainly concern the visual

Table 1.1 F.P.E for the low-income class of India' through the P.O.L.E Framework

P.O.L.E	Categories	Variables	Specifics
Physiological dependency	User dimensions	Fitting and use	Hand and face average measurements
			Ergonomic fastening mechanism
			Complete orifice coverage
	Sensory input	Prolonged use	Skin contact engineering
		Odor	Material selection
		Vision obstruction	Angle of view design
Ontogeny	Trends during lifetime	Non-familiar (exception of high air pollution areas)	Minimum
	Geographic influences	Diverse usage	Minimize geographic disparity in usage
	Economic comfort	User transaction range	2 digit and lower 3 digit transactions
	Emotional status	Moment of purchase	Surprise, hurry, worry, tense
Laws of (design) nature/limitations of the individual	Economic capability	Low	Under five hundred rupees
	Functional design preference	None	Easily adoptable design
	Knowledge limitation	Limited to word of mouth, personal experience	Self-informing product
Environmental limitations	Social facilities	Limited	Local shops, medicals, etc.
	Social acceptance	New to the society	Minimum visual intervention for the society required
	Option availability	None initially, potential saturation later	Competent design to combat cheaper products

modality of the user, social facilities will change to the Internet, the laws of design nature would limit itself to the digital screen, and social trends would concern the society that has access to the product through a digital interface. If the product design requirement is that of a garment, then the geographic influence, trends during lifetime, and social acceptance would play a greater role in the process. It is hoped that the proposed framework can provide guidelines to a more holistic approach to a design process by piecing together the various attributes that influence subjective perception and encourages collaboration with other disciplines. This is expected to lead to the improvement of design processes, which in turn, are expected to improve the chances of producing a successful product, however, that is the scope of subsequent studies.

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Chapter 2
Questionnaire-Based Investigation of Preferences in Idea Evaluation Depending on Educational Backgrounds

Yuki Taoka, Yuya Suka, Yoshifumi Nishida, and Shigeki Saito

Abstract It is a key competence of companies to develop innovative products. Those products are developed by a team of people from diversified backgrounds. However, merely forming a multidisciplinary team does not directly link to a higher degree of creativity of outcome. The degree of creativity of outcome is largely contributed by early phase of design projects, namely concept development. It can be further divided into divergence (such as idea generation) and convergence (such as evaluation and selection of concept). Although creative ideas should be selected during the convergence process, factors influencing successful concept selection are still unknown. Therefore, it is of importance to support multidisciplinary teams in concept developments, especially on concept selections. We hypothesize that people prefer specific aspect of ideas depending on their discipline. This paper focuses on the development of a questionnaire and clarify differences in the choice of ideas between arts and engineering students. The developed questionnaire has eight pairs of ideas, each of which has an idea having a significantly higher degree of feasibility but a lower degree of novelty (feasible idea) and the other idea has vice versa (novel idea). Participants are asked to choose one good idea from each pair. The questionnaire was responded by both fifteen engineering and art students. The result suggests that there might be more similarity than significant differences in the preference of creativity due to educational backgrounds. The results also imply that the novelty aspect tends to get fewer attentions while usefulness gets much attention. This paper offers findings in factors of individual idea selections.

2.1 Introduction

In highly competitive markets, companies have to develop innovative products or services through design projects. Concept generation in design projects generally has divergence phase and convergence phase. In the divergence phase, possibilities

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A. Chakrabarti et al. (eds.), *Design for Tomorrow–Volume 3*,
Smart Innovation, Systems and Technologies 223,
https://doi.org/10.1007/978-981-16-0084-5_2

of design spaces are expanded (i.e., idea generation) while design options are evaluated and selected during the convergence phase (i.e., idea evaluation and selection) [1, 2]. Since few ideas from concept generation are moved forward and commercialized, successfully selecting creative ideas is as important as generating creative ideas [3]. There are numerous tools to support to generate creative ideas in divergent phase (i.e., brainstorming), which seems to be widely accepted by design practice. There have also been many tools proposed for idea evaluation and selection. However, the currently proposed tools for supporting designers to evaluate the creativity of ideas are not widely used by design practice [4]. It remains to be unknown about what factors influencing successful idea selection [5]. In design projects, it is crucial to have teams consisting of people from diversified backgrounds. The members' diversity allows diversified viewpoints which determine the number of resources available to apply to the solution of the problem [6]. The variety in resources potentially lead to innovative outcomes [7]. However, an increasing degree of diversity in a team does not directly link to a higher creativity of project outcomes [8]. Diversity in a team can also hinder the design process due to a decrease in common understandings and shared experiences. Recent research found level of experiences in design [9], cognitive styles diversity and self-efficacy [10], intergroup conflicts [11], and personality trait [12] as factors influencing group design. Considering the fact in design practice that design projects are carried out across traditional departments in companies, it is of importance to clarify the influence of educational backgrounds on design collaboration, especially on idea evaluation and selection. It is also useful for educators to be aware of possible impacts of disciplinary backgrounds in design educations.

Therefore, the objective of this paper is to explore the impacts of educational backgrounds of people taking part in design activities, to idea evaluation and selection. This paper reports development of a computer-based questionnaire to test the impacts and a preliminary result of a comparison between university students studying art and engineering.

2.2 Creativity and Concept Selection in Design Process

In the early phase of new product development, concepts of solutions are generated. The concept development phase typically consists of divergence and convergence process [1, 2]. As failure in concept selection costs extra time and money, it is of importance to support designers to evaluate and select promising ideas. In concept selection, creativity is one of the criteria to measure a design outcome [13]. Many scholars have attempted to define creativity [14, 15]. A common understanding of creativity is that a creative design outcome has "novelty," "usefulness," and "easibility" [15]. As novelty refers to newness to humans, we define a novelty *is a degree to which an idea is rare, unusual, or uncommon.* Usefulness refers the *degree to which an idea effectively solves problems.* Feasibility is defined as *technically feasible and socially easy to put into practice* [14, 15]. Having creative ideas is crucial for new product developments. However, creative ideas are often failed to be selected during concept selection [5]. Factors influencing such failure are researched, which includes preferences of conventional ideas, ownership bias [1], confirmation bias [16], and personality and team attitudes toward risk and ambiguity [5]. The degree of education also influence perceptions of ideas in terms of creativity [5]. However, it is still unknown influence of differences in educational backgrounds on concept selection.

2.3 Research Question and Overview of Method

Our overall goal is to support concept generation by groups of people having multidisciplinary backgrounds. As convergence is a critical phase of design process, it is of interest to explore how educational backgrounds impact on idea selection.

We consider that people might prefer one aspect of ideas depending on their discipline, which might eventually hinder group design activities. Increasing awareness of self-preference may help teams to conduct design activities. As a first step, we formulated three hypotheses to focus on clarifying differences in the preference due to educational backgrounds.

- H1: Students majoring art choose more novel idea than students in engineering.
- H2: Students majoring art prefer novel ideas than feasible ideas. Students in engineering do in vice versa manner.
- H3: There is a difference in factors to influencing idea selection.

The authors developed a computer-based questionnaire for two reasons. First, computer-based questionnaires allow us to focus on differences in educational backgrounds by eliminating known biases originated from design practice such as ownership bias which makes person evaluate ideas which he/she generated [1] and attitudes toward uncertainty which have person choose ordinal ideas [5]. Second, it can be easily applied to more numbers of people. This paper focuses on the development of a questionnaire and its preliminary evaluation to clarify differences in preference between arts and engineering. In order to imitate idea selection, the developed questionnaire has pairs of ideas, each of which has an idea having a higher degree of feasibility but a lower degree of novelty (feasible idea) and the other idea has vice versa (novel idea). The ideas were shown with a persona and design issue to which each pair of ideas were generated for participants are asked to choose one good idea from each pair for the personas and the design issue. This paper consists of two parts; questionnaire development reported in Sect. 2.4 (Fig. 2.1, 4) and preference test reported in Sect. 2.5 (Fig. 2.1, 5). The profiles of participants were similar in three experiments. The participants (mean age: 21.9, SD: 1.81) were undergraduate or graduate students studying in either art universities (fine arts, products design, etc.) or in an engineering university (mechanical, chemical, etc.). Most of the engineering students does not have any experiences in product designs while the art students have some experiences in product designs. The participants of all experiments were not the same.

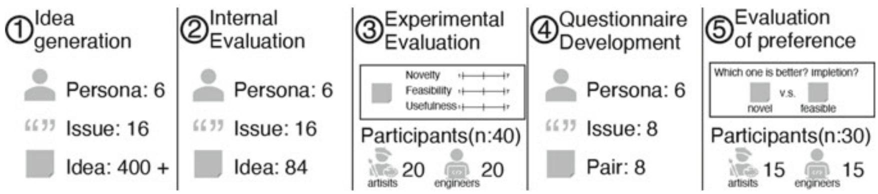

Fig. 2.1 Overview of the research process

2.4 Development of a Questionnaire

To develop the questionnaire, the authors firstly created six fictional personas, sixteen design issues. Then the authors generated more than four-hundreds ideas toward the personas and design issues (Fig. 2.1, 1). After the idea creation, the authors selected eighty-four ideas which the authors believe are either significantly novel or feasible idea (Fig. 2.1, 2). Each idea has an illustration and a brief explanation in texts (Fig. 2.2). As each idea should be stably perceived by anyone, the ideas were evaluated with seven points Likert scale in terms of novelty and feasibility (Fig. 2.1, 3). Since the number of evaluated ideas were too many to be evaluated by one participant, eighty-four ideas were randomly divided into two sets in order to reduce the burdens of participants (set A: forty-three ideas, set B: forty-one ideas). Each set was evaluated by a group of twenty students. Each group consisted of ten engineering students and ten art students. Therefore, the number of participants in total was forty.

Each idea was shown with a description of target users (Fig. 2.2) and a design challenge toward for which the idea was created (e.g., "*Medical services that are comfortable for seniors*"). Before the evaluation, the participants read brief definitions and examples of novelty and feasibility. The instruction is "*You will be asked to evaluate ideas. The ideas are generated for each issue which a target subject has. Evaluate the ideas with the following three criteria.*" Table 2.1 summarizes terms, definitions, and examples of three criteria. A brief sentence of terminology such as novelty was presented along with a short explanation instead of showing terminology itself. In Table 2.1, the example is modifications of instruction by Dean et al. [14].

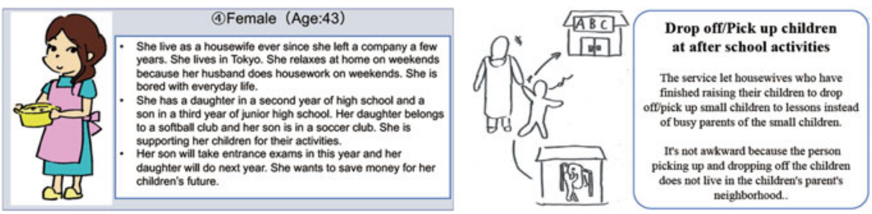

Fig. 2.2 An example of a persona and an example of an idea

Table 2.1 Summary of criteria shown to participants prior to evaluation

Criteria	Presented terms	Explanations	Examples
Novelty	Not only is it new, but it is imaginative and unexpected	Whether the idea is inventive, imaginative, unexpected, or humorous	1: advertise photos of sightseeing spots 7: say a religious relic like "Tokugawa reserves fund"
Feasibility	Technically feasible and socially easy to put into practice	Whether the idea is a low cost, or technically possible, or easily realized without dramatic change	1: Create a sea 2: Create a list of things to do under 1500 Japanese Yen
Usefulness	Effective in solving problems	If feasibility is not considered, the idea is reasonable and solves the stated problem	1: tell tourists to bring their water bottles 7: Research to discover the target market for tourists

The authors modified the example as the original examples include sociocultural-dependent knowledge such as name of city. The design prompt of the examples is "*How can we attract more tourists to Saitama-prefecture?*".

Nonparametric test was used to statistically analyze the responses to find pairs, each of which has one idea of having significantly high feasibility compared to the other idea and the other having significantly high novelty compared to feasible ideas. The statistical analysis was conducted with two steps: within idea analysis and inter idea analysis. "Within idea analysis" was conducted to find out significantly either novel or feasible ideas. For example, a novel idea should have a significantly higher score of novelty than usefulness and feasibility. The analysis eliminated sixty-eight ideas which do not have significant difference between two criteria. In other words, twenty ideas (eight novel and twelve feasible ideas) remains as candidates of idea pairs. "Inter idea analysis" was conducted to create pairs in which novel idea has significantly higher novelty than the feasible idea and lower feasibility than the feasible idea (Fig. 2.1, 4). Ideas of each pair should share a common persona and a design issue. Table 2.2 shows the statistical result of the evaluation scores with Likert scale of the remaining sixteen ideas of "within idea analysis." Table 2.3 summarizes the results of "interidea analysis" and created eight pairs of ideas. In Tables 2.2 and 2.3, the not-used ideas were omitted due to the limitation of the space of paper.

2.5 Testing Preference of Idea

In order to explore how students choose ideas, the developed questionnaire consists of eight pairs of ideas. Participants are asked to choose a better idea within a pair of ideas and to fill in a brief sentence about what they feel and/or think about each idea. As each pair has a significantly feasible idea and a significantly novel idea, the

Table 2.2 Statistical analysis result of within-idea evaluation in developed questionnaire

No.	Criteria	*p*-value/effect size		No.	Criteria	*p*-value/effect size	
		U.	F.			U.	F.
21	N.	0.003/0.67	0.00/0.84	55	N.	0.047/0.45	0.003/0.67
	U.	*	0.04/0.46		U.	*	0.049/0.44
26	N.	0.001/0.76	0.00/0.84	56	N.	0.051/0.44	0.007/0.60
	U.	*	0.001/0.74		U.	*	0.07/0.41
29	N.	0.743/0.07	0.00/0.78	61	N.	0.001/0.74	0.001/0.86
	U.	*	0.00/0.80		U.	*	0.004/0.64
30	N.	0.013/0.56	0.00/0.81	62	N.	0.003/0.68	0.010/0.58
	U.	*	0.003/0.67		U.	*	0.271/0.25
33	N.	0.005/0.63	0.011/0.57	66	N.	0.007/0.60	0.001/0.88
	U.	*	0.568/0.13		U.	*	0.002/0.82
36	N.	0.011/0.57	0.003/0.86	68	N.	0.002/0.71	0.002/0.82
	U.	*	0.001/0.77		U.	*	0.013/0.55
42	N.	0.002/0.7	0.001/0.73	82	N.	0.485/0.16	0.015/0.55
	U.	*	0.131/0.34		U.	*	0.003/0.67
43	N.	0.005/0.64	0.001/0.73	84	N.	0.001/0.75	0.005/0.63
	U.	*	0.008/0.59		U.	*	0.904/0.03

N.: Novelty, F: feasibility, U.: usefulness

participants are forced to choose either feasible or novel ideas. The questionnaire was responded by both fifteen engineering students and fifteen art students. The students are not the same as the participants of the questionnaire developments. The responses were analyzed by two methods. One is counting the number of feasible ideas and novel ideas chosen as good ideas by each participant, which is supposed to reflect preferences of an aspect of creativity of ideas. The number was statistically analyzed to explore H1 and H2. The other is deductive and open coding of free comments. As a preliminary analysis, the coding focus on aspects of creativity, which are novelty, feasibility and usefulness.

Tables 2.4 and 2.5 summarize the results of the number of selected ideas. Table 2.4 shows the results of comparisons between art students and engineering students. As there were no significant differences, H1 was not supported. On the other hand, there were significant differences in preferences within participants as Table 2.5. The results suggest that the participants, especially those studying arts, tend to choose feasible ideas than novel ideas. H2 was practically denied. The preference of feasible ideas in concept selection is consistent with the preference of conventional ideas due to avoidance of uncertainty [5, 17]. However, this experimental setup is supposed to exclude the factor because the participants are not to develop the selected ideas further. The result suggests that there may be differences in biases of creativity between engineering students and art students.

Table 2.3 Statistical analysis result of interidea evaluation in developed questionnaire

	Mean (SD)	Novel idea	Feasible idea	*p*-value	Effect size
Q1*	Item No.	#21	#26		
	Novelty	5.20 (1.40)	2.35 (1.42)	0.0002	0.84
	Feasibility	3.20 (1.75)	4.20 (1.72)	0.0001	0.86
	Usefulness	2.05 (1.36)	6.30 (0.84)	0.038	0.46
Q2	Item No.	#29	#30		
	Novelty	4.95 (1.47)	3.75 (1.34)	0.0023	0.68
	Feasibility	4.90 (1.22)	5.00 (1.55)	0.0001	0.86
	Usefulness	2.10 (1.30)	6.05 (0.92)	0.7956	0.06
Q3	Item No.	#33	#36		
	Novelty	5.10 (1.61)	2.55 (1.6)	0.0007	0.76
	Feasibility	3.80 (1.78)	4.05 (1.69)	0.0002	0.82
	Usefulness	3.50 (1.60)	6.35 (0.73)	0.6868	0.09
Q4	Item No.	#42	#43		
	Novelty	3.75 (1.76)	6.10 (1.14)	0.0003	0.82
	Feasibility	5.55 (1.50)	4.90 (1.61)	0.0003	0.81
	Usefulness	6.15 (1.15)	3.50 (1.66)	0.1278	0.34
Q5	Item No.	#55	#56		
	Novelty	5.60 (1.36)	4.25 (1.51)	0.009	0.58
	Feasibility	4.55 (1.56)	5.05 (1.36)	0.002	0.71
	Usefulness	3.85 (1.56)	5.65 (1.31)	0.166	0.31
Q6*	Item No.	#61	#62		
	Novelty	5.15 (1.24)	2.85 (1.28)	0.0002	0.84
	Feasibility	3.25 (1.41)	4.85 (1.68)	0.0002	0.84
	Usefulness	1.90 (1.09)	4.55 (1.80)	0.001	0.75
Q7	Item No.	#65	#68		
	Novelty	5.20 (1.08)	2.85 (1.28)	0.0002	0.83
	Feasibility	4.20 (1.44)	4.80 (1.6)	0.0001	0.86
	Usefulness	2.25 (0.99)	6.00 (1.26)	0.226	0.27
Q8	Item No.	#82	#84		
	Novelty	4.80 (1.36)	3.50 (1.28)	0.004	0.65
	Feasibility	4.95 (1.28)	5.20 (1.25)	0.001	0.73
	Usefulness	3.35 (1.49)	5.35 (1.53)	0.616	0.11

Table 2.4 Statistical analysis of the number of novel ideas selected by each group

Types	By Art Stu. M (SD)	By Eng. Stu. M (SD)	Effect size	*p*-value
Novel	3.00 (1.65)	3.47 (2.29)	0.114	0.683
Feasible	5.00 (1.65)	4.53 (2.29)	0.114	0.683

Table 2.5 Statistical analysis of the number of ideas by students

Profile	The number of novel ideas M (SD)	The number of feasible ideas M (SD)	Effect size (ES)	*p*-value
All	3.23 (1.98)	4.77 (1.98)	0.38	0.039
Art	3.00 (1.65)	5.00 (1.65)	0.53	0.039
Engineering	3.47 (2.29)	4.53 (2.29)	0.25	0.34

480 free comments were collected. Free comments were analyzed in two ways. One of the analysis is a deductive coding, in which two authors used predefined codes. As a secondary analysis, two authors carefully read the results and creates categories of comments.

Table 2.6 shows the description of codes and the result of the deductive coding. The list of codes was mainly created based on the definition of creativity. Code of *idea* is added because literature suggests that converging process stimulates idea generation. The deductive coding procedure consists of two steps. First, two authors independently code the results of six participants (three artists and three engineers). The intercoder agreement, Kappa, was calculated (Kappa: 0.68), which is good enough [18]. Then, each author independently evaluated the results of twelve participants (six artists and six engineers). The sum per person of the numbers of ideas to which the code was assigned was calculated. Within the coding, a sentence can be coded by more than two codes (e.g., "feasibility positive" and "usefulness positive"). The results suggest that there were no significant differences between art students and

Table 2.6 Comparison between art and engineering students in coding regarding creativity

Code	Example	Art M/SD	Eng. M/SD	*p*-value (ES.)
New idea	I think that adding the VR function will make the experience more realistic	2.07 (1.62)	2.00 (1.60)	1.00 (0.001)
Novelty positive	The idea has novelty. This is a service that has never been offered before	0.40 (0.63)	0.40 (0.74)	0.87 (0.013)
Novelty negative	It is a low-risk option, but it doesn't feel novel	1.67 (1.23)	1.60 (1.30)	0.81 (0.016)
Feasibility positive	The current train already has a monitor, so it seems feasible	0.60 (0.83)	0.40 (0.63)	0.57 (0.040)
Feasibility Negative	It is going to take a lot of money, time and effort	3.80 (2.91)	4.87 (2.10)	0.25 (0.069)
Usefulness positive	I think the idea enables you to commute and to relieve stress at the same time	3.07 (4.15)	2.60 (2.20)	0.65 (0.028)
Usefulness negative	I wonder if the robot will be able to relax	4.93 (3.69)	5.20 (3.19)	0.87 (0.011)

engineering students. As a general tendency, participants commented usefulness of ideas more often than feasibility or novelty of ideas. The result implies that participants tend to focus on usefulness of ideas and to ignore novelty aspect of ideas in idea selection. When mentioning usefulness, the comments can be both positive (praising usefulness) and negative (pointing out problems). However, participants tend to point out problems of novelty and feasibility rather than mentioning positive aspect of ideas. Those tendencies are common in both educational backgrounds. Evaluating usefulness might require less effort than novelty and feasibility. At the same, pointing out problems may need less effort than finding favorable points of ideas. There might be a need for developing tools to supports designers to evaluate novelty of ideas.

Table 2.7 shows the result of open coding. The authors found that feasibility and usefulness can be further divided into several aspects. The participants commented feasibility in terms of three aspects; social, economical, and technical. Social aspect is often addressed when ideas violates current ethical norm in society. Economical aspects refer to costs of realizing ideas while technical feasibility refers to existence or lack of technologies to realize solutions. Those classifications are consistent with definition of feasibility in creativity evaluation [14]. The result suggests that the participants fairly evaluated feasibility aspects. Usefulness can be divided into four categories, for persona, for stakeholders, for myself, and for general people. "For persona" and "for stakeholders" are relevant to the current idea selection because the participants are supposed to select a good idea for an issue of persona. However, the result shows that the participants evaluated ideas based on usefulness of other person(s), whom are not targets of concepts. The result implies that incorrect evaluation may hinder the participants to select a good idea in design practice. We do not report the number of each coding because the comments are sometimes too short to be analyzed accurately. For example, one comment for an idea which itself is coded as "usefulness for myself" can be categorized as "usefulness for persona" after reading comments for several different ideas written by the participant. The category may be

Table 2.7 Category of open coding

Class	Category	Example
Feasibility	Social (ethical or legal)	The idea ignores privacy and confidentiality
	Economical	What about the cost of installation and such?
	Technical	How do you use facial recognition to determine if you are a prowler?
Usefulness	For persona	The desire to "relax at home" cannot be fulfilled
	For stakeholders	Neighbors will not be able to hear necessary sounds (e.g., alerts of disasters)
	For myself	The euphoric feeling I have […] I was not very happy even if they mailed it to me
	For general people	[…] It seems to be less effective for people who use their smartphones

able to act as a reference for sorting out discussion on feasibility and usefulness of ideas within multidisciplinary team.

As the participants of this study are university students, it is of interest to use the developed questionnaire with experts who have professional experiences in their fields. The difference might be more significant. It is also of interests to use the developed questionnaire with different educational backgrounds. It is an area of future research to develop a questionnaire within which participants choose one idea among three types of ideas, namely novel, useful and feasible.

2.6 Conclusion

In this study, we developed a questionnaire to measure individual preferences of creativity and reasoning in idea selection. The questionnaire was used to explore differences in engineering students and art students. The result suggests that there might be more similarity than significant differences in the preference of creativity due to educational backgrounds. The preliminary content analysis implies the participants focus on usefulness aspect of ideas than novelty and feasibility aspect of ideas. The participants also tend to point out problems rather than praising good points in ideas selection. This paper offers findings on factors which influence individual idea selections and its relevance to educational backgrounds.

Acknowledgements This research was supported by the Japanese Society for the Promotion of Science, KAKENHI Grant Number 20K20116.

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Chapter 3
Decoding Nature-Inspired Form Generation Processes

Shiv Kumar Verma and Ravi Mokashi Punekar

Abstract Form giving/styling for nature-inspired designs is a creative problem-solving activity that involves a rigorous visual analysis of natural forms. In this paper, we attempt to understand the 'designerly' way of thinking for products that draw inspiration from nature. For our study, we examine the works of Owen Jones, Christopher Dresser, Arthur Heygate Mackmurdo, Luigi Colani and Ross Lovegrove, who are internationally known for their biomorphic style of design. The study follows a qualitative research methodology of grounded theory to closely examine the research material drawn from published articles, interviews, and audio-visual material for analysis. Inferences and insights are drawn to suggest methods that may assist novice designers to reinvent their design methods and approaches.

3.1 Introduction

Nature has a strong influence on art and design movements, and this is seen reflected in movements of different eras in the past: Glass with silver mounts by Charles Robert Ashbee and Wallpaper by John Henry Dearle—Arts and Craft Movement, Inky cap lamp by Emile Galle and chair by Mackmurdo—Art Nouveau Movement, Coconut chair by George Nelson and PH-lamp series by Poul Henningsen—Modernism, Spirit of the Wind by Rene Lalique—Art Deco, Mae West Lips Sofa by Salvador Dali—Surrealism, Panton chair by Verner Panton and Voronoi Shelf by Marc Newson—Organic Design Movement, Egg chair by Arne Jacobsen—Scandinavian Modern Movement are few examples.

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A. Chakrabarti et al. (eds.), *Design for Tomorrow–Volume 3*,
Smart Innovation, Systems and Technologies 223,
https://doi.org/10.1007/978-981-16-0084-5_3

Understanding the complexities of the natural form and transforming them into a three-dimensional form can be a prime concern for designers. During this transformation, a designer often struggles to avoid any direct imitation of natural form and often attempts to achieve a degree of abstraction in the designed form. However, for the lack of any established approach to form generation, novice designers often struggle during the early stages of their careers to maintain this balance between imitation and abstraction. Fascinated by the beauty of the natural form, they incorporate certain visual cues in the product form without understanding the underlying principles in nature. However, professional designers seem to have overcome this shortcoming with experience. In this study, we aim to undertake a study of the processes followed by five leading professional designers to examine their form generation process. The study will help to identify the various factors involved in the generation of product forms inspired by nature. The outcome of the study will help to outline and develop nature-inspired design methods and tools that can assist design practitioners and educators in the future.

Nigel Cross in 'Designerly Ways of Knowing' [1] explains that knowledge in design research can be gathered from three sources: processes, products and people. He further clarifies that the focus on 'people' includes an investigation into the human ability to design. By probing into the processes and methods that well-known experienced designers follow, we can attempt to decode the underlying principles of nature-inspired form generation processes.

In this paper, we attempt to answer the following research question:

- What design factors do professional designers consider during their process of designing nature-inspired product forms?

we present the outcome of a study that set out to examine the design approach of five well-known designers and identify various factors they considered in their design process to generate forms inspired by nature. Five acclaimed international industrial designers were selected for the current study based on their work on nature-inspired design: Owen Jones, Christopher Dresser, Arthur Heygate Mackmurdo, Luigi Colani and Ross Lovegrove.

3.2 Methodology

Published literature that examines the approach of designers engaged in designing nature-inspired product forms is very limited [2–4], and those specifically focused on design factors of such product forms are almost non-existent. However, a few research papers were identified in the area of forms and nature [5–7]. Considering this limitation, we opted for a methodology based on grounded theory [8, 9] for our study to achieve our research objectives.

3.3 Data Collection and Analysis

Published literature suggests that documentary evidence and textual data are the research material that can provide significant information about human thoughts and human behaviour [10]. Researchers have used documentary and textual analysis in architectural research [5, 11, 12], industrial design research [13, 14] and engineering design research [15]. These research materials include memoirs, letters, diaries, newspapers, maps, photographs, paintings, etc. Investigators in the social sciences use a different type of research material, e.g. ethnographers use data from field notes and interviews obtained from field observations [8].

For this study, we followed a three-stage process for data collection and analysis. As source material for our study, we gathered information on the works of the five international designers from books and research papers along with the transcripts of their interviews available on the Internet [2, 16–24].

In the first stage, we sorted and organized the data based upon their type and source of information. The second stage involved reading through all the data to understand their overall meaning. Chunks and segments of the data that contain information about the design process were identified during this stage. In the third stage of coding, these chunks and segments of texts were coded following the grounded theory procedure proposed by Strauss and Corbin [8]. The two-stage coding scheme included: open coding and axial coding. Open coding, the first stage of coding, was achieved by analysing a sentence, paragraph, and also perusing books as the data source and included simple and precise words that captured and condensed the meanings in the textual data. Coded concepts obtained during open coding were then categorized under core categories during the axial coding process that followed. During this second stage, the codes that made most analytic sense were brought together around a core category to build a dense network of related codes. The codes/coded concepts were related to the core categories based on their properties. The entire coding process was done through a continuous comparison between data to data and data to codes [8, 9]. Following the paradigm of Strauss and Corbin [8], we established the emerging connections between codes/coded concepts and core categories. The basic components of this paradigm (Conditions, Action/Interaction and Consequences) helped us to understand 'Why' and 'How' designers respond in a certain way while designing product forms inspired by nature.

For example, the coded concepts '*Botanical imagery*', '*Microscopic forms*', '*Natural growth patterns*' and '*Shapes in nature*' have a similar property of 'Sources of Inspiration'. Therefore, these four codes/coded concepts are grouped under the '*Inspiration*' core category. The core categories '*Inspiration*', '*Observation*' and '*Necessary conditions*' are identified as '*Conditions*' because their subcategories/coded concepts answer why designers respond in a certain way.

As an outcome of this protocol, fifty-one codes/coded concepts were identified and these were grouped under fourteen core categories based on their properties. These fourteen categories were subsequently identified as Conditions, Action/Interaction or Consequences. These core categories and coded concepts form the major findings of this qualitative study that are discussed in detail in the next section to follow.

3.4 Findings

The text analysis of the selected five designers under study resulted in the identification of fifty-one coded concepts, grouped under fourteen core categories: *Inspiration, Observation, Necessary conditions, Laws in natural forms, Principles in natural forms, Manipulation in natural forms, Mental conceptions, Symbolism, Art, Pleasure and emotions, Modes of externalizing ideas, Transformative processes, Previous work, Design philosophy* (Fig. 3.1). The core categories and the linked coded concepts were the design factors that influenced the work of these five designers, and these have been organized into a network diagram (Fig. 3.1). This diagram is grounded in the words and text of designers under study as all the design factors were directly coded from the primary source of data.

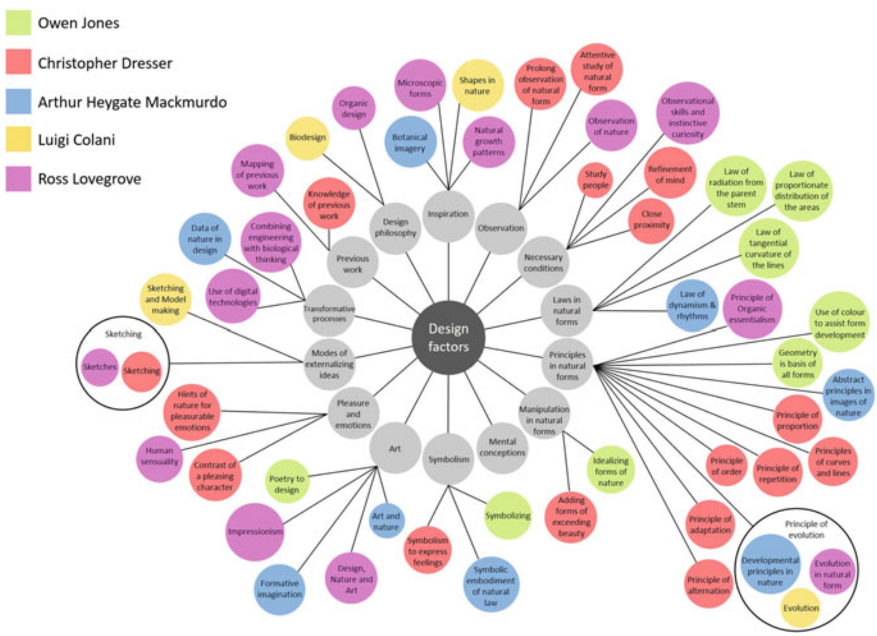

Fig. 3.1 Design factors (core categories and coded concepts) identified from the text analysis of the five selected international designers. *Source* Authors

A detailed discussion of the fourteen core categories and their subcategories/coded concepts follows:

1. **Inspiration**
   The core category indicates the type of inspiration from nature, which designers mostly preferred for their design work. Mackmurdo preferred the use of *Botanical imagery* for his designs; these are the images of natural environments like marine vegetation [2]. Ross Lovegrove explored *Microscopic forms* for his inspiration. These microscopic forms are the sources of new form elements as they are not visible to the naked eye but can be explored only using instruments like an electron microscope. He has also drawn inspiration from *Natural growth patterns* like fractals in nature [16]. Luigi Colani looks for *Shapes in nature* to get inspiration. Products designed by him display a close resemblance with natural shapes and forms [17].
2. **Observation**
   Observation of a natural form is necessary to collect visual information about that form. Ross Lovegrove mentions that his work is very much influenced by the *Observation of nature* [18]. Christopher Dresser suggests that a *Prolong observation of natural form* is necessary to investigate and to understand its refined shapes. He also explains that this observation could be an *Attentive study of natural form* which involves the study of various parts and their orientation, shapes, lines, colours, contour in organs and sections of forms [19].
3. **Necessary conditions**
   These conditions support and help designers to understand nature and reflect it in their design work. Dresser proposes that being in *Close proximity* of natural form helps to discover new forms within a single natural form. He states that to appreciate the delicacies of form and line, *Refinement of mind* is required. For this refinement, constant observation and investigation of natural forms are required. He suggests that to design an ornament for the people, it is necessary that one should enter the spirit of ornament. For this, the student must *Study people*, their religion, habits, nature of their food and character of their climate, etc. [19]. Referring to the drawings of Leonardo da Vinci, Ross Lovegrove explains how good *Observational skills and Instinctive curiosity* work together to create amazing art [16].
4. **Laws in natural forms**
   These are the laws that we find everywhere in nature. Laws on which leaves and flowers grow. Owen Jones identifies some of these laws like *Law of radiation from the parent stem*—'In surface decoration all lines should flow out of a parent stem. Every ornament, however distant, should be traced to its branch and roots'. *Law of proportionate distribution of the areas*—'Areas in the leaf are so perfectly distributed that repose of the eye is maintained'. *Law of tangential curvature of the lines*—'All junctions of curved lines with curved or of curved lines with straight should be tangential to each other' [20]. Mackmurdo's work was based on the *Law of dynamism & rhythms*, which is about

the dynamic changes or rhythmic changes in the natural form in response to an external force of wind or water, e.g. swaying of plants in air or water [2].

5. **Principles in natural forms**
   These principles are the guiding ideas that may help a designer to observe, study and understand the natural form or any natural phenomena. Christopher Dresser explains some of these principles which are discussed below [19]:

- *Principle of order*: Various parts of a plant follow a principle of order during their development phase. This principle of order is a result of a geometric arrangement that exists in these parts, e.g. spiral leaf arrangement.
- *Principle of repetition*: It is an indication of plant growth. Repetition is further divided into four categories: radiating repetition (in flowers), elongated repetition (in leaves), extended repetition (growth of the plant in a divergent manner, e.g. parsnip flower), repetition of a spot or a part.
- *Principle of alternation*: Alternation is the arrangement of parts of the flower and distribution of leaves on a stem. In flowers, the principle of alternation governs the arrangement of four series of parts: first series (ring of outer green leaves), second series (ring of coloured leaves), third series (awl-shaped or thread-like members) and inner series (a central organ). These series are arranged in an alternate fashion, for example, third series parts do not fall over the second series parts but in the space between them, they alternate with them and also with inner series. In case of leaves, the second leaf is situated at the opposite side of stem and when viewed from the top second pair falls between the spaces of units of first pair.
- *Principles of curves and lines*: There is beauty and power associated with curves and lines. Beauty lies in the subtlety of a curve. Curves are full of energy and life. To capture that beauty of life, one must have energetic curves in design. If observed carefully one can easily spot curves like parabola, hyperbola, ellipse, catenary, involute, convolute and arc in nature. Among various curves that exist in nature, the line is found to be the most powerful in character. The line of life is a class of line, which expresses a strong vital power in nature. The direction of growth of leaf and buds is related to this line. The rule of the tangential union, which states that 'the union of curves with curves, or curves with right lines must always take place in a tangential manner'.
- *Principle of proportion*: Proportion in nature is a harmonious relationship among several parts or to the whole organism. Proportions in nature are very pleasing and are of subtle character. Professor Adolf Zeising proposed the 'Golden cut' as a law prevailing in the entire universe.
- *Principle of adaptation*: The form of different parts of plants is in harmony with the surroundings and adapted to the environmental conditions in which the plant exists. Similarly, objects should be made adaptable to the purpose for which they are intended. For example, in nature plants that appear as horizontal objects have radiating structure and plants that appear as vertical

objects have a bi-symmetrical structure. In architecture, the same principles are applied to the floor-patterns and wall-decorations.
Owen Jones explains two principles that he observed in natural forms [20].

  – *Use of colour to assist form development*: Different colours separate different forms in an organism. Just like the natural law that exists in nature where we generally find primary colour on buds and flowers and the secondary colour on leaves and stalk.
  – *Geometry is the basis of all forms*: one can observe the symmetry and regularity in the natural forms like flowers when viewed in plan or elevation.

- *Abstract principles in images of nature*: Mackmurdo explains the abstract principles in images of nature as principles of irregularity, arbitrariness, and economy of form that exist in nature [2].
- *Principle of organic essentialism*: Ross Lovegrove defines the principle of organic essentialism as reducing a form to its minimum material mass, which means the removal of the extra material from the form that is not required [16].
- *Principle of evolution*: Many designers have noticed the role of evolution in the development of natural forms. Mackmurdo explains that even for an artist it is necessary to understand the *developmental principles in nature*. These are the principle of organic evolution derived from the observation of natural phenomena [2]. Natural forms improve and evolve with time. The form of organisms is a result of millions of years of evolution, which are highly functional [16, 21].

6. **Manipulation in natural forms**
Owen Jones suggests that for a good work of art the forms of nature must be *idealized* based on the observation of principles, which regulate the arrangement of forms in nature [20]. Christopher Dresser also proposes that *adding forms of exceeding beauty* can modify natural forms. These adaptations and modification of natural form may be used to enhance our pleasure [19].
7. **Mental conceptions**
Mental conceptions related to natural forms are the embodiment of the idea or conception of natural form into the form of the existing object, e.g. conception of blooming of flowers. This mental conception could be about the orientation of parts, shapes of parts, colours and details related to a particular form like character of line and order [19].
8. **Symbolism**
Natural forms are very often used to *symbolize* something else in the man-made world like in ancient Egypt, lotus was the symbol of power [20]. Dresser used *symbolism* to *express feelings*. It is the way of expressing definite ideas through ornamental shapes making use of forms having acknowledged significance, e.g. leaf buds for spring, leafless branches for winter, and orange blossoms for innocence [19]. Mackmurdo also advocates the *symbolic embodiment of*

natural law. He describes the embodiment of natural law in the form is a way to approach the symbolic function of botanical design [2].

9. **Art**
Designers have identified art as an important factor for nature-inspired designs. Mackmurdo explains the link between *art and nature* as work of art is similar to the work of nature. Design, as manifested in art, is work of human, and plant is a work of nature. Primarily plant and humans both are influenced by the same 'nature', and therefore, work of art is similar to work of nature. He also suggests that the independent role of *formative imagination* can help to avoid transcription of nature [2]. *Design, Nature and Art* are the three things that significantly influence the work of Ross Lovegrove. He also supports the use of *impressionism* as an important art form for expressing ideas [16]. Ornamentation is not different from the architectural member rather it forms a part of that member. This harmony between ornamentation and architectural elements adds *poetry to design* [20].

10. **Pleasure and emotions**
Christopher Dresser in his book discussed *hints of nature for pleasurable emotions*. He suggests that while following hints of nature with an inward instinct or passion one can design the forms, which yield pleasure to our mind. He also explains how the diversity of character in parts within a natural form gives rise to the production of a *contrast of a pleasing character* [19]. Ross Lovegrove believes that nature has a direct link with *human sensuality*. Organic design influences directly the human senses and their sense of relationship with things [16].

11. **Modes of externalizing ideas**
Designers mostly rely on two modes to externalize the ideas that they have in their minds: Sketching and Model making. Christopher Dresser suggests that *sketching* every stage of form development of the natural form can help the student to describe that natural form precisely with delicacy and feelings, which will further help the student to define the use of that form in ornament and its symbolic significance [19]. Ross Lovegrove *sketches* whatever he visualizes [18]. In his design process, Colani develops his idea through *sketching and model making* [17].

12. **Transformative processes**
This factor includes the approaches followed by designers to transform their ideas into tangible designs. Mackmurdo's designs are the result of his unique design approach in which he combines the *data of nature* with the rules of abstraction and the requirement of decorative design [2]. Ross Lovegrove employs *digital technologies* like parametric design software, 3D printers and 3D scanners to reinvent his design process of form creation. When industrially manufactured products are subjected to biomorphic or organic design treatment, one has to search the creative solution within engineering constraints but in harmony with nature, he attempts to find such creative solutions by *combining engineering with biological thinking* [16].

13. **Previous work**

Sometimes referring to previous work may help designers to overcome design fixations. Ross Lovegrove says the *mapping of previous work* helps to position himself and see the missing gap or new scope of work [22]. Dresser has also many times referred his *previous work to gain knowledge* of what has already been done [23].

14. **Design philosophy**
With experience gained with time and years of design practice, designers have developed their own design philosophies. Famous for his philosophy of *Biodesign*, Luigi Colani has designed products that are characterized by round and organic forms inspired by nature [24]. Ross Lovegrove is well known for his design philosophy of *Organic design*, based on his principle of organic essentialism [16].

3.5 Discussions

Referring to the paradigm (analytic tool/organizational scheme) proposed by Strauss and Corbin [8], the above fourteen core categories in our study have certain properties based on which they can be related to 'Structure' and 'Process' of the phenomenon of designing nature-inspired product forms. An understanding of such relationships will help us to answer 'Why' and 'How' designers respond in a certain way while designing product forms inspired by nature. The basic components of the paradigm are conditions, actions/interactions and consequences. We identified fourteen core categories as conditions, actions/interactions and consequences to understand the complexity of the phenomenon (Fig. 3.2).

Conditions—These are the events that build situations related to a phenomenon and explain why people respond in certain ways. The subcategories/coded concepts of core categories under conditions answer to the question of why designers respond in a certain way while designing product forms inspired by nature. These core categories form the 'structure' of the phenomenon. The core categories under this component are: *Inspiration, Observation* and *Necessary conditions.*

Actions/Interactions—These are the responses that are deliberately made by people to the events under conditions. It includes core categories that display actions/interactions of designers in response to the conditions. The subcategories/coded concepts of core categories under actions/interactions answers the question of how designers respond. These core categories represent the 'process' of the phenomenon. The core categories under this component are: *Laws in natural forms, Principles in natural forms, Manipulation in natural forms, Mental conceptions, Symbolism, Art, Pleasure and emotions, Modes of externalizing ideas, Transformative processes* and *Previous work.*

Consequences—These are the outcomes of actions/interactions. Core categories under consequences represent the outcome of the actions/interactions of the designers. The only core category under this component is *Design philosophy.*

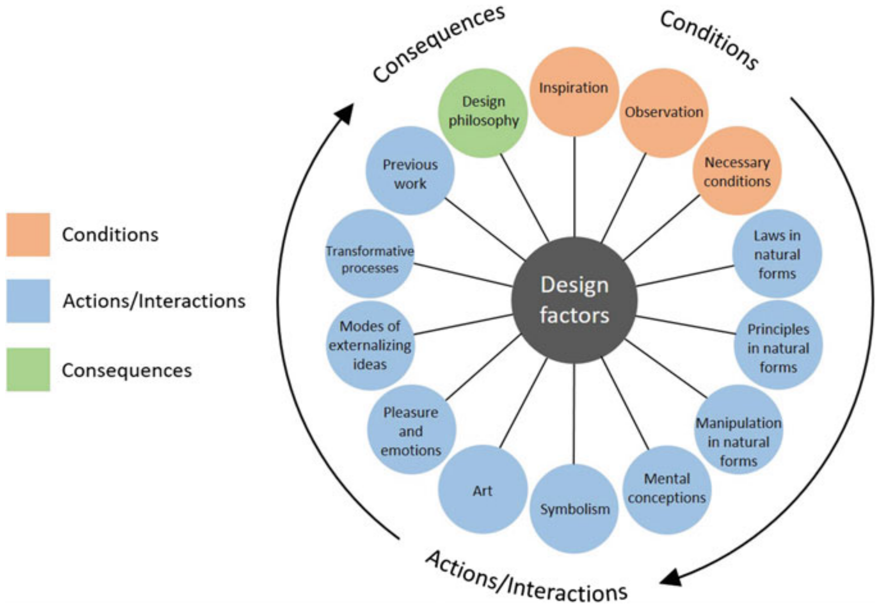

Fig. 3.2 Fourteen core categories under three components of paradigm. *Source* Authors

The paradigm helped us to integrate the structure with the process which gives a clear picture of the complex phenomenon of nature-inspired form generation. The identification of fourteen core categories under three components of paradigm can contribute to the development of a framework, methods/tools and classroom assignments.

Only five designers are covered in this study, and data from more designers must be extracted to reach theoretical saturation. Data from more designers may lead to the emergence of new core categories and subcategories which may result in further enrichment and modification of the network diagram.

3.6 Conclusions

Following the Nigel Cross taxonomy, in this study, we have focused on the approaches undertaken by the five selected international designers in developing their product forms drawing from principles reflected in nature. Through an analysis of their works, we were able to extract the underlying fourteen core categories/factors that have driven the form generation process of these selected designers in seeking answers to our research question.

The underlying processes and principles in nature and their implication on design identified under these fourteen core categories/factors constitute, in our view, a form of knowledge that can be used in different contexts by design practitioners engaged in various projects focused on product form generation. Design researchers can use this knowledge to further develop a framework/model or design tools for the generation of nature-inspired product forms. The three components of the paradigm will guide them to relate and integrate other elements of the framework/model with these fourteen identified core categories.

It can also help design educators to integrate this knowledge in structuring an advanced course on 'nature-inspired form studies for product design'. The three stages of this course can be developed based on the three components of the paradigm. The core categories under condition will help the educator to explore different ways to motivate and prepare students in the first stage of the course; e.g. educator can create an engaging environment that will support the attentive study of natural form. The educator can refer to the core categories of actions/interactions during the second stage of the course; e.g. educator can introduce principles and laws of visual form in nature as the theoretical inputs for the course. Based on these principles, they can develop a series of creative classroom assignments to encourage the use of these laws and principles in the form generation process. This will help students in detailed three-dimensional visual analyses of natural form. In the third stage of the course under consequence, the educator can encourage students to develop their own unique style or form language to design product forms inspired by nature.

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Chapter 4
Practices in Bio-design: Design Research Through Interdisciplinary Collaboration

Assia Stefanova

Abstract Within the emerging field of bio-design, there is a growing need for interdisciplinary practice and collaboration that enables design with living organisms. To facilitate such work, designers often venture outside of the limits of their own design field and engage with methods, knowledge and language of other disciplines. Bio-design collaborations range from fundamental studies to applied research that incorporates existing knowledge and ideas. The examples presented in this paper are part of the author's doctoral research in architecture by creative practice that include a fundamental study of photosynthetic bio-composite materials, an applied materials study through the use of fabrication with living organisms and an eco-philosophical graphic novel based on conversations with scientists. The outlined studies demonstrate the adoption of laboratory methods within design practice, the integration of existing scientific work within design and the organic exchange of ideas through alternative methods of visual communication. The paper explores the opportunities and limitations of such practices and highlights their importance within the field of bio-design. The presented studies help define a spectrum of interdisciplinary collaboration in relationship to discipline specific skills utilized depending on design intent and outcome. This paper seeks to highlight the benefits of knowledge and skills transfer through bio-design collaboration, offering a range of possibilities using different mediums and modes of communication between practitioners of the science and design fields.

4.1 Introduction

There is a long history of collaborations between designers and scientists that are at the basis of innovation and social change including the translation of scientific principals into commercial products, early stage prototyping and education and public engagement [1]. These types of collaboration have grown in importance with the

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A. Chakrabarti et al. (eds.), *Design for Tomorrow–Volume 3*,
Smart Innovation, Systems and Technologies 223,
https://doi.org/10.1007/978-981-16-0084-5_4

emergence of bio-design [2]. In this hybrid field, the role of the designer is reframed to encompass practices that were previously considered outside of the scope of design, where design outcomes embrace scientific principles or designers participate in the development of biotechnology. Interdisciplinary collaboration takes on a central role within bio-design as there is an innate exchange of knowledge, skills and philosophical perspectives that takes place when working with living organisms. By working closely with other practitioners, architects are able to bring living organisms into a manmade realm either by integrating them into our everyday surroundings, or by bridging the gap between scientific practice and the rest of society [3]. This mode of design through the exchange of ideas between different fields was defined as *information design* by Andersson and Pettersson [4]. In the field of bio-design, this typically occurs through collaboration with scientists, industry or other bio-designers.

Despite the growing focus on the field, much remains to be said about how these collaborations can occur and in what forms. This paper reflects upon the similarities within the scientific research and design processes and the informal knowledge exchange within interdisciplinary collaboration and demonstrates how these factors influence three distinct forms of bio-design work. The highlighted examples serve to illustrate three types of bio-design research that are structured to achieve various objectives including fundamental investigation through scientific practice for the developing of a living bio-material, adoption of scientific principles to generate a living materials installation, as well as a design-led exploration of language to propose design solutions through the use of storytelling and drawing. The examples presented in this paper are part of the author's doctoral research by creative practice and tell the story of the presented collaborations from the perspective of an architect collaborating on interdisciplinary bio-design projects. The collaborations vary in duration as well as method and range across a wide spectrum of collaborative exchange, from the adoption of science into a design practice, to long-term laboratory experimentation where designers learn, adopt and adapt scientific methods so as to understand processes and work towards solutions that can be scaled and employed outside of a laboratory setting.

4.2 Scientific and Design Processes

Science has historically assumed a positivist approach to knowledge, one that is limited to the experiences of the senses and that dismisses metaphysical explanations [4]. In more recent history, science has also allowed for ideas from the hermeneutic tradition that has a more expansive view of knowledge and that accepts methods such as acquiring meaning through doing [5] or making as is the case with design, providing a common ground for collaboration. Furthermore, scientific and design research both engage in a creative process that can be divided into four stages as defined by Graham Wallas, which include preparation, incubation, illumination and verification [6]. However, in both cases whilst these stages occur, they do not necessarily unfold as a linear process as there is an element of uncertainty present within both practices. Due to this uncertainty the bio-design process, although differing from scientific practices, it is in a state of flux where variables are gradually revealed and initial planning presents challenges, as the process must accommodate changes and evolution of ideas during the making process. These stages of investigation may take on the form of laboratory testing, prototyping or drawing as will be demonstrated in the examples. These similarities across disciplines serve as a common ground for collaborations between scientists and designers and are the focus of existing research that this paper builds upon, such as the work of Rust [7, 8] and Polanyi [9] as well as architectural bio-design research undertaken by architects and scholars such as Imhof and Gruber [10] and Armstrong [11] who engage in interdisciplinary research through practice. The examples in this paper expand upon such practices and demonstrate the types of knowledge transfer from the scientific to the design field identifying the adoption of tools and knowledge necessary for the three different types of design objectives, ranging from the furthering of knowledge with future application in mind, the scaled testing of novel biotechnology and engaging within scientific ethics through the use of design tools.

4.3 Casual Knowledge Exchanges in Interdisciplinary Collaboration

Within the examples presented in this paper, there is a level of informal exchange that precipitates learning and testing of ideas in each project. This paper advocates the importance of such informality within the field of bio-design and proposes that it is an essential tool for research through practice in an interdisciplinary setting. The paper seeks to demonstrate the types of collaboration that are available and appropriate depending on the type of bio-design practice and objective as well as to highlight the benefits and limitations of these kinds of practice.

Knowledge exchanges typically occur through conversation during the prolonged time spent in the laboratory by cultivating close relationships with scientists. Such input accelerates the learning process through the demonstration of methods, translation of scientific jargon and explanation of fundamental principles [12]. This type of learning, as observed by Sawa [13], is very much reliant on informal social interaction as part of a natural bonding process facilitated by proximity and frequency of encounters within the laboratory. The casual learning of methods and practices is a process that occurs over a long period and that cannot be facilitated through sporadic observation or formal interviews and discussion as in those cases, each participant is locked within the limits of their own professional reference point. In these instances, there is a danger of oversimplifying the intricacies of the other field through the overuse of accessible analogies necessary for communicating specialized knowledge to an outsider. It is not to say that such analogies are of little value as they enable the translation of ideas from one form of practice to another often to serve a different purpose. For example, narrative development, as shown within the final example, captures the conversations that take place within scientific settings and communication of ideas by scientists, in a language foreign to laboratory culture. The graphic novel helps identify an attitude towards the work and aids an understanding of the world gained from working within science. Designers and architects translate information to create scenarios of future social systems and propose potential manifestations of such technology into scalable global strategies that do not abide by the limitations of current levels of scientific progress.

4.4 Adoption of Laboratory Methods: Material Development

The exclusive space that constitutes the laboratory can be intimidating and inaccessible both within the legal structure that governs it, as well as the highly specialized spaces that are hidden behind doors full of paraphernalia that is not referenced in everyday life [14]. However, with the growing dialogue between designers and scientists, bio-designers are beginning to embrace laboratory testing within their work that allows them to participate in the early stages of material development that permits participation in the shaping of a new type of living building fabric as demonstrated in the following project (Fig. 4.1).

An example of such work is testing of photosynthetic ceramic bio-composite material experiments conducted as part of the author's doctoral research by creative practice in architecture. In this instance, the work was undertaken by an architect following, modifying and subverting existing scientific methods [15]. The work was preceded by a period of shadowing of science researchers as well as the building of basic scientific knowledge and understanding through a theoretical survey and informal conversation. This preliminary work is fundamental to the ability of a

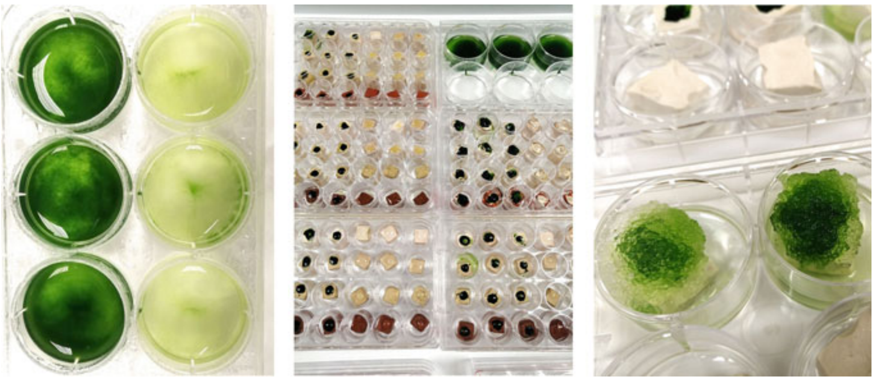

Fig. 4.1 Microalgae (*Chlorella vulgaris*) grown on various types of ceramic substrates as part of a laboratory experiment (work by author, in collaboration with Dr. Gary Caldwell and Pichaya In-na)

design practitioner to operate within a laboratory setting and is dependent upon a strong interdisciplinary partnership. By being able to adopt scientific methods of testing, the research focus was directed at material substrates and organisms that would be suitable for application within architectural design projects [16]. Furthermore, the types of tests were directed at enabling the organism to function outside of a controlled laboratory setting, an aspect often overlooked during fundamental testing as the scientific emphasis at these early stages of experimentation is on obtaining repeatable data [17]. Controlled experiments are predominately studied within laboratory research as they provide a consistency of results; however, they are not reflective of real-life environments that are of interest to designers. Whilst scientists in the laboratory may be undertaking similar type of investigation, there is a clear distinction between the roles of the scientist whose work is centred around a deep understanding of biological processes through the use of a wide range of data. This is in contrast to the work of the designer whose mission is to develop solutions with application as the end goal. The level of knowledge and understanding of the designer is likely to be limited to the particular area of investigation and is focused on data that determines tangible performance. Therefore, there is a reliance on the scientific counterparts to provide guidance and advice as experimentation unfolds and results bring about new questions. From a design perspective, the value of engaging in laboratory experimentation lies in the performance of the experiments as an act of making as well as in the data acquired. Although the processes may be identical, the objectives of the design practitioner are influenced by the tacit knowledge acquired through engagement in another discipline's practices and work environment. This knowledge serves to define future experimentation and guides the direction of research.

4.5 Integrating Science Within Design Practice: Yggdrasil

Bio-design has been adopted by many design practitioners and these works often employ or build upon existing scientific research that they integrate into design applications. Practitioners have utilized biological processes and living organisms within a variety of application including fashion [18], interior design [19] and building materials [20, 21]. Such works often emerge from collaborations between bio-designers that can harness each other's acquired scientific knowledge and understanding of biological principles to inform a hybrid practice as shown in Fig. 4.2.

Yggdrasil, a bio-design exhibit presented at the OpenCell Exhibition part of London Design Festival, 2019 [22] featured a range of experimental bio-design pieces demonstrating early testing of biological materials. The exhibit was created through a close collaboration between the author and other bio-designers with a background in architecture, where material research conducted as part of laboratory practice was used to create a living materials installation. The collection of work speculated as to the potential of biological matter to be used as building material and the fragility of the organisms used in such novel technologies, introducing an ethical component to

Fig. 4.2 Yggdrasil, bio-design exhibit at OpenCell, London Design Festival, 2019 (Thora Arnardottir, Assia Stefanova, Dilan Ozkan, Sunbin Lee)

material practice. The work highlighted the ability of these new approaches to create relationships within our immediate environment establishing connections between different actors [23], human and non-human, creating partnerships and exchanges. This type of design acts as a bridge between scientific and design practice, where design skills are more actively incorporated and the learning curve is less significant for designers as there is a greater emphasis on issues of scale, form and integration within the built environment that are integral to the field of architecture and are a familiar challenge encountered by designers. The type of knowledge exchange necessary for this type of bio-design work does not necessarily occur exclusively between scientists and designers. The source of knowledge can become practitioners and experts that do not necessarily feed into an institutional research framework, but utilize biological process within different artistic or commercial fields. Outside of the external sources of knowledge bio-designers have the ability to come together and bring their acquired expertise regarding organisms and methods, as was the case of *Yggdrasil*. The collaboration led to further fundamental research testing and use of laboratory protocols to investigate the compatibility of these hybridized solutions. Therefore, such collaborations can prompt creative thinking and early prototyping that demonstrates the scientific principals and aids public engagement at an early stage of the research as was the aim of the exhibit.

4.6 Casual Exchange for Narrative Creation: Ecological Graphic Novel

Many collaborations between scientists and artist occur through initiatives designed to make science accessible to the public. These collaborations are often based on observation of scientific practice, techniques and conversations, between scientists and design practitioners. The designer in this case is entrusted with translating scientific practice into a media that is accessible to the public, whilst proposing further interpretation and application of scientific ideas, a practice that goes beyond literal communication. The media vary from employing scientific artefacts such as tissue culture as in the case of art works such as *Victimless Leather* [24] or creating proxies through digital simulation and fabrication to explain principles [25] or the use of various types of storytelling [26–29]. In an effort to propose wider integration as well as to address ethical issues, narrative creation becomes a means for testing of ideas on a wider scale; it helps identify social issues that are likely to affect implementation such as the work in Fig. 4.3.

A bio-design narrative example is the graphic novel, *Bios in Search of Zoe*, a work created as part of the author's creative practice doctoral research in architecture. The work provides a glimpse into scientific practices and offers a critique of certain types of scientific investigation whilst proposing strategies for implementation of biological processes to create a new type of built environment. The story centres around the dualism between Bios and Zoe that originates from the two Greek terms for life. Bios embodying nature as controlled and beneficial to humankind and Zoe, representing nature as all-encompassing life, without an anthropocentric bias [30]. The work is based on conversations between scientists and architects and the existing research on ethics of working with microorganisms [31–33]. The graphic novel in this example is a method of research that positions bio-design practice into a broader social and political context as explored by social scientists, anthropologists and ecological thinkers [34–36]. Humanity's disruption of natural networks provides the starting point of the narrative that as the story unfolds, places humanity within a complex multi-species entanglement that proposes an ethical approach to working with living organisms. The narrative serves to illustrate how biological solutions could feed into a broader

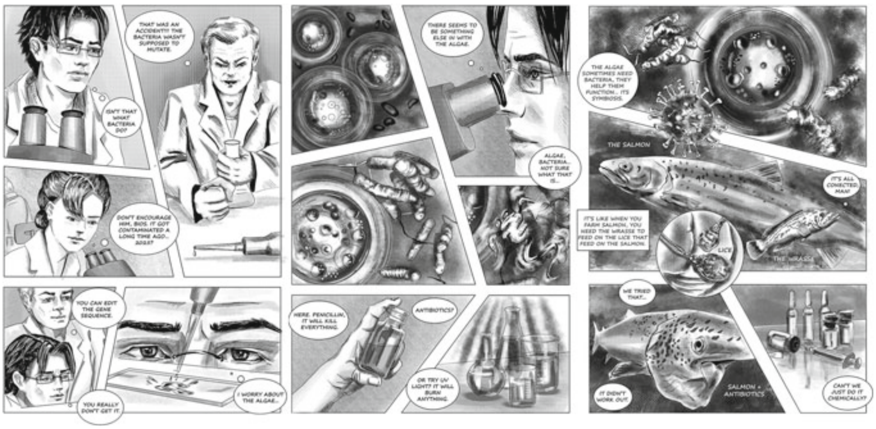

Fig. 4.3 Excerpts from the graphic novel "*Bios in Search of Zoe*", work in progress as part of the author's Ph.D. by creative practice research (work by Author)

global practice and the societal restructuring necessary to allow wide scale adoption of such technology. The use of fiction and drawing practice permits a critical examination of the implications of adopting emerging biotechnologies whilst reflecting on ethical issues of collaborating with living organisms. This type of synthesis of scientific practice serves to encourage engagement of non-scientific audience and allows the public to participate in scientific debates. This interpretation of conversations goes beyond the understanding of problems and the accurate representation of scientific facts. Designers take on the responsibility of interpreting tacit knowledge acquired during informal conversations, a process of *indwelling* or emersion within the discipline as defined by Michael Polany, a type of learning prevalent within both the science and design fields.

4.7 Discussion

The studies presented demonstrate three different points on the spectrum of bio-design collaboration. They identify the types of skills and knowledge exchange that could potentially occur, with practices situated closer to the social realm involving greater use of design tools whilst, practical performance-based objectives require a greater level of engagement with scientific methods as demonstrated in Fig. 4.4.

Use of scientific methods and laboratory practice within design development allows designers and architects to actively participate in the creation of biotechnology and guide the direction of the research with application in mind. In the field of architecture, this means that testing can be directed so that it takes into consideration conditions offered by the built environment, from the early inception of such research. This mode of working within a science setting presents challenges in terms of bridging a wide knowledge gap that designers must overcome in order to engage effectively in fundamental biological material development and testing. It highlights the reliance on willing and receptive scientific partners that could facilitate and benefit from designer input at an early stage of the research [37]. This type of

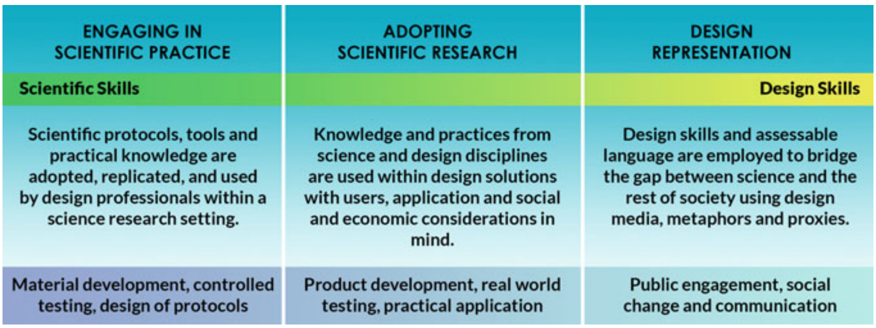

Fig. 4.4 Spectrum of discipline-related skills against type of practice and their potential application

practice requires a greater level of understanding and the gradual building of foundational knowledge that enables the design requirements to guide the development of solutions.

In contrast, by adopting existing scientific research, the generated design work has the potential to bridge laboratory experimentation and scaled prototyping, situating the work closer to a traditional design practice. This type of testing differs from the commercial scaling of developed biotechnology and places a greater emphasis on bridging the gap between the exclusive practices adopted in early stage scientific investigation and the public. However, there is a danger that the performance of the living organisms could be overlooked in favour of design considerations through a lack of in-depth understanding of biological processes on the part of the bio-designer or the lack of testing equipment necessary to assess the health of the organism. In the example of *Yggdrasil*, there was a recognition that the installation provided a working demonstration of materials and was not a functional product and quantitative data could not be obtained. However, the role of *Yggdrasil* was to serve as a catalyst for further fundamental research made possible by engaging in both prototyping and laboratory testing simultaneously, which helped to identify future areas of exploration.

The issue of language becomes more problematic as different disciplines employ jargon and assign different levels of exactitude to language. This is particularly challenging when the design work aims to communicate principles and specialized methods to an audience that may not necessarily possess a foundational understanding of such ideas. Communication takes on less prescriptive role in graphic design, and in the case of *Bios in Search of Zoe*, it invites the reader to engage with issues that are presented as part of a broader discussion. As designers we use tools from design disciplines to interpret the information, propose solutions and anticipate plausible scenarios. Through the use of a drawing practice common within the field of architecture, bio-designers engage in an intuitive process that relinquishes control of the viewer's interpretation, which is in contrast to scientific processes of problem identification and theory modelling. The presented graphic novel builds upon an investigative drawing methods employed by other researchers within the field of architecture, examples include *Practiceopolis* and *Citizens of No Place* [38, 39]. In these instances, the architectural profession and design concepts are challenged through the construction of visual compositions that carry embedded information in an image format that influences the viewer on a subconscious level. Further exploration is necessary to determine the impact that such work has and the level of engagement and understanding it can facilitate within the field of bio-design.

4.8 Conclusion

The presented case studies feed into a spectrum of interdisciplinary collaborations typical of the emerging field of bio-design. The projects highlight the necessity for such working partnerships and demonstrate bio-design research and testing strategies through a variety of working methods and different levels of engagement with scientific research. The studies have identified that language and communication are integral parts of bio-design collaboration and knowledge exchange. However, language also presents challenges in the differences in terminology which can cause misinterpretation or could create barriers that need to be overcome by designers when engaging with scientific knowledge. Designers are therefore able to postulate outcomes and draw on expertise outside of the scientific field to add a layer of critical reflection within bio-design research. The examples presented demonstrate work that encompasses fundamental and applied research in the field of bio-design that enforces the notion that the boundaries between the two are less clearly defined than commonly accepted. The co-creative process serves as a catalyst that prompts thinking regarding applied research during the fundamental testing phase or as a method of reflection upon the wider social impact of scientific practice.

Acknowledgements The author would like to thank Professor Rachel Armstrong and Dr. Ben Bridgens, School of Architecture, Newcastle University, for their guidance and support. The author would also like to thank Pichaya In-na School of Chemical Engineering, Dr. Gary Caldwell from the School of Natural and Environmental Sciences, Newcastle University, for their collaborative input in developing living materials as well as bio-design collaborators Thora Arnardottir, Dilan Ozkan, Sunbin Lee from the School of Architecture, Newcastle University. This research was funded by Research England as part of the Hub for Biotechnology in the Built Environment.

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Chapter 5
Tool for Flood-Proof Residential Design

Minu Pradeep

Abstract Kerala has been inundated by floods, in 2018 and 2019 which have had a great impact on every citizen's mind. Loss of life, property, and most importantly "dreading the next flood" has left an average person wondering if there is an end to this. Residential construction in Kerala accounts for a huge percentage of its existing ground coverage. The paper aims to bring about a useful tool for architects, specifically for flood-resistant residential design catering to Kerala. The paper attempts to make a concise design tool based on regulations and local knowledge. The tool will be designed to give out a set of concise guidelines to architects based on the inputs given, which can be easily followed in the design process. The tool will help in building a better tomorrow, in the context of global warming and increased flooding episodes across the globe.

5.1 Introduction

The density of buildings in Kerala is 2.9 times (census 2011) the national average, and 68.67% (census 2011) of the buildings in Kerala are residences. Considering the floods of 2018 and 2019 that affected the State, this tool if used will ease the design process for the architect to design future residences that can cater to the flood situation.

Several flood-proof designs by eminent architects, especially low cost housing, have taken shape successfully in Kerala. This paper does not specify a design typology for flood-proof design, but proposes a tool that helps the architect to make better choices efficiently, based on the site conditions and client requirements to design a flood-proof residence, which may be applicable to all typologies of houses including low and high cost.

The paper primarily looks at providing architects with a tool to provide concise guidelines/recommendations for space planning and architectural design including

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A. Chakrabarti et al. (eds.), *Design for Tomorrow–Volume 3*,
Smart Innovation, Systems and Technologies 223,
https://doi.org/10.1007/978-981-16-0084-5_5

materials and methods of building construction to be followed in order to achieve a flood-proof design. Information from traditional and vernacular practices has also been included for a holistic approach. The tool also provides technical aspects to be considered in a condensed form to the architect for reference. The tool requires the latitude and longitude of the site in consideration for giving the output guidelines. The guidelines/recommendations are meant to be helpful to the architect specifically in the planning stage, The detailed specifications required for execution do not form part of the guidelines. References/links to help in detailing will be provided in the tool.

5.2 Basic Terminologies of Flood Proofing

BFE: Base Flood Elevation:

Federal Emergency Management Agency (FEMA) defines the base flood elevation (BFE) as "the computed elevation to which the flood is anticipated to rise during the base flood. The base flood is also referred to as the one percent annual chance flood or 100-year flood."

Regulatory Flood Datum (RFD):

BFE + Freeboard factor of Safety [1]. This depth/height above sea level is used for all design calculations and decisions. National Disaster Management Authority guidelines indicate this Freeboard factor of Safety to be 0.6 m.

Dry Flood Proofing:

The lower portions of the building that are prone to flooding are designed to be water proof and impermeable to flood waters [1].

Wet Flood Proofing:

The building is designed to be flooded by potable water or flood water on the lower floors. The structure is designed to withstand the forces, and the material finishes are also resilient to the deluge [1].

Active Flood Proofing:

Manual intervention is required to activate the flood proofing. This method can be applicable only when reliable early warning systems in place [1].

Passive Flood Proofing:

The building is resistant to floods without any requirement for manual intervention or activation [1].

5.3 Learning from the Vernacular/Traditional

See Table 5.1.

5.4 Technical Aspects

The combined effect of all loads on the structure including loads related to flooding should fall within the permissible stress levels. The following are the main loads relating to floods acting on the structure [1].

5.4.1 Water Loads

See Table 5.2.

5.4.2 Impact Loads

See Table 5.3.

5.4.3 Soil Loads

During floods, the bearing capacity of soil is reduced due to buoyancy effect, where expansive soil conditions are present, the structure has to be designed considering this. All effects of floodwater above and below the soil have to be considered. Soil that totally loses its bearing capacity should not be used for the support of the structure [1].

5.4.4 Stability Issues to Be Considered During Floods

See Table 5.4.

Table 5.1 Learning from vernacular

Traditional/Vernacular elements		How it helped in overcoming floods	Applicability in current context	What can be adopted to the guidelines
Raised plinth up to 1.5 m observed in an old house (Mattathil House Pathanamthitta [2])		Saves life and belongings	Can be applied currently, the elevations need to be according to the local flood levels	Raising above base flood elevation already part of current guidelines
Features of Traditional Houses in Thazhathangadi Kottayam, Kerala (beside the Meenachil river)				
Traditional prefabricated construction where walls are made up of modular wood planks that click together [2]		Helpful feature for reuse and re building/shifting in case of flood damage	Applicable currently	Can be adopted, modular and prefabricated newer materials can also be suggested additionally
Double walled chambers (*Ara* with *Nira*) for storage [2]		Additional protective layer	Applicable where space permits. Grains storage is no longer necessary, but concept can be applied for other important spaces	Concept of additional protective layer for primary spaces
Attic Spaces [2]		Can serve as refuge areas	Can be applied	Concept of Refuge Areas
Features from Typical Kerala Residential Architecture				
Padipura with compound wall		Additional protective layer like floodwalls	Not applicable as is, as currently vehicle entry is required	Vehicular entry gates need to be given additional flood enclosures
Ponds (traditional houses had multiple ponds within the compound which served as flood sinks)		Excess water sinks	May not be widely applicable due to typically smaller plot sizes	Can be applied in larger plots
Local/Traditional materials of Kerala				
Material				
Laterite	Class 5	Easy availability of material and labor for rebuilding Sustainable and climate responsive materials	Can be applied	Class 5 materials can be used even in non-flood-proofed areas below RFD, lower class materials can be used in areas that are above RFD or have been dry flood proofed [1]
Granite	Class 5			

(continued)

Table 5.1 (continued)

Traditional/Vernacular elements		How it helped in overcoming floods	Applicability in current context	What can be adopted to the guidelines
Mud/Stabilized blocks	Class 2			
Clay tiles	Class 5			
Bamboo (Treated)	Class 5			
Wood	Class 1 or 2			

Table 5.2 Water loads

Hydrostatic [1]		
Caused by water that is either stagnant or moves at very low velocities up to 1.5 m/s Hydrostatic load = water pressure × Area of the surface it acts on Water pressure = unit wt of water × head Hydrostatic pressure always acts perpendicular the surface where pressure is applied	Vertical	Acts vertically downward, caused by the weight of floodwaters above them
	Lateral	Acts horizontally: tends to cause overturning/lateral displacement
	Uplift	Acts vertically upward
Hydrodynamic [1]		
Lateral loads; direct impact and drag force are to be considered	Hydrostatic loads needs to be calculated by competent bodies, as per evaluation In cases where velocities do not exceed 3 m/s, hydrodynamic loads can be converted to equivalent hydrostatic loads by increasing the RFD by an equivalent surcharge depth on the headwater side and above ground level $dh = av^2/2g$ (a = shape factor coefficient, v = avg velocity, and g = acceleration due to gravity) dh is added to RFD where surfaces are perpendicular to the flow and for surfaces parallel to the flow, the hydrostatic pressures are considered up to the RFD only	

Table 5.3 Impact loads

Normal impact [1]	
"Normal impact loads are those which relate to isolated occurrences of logs, ice blocks, or floatable objects of normally encountered sizes striking buildings or parts thereof"	"Concentrated load acting horizontally at the RFD or at any point below it, equal to the impact force, produced by a 1000-lb mass traveling at the velocity of the floodwater and acting on a one square foot surface of the structure"
Special impact [1]	
"Special impact loads are those which relate to large conglomerates of floatable objects, such as broken up ice floats and accumulation of floating debris, either striking or resting against a building, structure, or parts thereof"	"Intensity of load shall be taken as 100 lb per foot acting horizontally over a one foot wide horizontal strip at the RFD or at any level below it, where natural or artificial barriers exist which would effectively prevent these special impact loads from occurring, the loads may be ignored in the design"
Extreme impact [1]	
"Extreme impact loads are those which relate to large floatable objects and masses such as runaway barges or collapsed buildings and structures, striking the building, structure, or component under consideration"	"It is considered impractical to design buildings having adequate strength for resisting extreme impact loads"

Table 5.4 Stability

Overturning	Floatation	Anchorage
The structure should be designed to resist flood loads or combined loads that cause sliding or overturning with a factor of safety of 1.5 [1]	The structure should have enough weight to resist buoyancy forces with a factor of safety of 1.33 [1]	"Any building and structure as a whole, which lacks adequate weight and mass to provide the required factors of safety against overturning, sliding, and flotation, shall be dependably and permanently anchored to the ground and preferably to underlying sound rock formations." [1]
Some methods: Passive earth pressure Batter and vertical piles Permanent anchors [1]	Methods to reduce uplift pressure[1] Impervious cutoffs: impervious barrier below ground level and on the perimeter of building to reduce seepage/exit gradient Materials: interlocking steel sheeting, compacted barrier or impervious soil, grouted or injected cutoffs, impervious wall of interconnected concrete piles or panels, and similar seepage barriers, used alone or in combination Foundation drainage: this can be achieved where impervious cutoffs have been provided by provision of drainage blankets, trenches, and drain tiles or perforated drain pipes adjacent to footings and under floor slabs	

5.4.5 *Services*

Plumbing, mechanical, and electrical systems should be installed above the RFD. In case they are installed at lower level, the installations should be inside waterproof enclosures [1, 4]. Backflow and automatic shut off valves should be installed in all pipes leaving the system. During floods, there is a possibility of contamination from backflow, and these valves should be installed to all connections below the RFD [4].

Installation of solar power is recommended as it will be useful in case of a flood where electricity supply may be adversely affected. It is recommended to make all installations above the BFE.

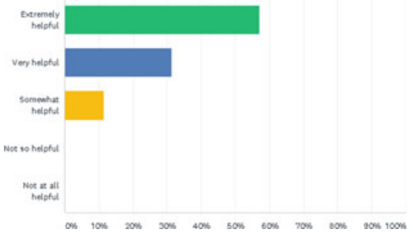
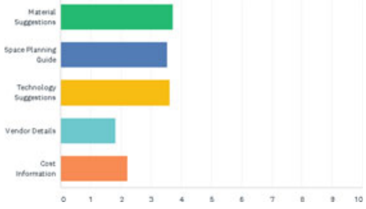
Potable drinking water is also a major issue during floods. Rainwater harvesting and purification is recommended as a solution. Atmospheric water generators (AWGs) can also be considered as an option.

5.5 Research Questions

5.5.1 *Research Question 1*

What kind of information is architects and designers expecting the most from this design tool? Is the tool valuable to designers and architects?

Table 5.5 Survey questions and responses

1. Do you think a tool (guidelines/app) to help you design a flood-proof residence would be helpful to you?  	2. Rank the type of information you would like from the tool. Pick and arrange the options in your order of preference 
3. Briefly describe how you want this tool to be (features, etc.) Sample responses • Flood level data is more important • Tools which helps the architect with materials, vendors, and technology • Well, there has a feature to check with the Google coordinate of the site, whether, firstly there is a threat of flood, at the site location • A tool which would give me details based on the climate, place, and soil • Proper guidelines with necessary details • Interface should be friendly, people with no knowledge of technology should be able to use it easily • Detailed parameters that provide several alternative methods and principles • It should correlate the space with geographical location and suggest the technology which go hand in hand with cost, durability, and time	4. Do you have any other comments, questions, suggestions, or concerns regarding the proposed tool? Sample responses • Will this be specific to locations and culture and technology (universally applicable?) what impact will choice of materials and sizes have? • Water table levels, soil drainage factors, runoff in the area, etc., could be input variables

This was the first query that needed an answer, in order to proceed with the design of the tool. A survey was conducted among architects using the SurveyMonkey platform. The survey received a total of 35 responses.

The respondents were between ages 18 and 45 and in the field of architecture.

The survey was able to collect some general responses toward the expectation of building designers from the tool. The survey clearly shows that a majority of respondents think that the tool will be useful to them (Table 5.5).

5.5.2 *Research Question 2*

What are the variables that impact the final guidelines?

The final output of the tool will be a set of customized guidelines according to the specific location. The variables that impact the final guidelines are

- RFD at the residential site.
- Is any part of the existing contour at the site below the RFD?
- Do the residents require a refuge area?
- Age or specific requirements of the residents.

Other variables were also considered, like cost of implementing the guidelines. It was decided not to input cost as a variable, as designers have a choice of materials to adjust costs and they can choose among the guidelines for final implementation.

Other Demands and Wishes Expected of the Tool

The design tool should be concise and easy to use, and
The output should be easy to decipher.

(These requirements were deciphered from the survey conducted.)

5.5.3 Research Question 3

Are there specific challenges that have to be considered with respect to Indian conditions?

Emergency response may take time to arrive in remote areas especially in rural and fringe areas. Sanitation and water supply may be adversely affected during flood. In flood prone areas, living areas above the RFD needs to be provided mandatorily and reliable means of sanitation and water supply to be provided. If not possible at individual house level, then provisions may be provided at community level.

5.6 Literature Review

The paper "Flood Mapping Tools for Disaster Preparedness and Emergency Response Using Satellite Data and Hydrodynamic Models: A Case Study of Bagmathi Basin, India." by Amarnath et al. [5] describes the methodology used for flood mapping.

The paper by Manojlovic and Pasche [9], details a Web-based tool that gives technically justifiable solutions based on damage assessment and cost benefit analysis.

Current literature does not have any specific tools designed for Kerala/India. Tools specifically aimed to help architects and designers have the necessary information to design flood-resistant buildings are also lacking in the current literature.

5.7 Methodology

The requirements for the tool were established through a survey described in Sect. 5.5.1. The survey showed that most designers wanted local flood information. Based on these requirements, the format of the tool was decided to be in the form of an interactive map, and a table, wherein in the user can input the site boundary on the map and obtain the required information as a set of concise guidelines. A tabular form has also been provided to help the designer in taking decisions regarding space planning and material specifications (Fig. 5.1).

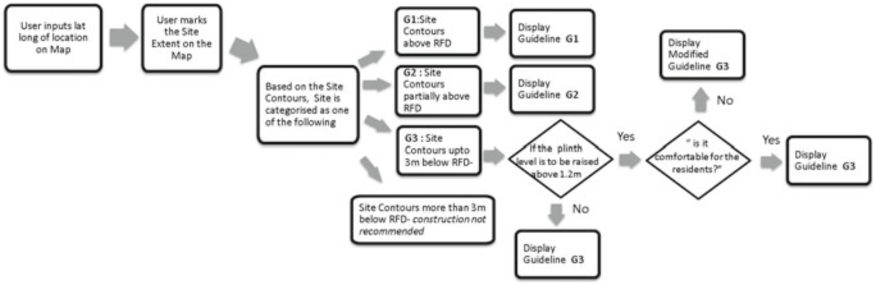


Fig. 5.1 Preliminary flowchart for the tool

5.7.1 Output Guidelines for Map Tool

The following set of guidelines were formulated for varying site conditions.

Tool Part 1: Output from Map

The map is being created in QGIS. Layers are combining the flood map of Aug 2018 (Kerala) with elevation and flood inundation. Shape file containing flood information on Aug 18, 2020, [6–8] is inserted as a reference file for floods in the absence of other BFE information for Kerala. The user can input the latitude and longitude on the map and mark out the site boundaries. Based on the site contours and flood inundation levels noted at the site, guideline G1, G2, G3, or G3 (modified) will be given as output (Table 5.6). Sample illustrations are shown in Figs. 5.2 and 5.3.

Table 5.6 Output guidelines

<table>
<tr><td colspan="4">Natural terrain/Site zoning [1–3]</td></tr>
<tr><th>G1</th><th>G2</th><th>G3</th><th>G3 (Modified)</th></tr>
<tr><td>Site contours above RFD</td><td>Site contours partially above RFD</td><td>Site contours up to 3 m below RFD</td><td>Site contours up to 3 m below RFD</td></tr>
<tr><td>• Ensure that the building footprint is as small as possible
• Ensure that the ground surfaces allow maximum percolation</td><td>• Place the building on the highest contour available
• The main access to the building to be provided from the highest location possible
• Avoid building access below RFD
• Building on fill can be considered for areas below RFD
• Site can be protected by dikes or floodwalls if possible</td><td>• Building to be raised above RFD through
– Stilts/Piles
– Building on fill
• Avoid building access below RFD
• Site can be protected by dikes or floodwalls if possible‘</td><td>• Site may be protected by floodwalls if possible
• If protected by floodwalls, whole structure may be dry flood proofed
• Building may be raised above RFD through (up to 1.2 m)
– Stilts/Piles
– Building on fill
• Spaces may be zoned as a combination of dry flood proofed and wet flood proofed
• If building access is below RFD, it needs to be protected with flood enclosures</td></tr>
<tr><td colspan="4">Landscaping [3] [applicable to G1, G2, G3, and G3 (modified)]</td></tr>
<tr><td colspan="4">• Creation of ponds where possible
• Planting vegetation that prevents soil erosion (e.g., Bamboo)
• Ground surface treatment to allow maximum water percolation [3]</td></tr>
<tr><td colspan="4">Building zoning based on RFD [applicable to G2, G3, and G3 (modified)]</td></tr>
<tr><td colspan="4">Link to sample building zoning tabular format (Table 5.7) to be given in tool</td></tr>
<tr><td colspan="4">Building materials [1–3] [applicable to G2, G3, and G3 (modified)]</td></tr>
<tr><td colspan="4">Use of local materials and prefabricated and modular materials are encouraged. Materials have been classified from Class 1 to Class 5, with Class 1 being most vulnerable and Class 5 being least vulnerable. Class 1 needs total protection from floodwaters, and Class 5 materials can be exposed to flood waters. Class 1 materials can be used only in DFP spaces. If DFP can be achieved, it is advisable to use local and traditional materials that have a low carbon footprint. Local material list form Table 5.1 will be provided in guideline. Link to material classes in US Army Corps Guidelines will be given in tool</td></tr>
<tr><td colspan="4">Contents of buildings [1] [applicable to G2, G3, and G3 (modified)]</td></tr>
<tr><td colspan="4">Contents of the buildings may also be classified as hazardous, and contents requiring protection at various levels may be zoned accordingly</td></tr>
<tr><td colspan="4">Building: structural considerations [1] [applicable to G2, G3, and G3 (modified)]</td></tr>
</table>

(continued)

Table 5.6 (continued)

Natural terrain/Site zoning [1–3]			
G1	**G2**	**G3**	**G3 (Modified)**
Water loads, soil loads, and stability issues caused by floods need to be taken into consideration in addition to the typical loads considered. Link to Sect. 5.5 details to be given in the tool			
Services [1, 4] [applicable to G2, G3, and G3 (modified)]			
Plumbing, mechanical, and electrical systems should be installed above the RFD. In case, they are installed at lower level, the installations should be inside waterproof enclosures Backflow and automatic shut off valves should be installed in all pipes leaving the system			
Sustainability aspects [2, 3] [applicable to G1, G2, G3, and G3 (modified)]			
• Ensure that the building footprint is as small as possible • Ensure that the ground surfaces allow maximum percolation • Use local materials as much as possible • When building on fill, it should not adversely affect the water flow pattern of the surrounding areas			
Design of refuge area [4] [applicable to G2, G3, and G3 (modified)]			
• Upper floor may be designed as a refuge area, with sleeping areas and kitchenette • Potable water supply: through rainwater harvesting (from areas above RFD only) and/or atmospheric water generators recommended • Emergency power supply through solar power recommended. All emergency power installations should be above RFD • Power supply to areas below RFD should be separate, and the main switch should be installed above RFD • Backflow and automatic shut off valves should be installed in all pipes leaving the system			

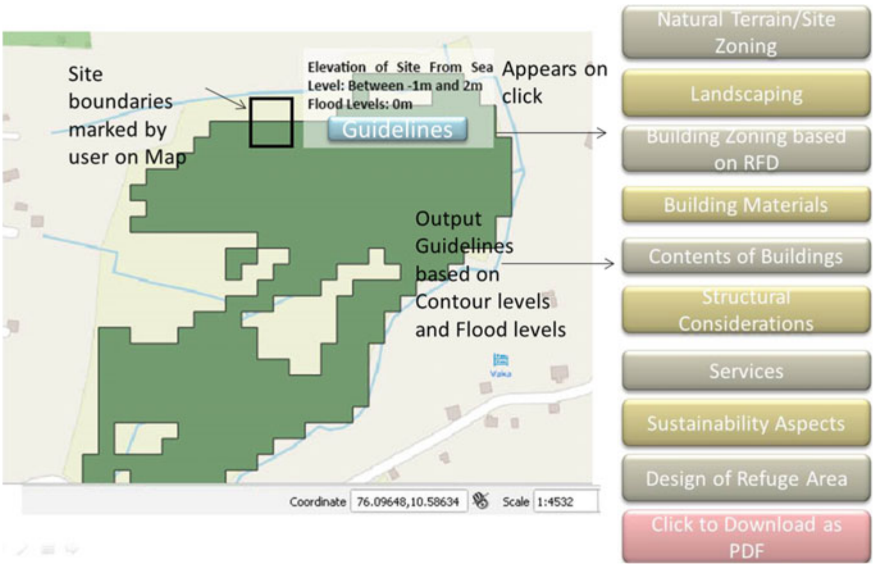


Fig. 5.2 Illustration showing site boundary input giving guidelines as output. The green area is the shape file indicating the flood extent on Aug 18, 2018, from satellite imagery

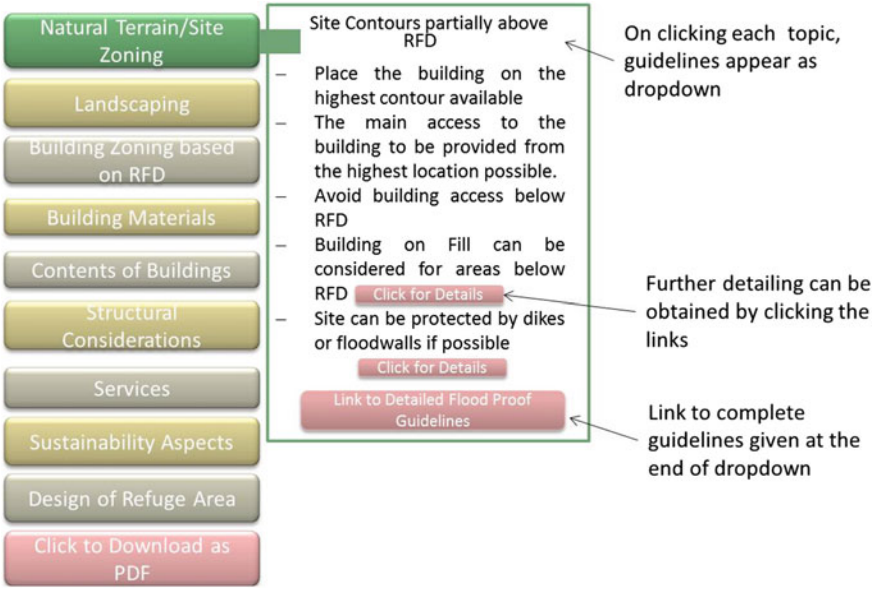


Fig. 5.3 Illustration showing guidelines being displayed under the topics on clicking

Tool Part 2: Tabular Form—Building Zoning

The process to be followed in designing the building are as follows

- Prepare a list of spaces required by the client based on activities and age of the residents.
- Decision: If the age group and requirements of clients are favorable for dry flood proofing, decision is made to elevate all living areas at least 0.6 m above design flood elevation.
- If not, certain low priority areas will have to be designed to be wet flood proofed.
- The spaces are classified into categories.
- The spaces are to be zoned vertically into various levels based on the proximity of similar wetness categories and also taking into account the possibility of creating a refuge area in the uppermost level.
- Materials to be used for the spaces can be decided based on the table recommendations (Table 5.7).

Table 5.7 Table template for building zoning and material class

Activities	Space requirements	DP/WP?	Space classification	Vertical zoning	Materials (min class)
Leisure-relaxing	Living area	Option 1: dry flood proofing (all spaces above RFD) Option 2: dry flood proofing of essential areas and wet flood proofing of low priority areas Option 3: wet flood proofing of all spaces *Option 2 to be chosen only if option 1 is not feasible, and option 3 to be chosen only if option 2 is not feasible*	W2	Above RFD	Class 2
Dining	Dining area		W2	Above RFD	Class 2
Cooking	Kitchen		W2	Above RFD	Class 1
	Kitchenette		W1	Refuge level	Class 1
Sleeping	Bedroom 1		W1	Above RFD	Class 1
	Bedroom 2		W1	Refuge level	Class 1
Bathing	Bath 1		W2	Above RFD	Class 2
	Bath 2		W2	Refuge level	Class 2
Parking	Car porch		W4	Ground level	Class 4

W1: Completely dry spaces; W2: essentially dry spaces; W3: spaces intentionally flooded with potable water; W4: spaces flooded with floodwater; W5: non-flood-proofed spaces [1]

5.8 Conclusion

Any flood-proofing measure adopted has its limitations. The main goals being addressed with this tool are to minimize losses and damages during flood and a faster return to normalcy [1]. The tool allows for design of spaces that can be used as refuge before help comes in.

A disadvantage of this approach is that residents may have a false sense of security and refuse to move out of their dwellings during an incident. The government needs to come up with guidelines and policies to be implemented along with modification of the building bye laws with respect to flood proofing. The base flood elevation (BFE) for all flood prone areas in the state needs to be formulated. The NDMA guidelines indicate 0.6 m elevation above the BFE to be followed.

Future work could include improvement of the tool based on feedback from users.

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Chapter 6
Understanding Emotion in Design Inspiration Contexts Through the Core Affect Model

Vimalkrishnan Rangarajan, Prasad S. Onkar, Alison De Kruiff, and Deirdre Barron

Abstract Inspiration is an important stage in conceptual design, wherein designers interact with different stimuli to generate creative ideas. Various cognitive processes like analogical reasoning have been described in design inspiration scenarios and have also been mapped to ontologies of cognitive psychology. However, the emotional processes in design inspiration are not clearly explained through ontological frameworks. In studies which report the significance of emotion in design inspiration, various aspects of emotion tend to get conflated. This conflation may lead to inappropriate choices of methods to measure emotion. To address this gap, this paper adopts the core affect model of emotion to offer a constructivist understanding of emotion in design inspiration contexts. The components of the core affect model are mapped to aspects of emotion reported in design inspiration scenarios which involve the use of stimuli. The paper then briefly outlines the potential of this ontological approach to study emotion in design inspiration. For this, a specific inspiration scenario is taken wherein a design student, while perceiving stimuli, thinks aloud to denote an emotion. It is then shown that this utterance could instantiate a detailed multipronged analysis in the framework of the core affect model, which delineates various constituent parts of emotion such as core affect, affective quality and so on. These constituents of emotion are broadly linked to different methodological

The original version of this chapter was revised: The author name "Vimal Krishnan R" has been changed to "Vimalkrishnan Rangarajan". The correction to this chapter is available at https://doi.org/10.1007/978-981-16-0084-5_76

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A. Chakrabarti et al. (eds.), *Design for Tomorrow–Volume 3*,
Smart Innovation, Systems and Technologies 223,
https://doi.org/10.1007/978-981-16-0084-5_6

frameworks with which they can be captured and analysed. The implications of this approach for future design research is also discussed.

6.1 Introduction

The Russian writer Vladimir Nabokov described the phenomenon of inspiration as having "neither source nor object. It expands, glows, and subsides without revealing its secret. In the meantime, however, a window has opened, an auroral wind has blown, every exposed nerve has tingled [1]". Such anecdotal accounts are complemented by empirical studies as well. Thrash and Elliot [2, 3] have validated inspiration as a psychological construct. They delineate two distinct component processes in inspiration. The first component is called "inspired by" which denotes an appreciation of an "evocative object". The second component is called "inspired to" which denotes the urge or motivation to extend some aspect of the evocative object to the new object that is being created. The studies of Thrash and Elliot [3] also note that "activation and positive valence", are strong correlates of inspiration. Whether described anecdotally as "nerve tingling" or technically as "activation", it seems that inspiration is inextricably linked to an "emotional high", often ensued by various creative acts such as designing.

Different process models of design and creativity [4, 5] include some aspect of inspiration. This means that a creative design process will invariably have an inspiration phase where new ideas and conceptual design solutions are conceived. Emotions play a significant role in this phase and they may shape such conceptual design ideas. This demands a clearer understanding of the emotion construct, specifically in design inspiration contexts. This paper offers such an understanding by extending the core affect model of emotion [6] to design inspiration contexts.

6.2 Background

6.2.1 Design Inspiration

The ability of designers to assimilate new information is critical to their creativity. Therefore, inspiration is an essential stage in a design process as it exposes designers to a variety of information sources from which they could develop novel ideas. According to Mougenot et al. [7] designers perceive inspiration as a continuous process. Designers have the habit of recording information available in their surroundings and retrieving such information when needed. Specifically, designers are sensitive to visual information and different modalities of visual stimuli significantly influences their problem solving [8]. Meggs [9] uses the term "ocular reconnaissance" to describe the tendency of designers to perceive and experience various things, especially visuals, which might be "fertile sources of inspiration". In a graphic design context, Laing and Masoodian [10] classify the various kinds of visual information that designers use to support ideation. These include images for personal development, cognitive aids, images for communication of an idea, aesthetic of the client, aesthetic of the audience and aesthetic of the market. Therefore, the design inspiration process is complex and multilayered, wherein designers combine disparate inspirational sources into coherent wholes.

There are several models of the inspiration process. According to Eckert and Stacey [11, 12], new design artefacts emerge from the transformation, combination and adaptation of elements available in already existing artefacts. This is a cyclical process. In this process, a source of inspiration is selected and then analysed. Depending on the requirement, the source is either discarded or adapted into the new design. After adaptation, the design progress is evaluated so that the problem may be reformulated. This in turn triggers another instance of source selection and analysis. Goncalves, Cardoso, and Badke-schaub developed a model of inspiration [13] which again represents inspiration as an iterative process. The model includes stages such as search, selection and analysis of stimuli. Upon analysis, if the stimuli are found to be appropriate, they are accumulated and are eventually adapted into the solution. Otherwise, the selection and analysis stages are repeated. Once adapted, the appropriateness of the adaptation is assessed, and the task is concluded. If the adaptation is not appropriate, then stimuli accumulation and adaptation are reinstated. These inspiration process models show that designers are "inspired by" various sources which in turn leads the designers to be "inspired to" adapt elements from such sources into their own creations. Emotion could play a significant role in orchestrating this movement from being "inspired by" to being "inspired to".

6.2.2 Emotion, Design Inspiration, and the Need for an Ontological Approach

In fields like bio-inspired design, inspiration is characterized as largely involving higher order cognitive processes such as analogical reasoning [14]. But this represents only one side of inspiration, as several studies have shown that emotion has a significant bearing on design inspiration and ideation. For instance, one study shows how a designer's autobiographical memories of "emotional" experiences influence architectural conjecturing [15]. Another study shows that inter-domain images "conveying positive affect" broadened designers' evocation of new sources of inspiration [16]. Yet another study reports that in a design project, designers included or excluded inspirational stimuli based on their own emotional reactions to the stimuli [17]. The importance of the emotion–inspiration linkage recurs in other areas of research such as emotions in search strategies for retrieving inspirational images [18], designers' emotional experiences and sensory stimulation [19], and affect-cognition interaction in conceptual design involving virtual reality references [20]. Another significant study shows that designers experience a higher degree of emotional arousal during the inspiration stage when they are in an immersive virtual reality workflow as compared to a traditional paper-based workflow. This enables them to embed more "emotional features" in their sketched design solutions [21].

Though such insights are promising and validate the significance of emotions in design inspiration, there is no clear understanding of the emotion construct itself in the design inspiration literature. This leads to conceptual ambiguities and conflations of various aspects of emotion. For instance, unless clearly defined, the term emotion could imply both individually felt emotions and emotional qualities perceived in stimuli [16, 21]. The impact of the foregoing studies can be enhanced if such conceptual ambiguities are resolved. Therefore, there is a need to establish a clear understanding of the emotion construct in design inspiration contexts. Design researchers have linked prevalent cognitive phenomena described in design processes to generic classifications in the field of neuroscience and cognitive psychology [22]. However, when it comes to emotion, there is no such standardization. As discussed earlier, this may lead to conceptual ambiguities and inconsistent application of methods. Instead, ontological models of emotion applied in the context of design inspiration provide a thorough understanding of the construct of emotion and its various components. Towards this end, a mapping of the core affect model of emotion to design inspiration contexts is proposed.

6.3 The Core Affect Model of Emotion in Design Inspiration

Emotion is a polysemous construct. Psychologists have developed various models of emotion such as dimensional models, discrete emotion models, meaning-oriented models and componential models [23]. Each of these models characterize emotion differently. The choice of a model to understand emotion can be guided by the research context. For instance, a design research study which attempts to understand how sociocultural and linguistic factors determine a designer's emotional response to various inspirational stimuli, may draw on meaning-oriented models of emotion. These models emphasize the subjective nature of emotions arising from various sociocultural and lexical structures. In this paper, a constructionist understanding of emotion through the core affect model developed by Russel [6] is presented. The fundamental components of the core affect model are explained and contextualized for design inspiration scenarios.

Before discussing the core affect model of emotion, three kinds of affective states namely emotions, moods and feelings must be distinguished. Emotions are "psychological states focused on the goodness or badness of events, actions or objects appraised for their relevance to one's goals, standards, and attitudes/tastes" [24, 25]. On the other hand, moods such as general happiness/general sadness are not directed at specific objects [24]. Therefore, it can be stated that emotions and moods constitute two polarities of a continuum, depending on the degree of the affective state directed at specific objects. The term feeling, technically known as core affect, denotes a combination of two dimensions, that of pleasure–displeasure (valence) and activation-deactivation (arousal) [26, 27]. This is "free-floating", undirected at any specific object and experienced by an individual at any given moment [26, 27]. Feelings function as internal signals that bring into consciousness, unconscious phenomena such as affective, physiological or cognitive processes [24].

As per Russel's core affect model, emotion is psychologically constructed, and it has two primitive elements namely core affect and perception of affective quality [6]. Core affect exists within an individual (Designer A's feeling of say, "excitement", which is a blend of positive valence and high arousal) and affective qualities exist in all kinds of stimuli (the "beautiful" colours or textures in an image, an "intimidating" venomous snake). When individuals perceive the affective qualities of stimuli around them, it may cause a change in their core affect (Designers may feel repelled while perceiving a "repelling" inspirational stimuli). This marks the onset of an emotion. It must be noted here that the perception of affective quality of stimuli might be a "hot" or "cold" process [6]. A simple instance of a designer perceiving a tree may be considered here. A "hot" process implies that the designer's perception of the tree as "beautiful", alters his/her own core affect. This combination of core affect and perceived affective quality marks the onset of an emotion. In contrast, if a designer saw the same beautiful tree without a change in his/her core affect the process would be "cold". This cold process is cognitive and does not result in an emotion according to the core affect model. Although a "cold" process does not generate an emotion, the process still contains affective assessments such as the tree being "beautiful" or "pleasant." The perception of stimuli as "beautiful" or "pleasant" is a form of subjective value conferment and is qualitatively different from cognitive engagements with stimuli such as analogical transfers which are studied in domains like bio-inspired design [14]. These subjective affective assessments may equally influence design outcomes. Therefore, the core affect model's delineation of emotion into various components is relevant for design inspiration scenarios where designers have emotional–perceptual relationships with inspirational stimuli.

6.3.1 Five Technical Terms of the Core Affect Model

The core affect model introduces five technical terms [6] which are as follows:

1. Core affect**.** A psychological state accessible at any given point of time which is a blend of valence and arousal. Valence denotes a range of pleasure–displeasure values while arousal denotes a range of sleepiness–activation values. This is the first primitive element of an emotion.
2. Affective quality**.** The ability of any stimuli to alter core affect of an individual. Affective quality can also be represented as a blend of valence and arousal. Perception of affective quality is the second primitive element of an emotion.

According to Russel [6] “phenomenologically, core affect is a feeling inside oneself, whereas an affective quality is a property of the thing perceived”.
3. Attributed affect. When an individual attributes his/her core affect to any stimuli, it becomes attributed affect, e.g. the feeling of fear experienced by an individual at the sight of a spider. It must be noted that attribution is not dependent on the reality of an object. Though it is typically quick and happens unconsciously, it can also be slow and deliberate.
4. Affect regulation. This denotes any action which is taken to regulate or alter core affect.
5. Object. This denotes any object towards which core affect is directed. It could be a person, a thing, a condition, an event or even a fictitious event such as a movie scene.

All these technical terms except affect regulation are considered in the following sections. This is because the focus of this paper is to show the relevance of emotion in design inspiration and ideation. Affect regulation would be more relevant in studies which focus on how designers manage their emotions during design practice [28]. In addition to these terms, the core affect model includes additional components like appraisal, instrumental action, physiological and expressive changes, subjective conscious experiences, emotional meta experience and emotion regulation [6]. Instantiation of all these components makes up a prototypical emotion episode [6]. For instance, if an individual experiences fear (change in core affect) after seeing a snake (perception of affective quality of object), the object is then appraised to further understand the situation. If the object poses a threat to life, then the instrumental action of deciding to move away ensues. In such cases, the emotional episode is marked by these additional components and not just the primitive elements which are core affect and perception of affective quality.

6.3.2 Mapping the Core Affect Model of Emotion to Design Inspiration Contexts

As explained in the previous sections, a fundamental aspect of the design inspiration process is the designer’s analysis of stimuli of various kinds. Designers are inspired by various stimuli, motivating them to incorporate some parts of such stimuli into their design solutions [11]. This engagement with stimuli could be regulated by emotion, as detailed in the core affect model. In this context, various studies on emotion and design inspiration report five aspects of emotion. They are:

1. The emotion experienced by designers.
2. An inspirational stimulus.
3. The ability of the inspirational stimulus to evoke a certain emotion.
4. The designer’s perception of this emotion evoking ability.
5. The emotion experienced by designers because of such a stimulus.

Table 6.1 A mapping of aspects of emotion in design inspiration contexts to the core affect model of emotion

Aspect of emotion in design inspiration/stimulus processing contexts	Mapping to the core affect model
(a) Subjective experience of excitement during perception of inspirational stimuli (b) Inspirational stimuli perceived as, say, "exciting"	(a) Change in core affect. Excitement as a blend of positive valence and high arousal (b) Perception of affective qualities of inspirational stimuli Core affect and perception of affective qualities are primitive components that make up an emotion
Subjective experience of excitement caused by inspirational stimuli	Attributed affect: attribution of core affect to inspirational stimuli, which is/are the object(s)
Decision taken to adapt inspirational stimuli to design iteration because of attributed affect/change in core affect/perception of affective quality	Appraisal (a cognitive phenomenon) and instrumental action

Without the guiding framework of an ontology such as the core affect model, these aspects tend to get mixed up in discussions of emotion in design inspiration. Therefore, there is a need to clearly define the constituent elements of emotion by extending the core affect model of emotion to design inspiration scenarios. The core affect model offers standard analogues and technical terms for each of the five aspects of emotion reported in design inspiration literature. Table 6.1 maps the technical terms of the core affect model [6] to design inspiration contexts. Table 6.1 uses the example of a designer getting excited by inspirational stimuli, which prompts the incorporation of aspects of that stimuli into a design iteration.

6.4 Potential of Adopting the Core Affect Model to Design Inspiration

This section indicates how the core affect model could enable detailed analyses of emotion and guide the selection of methodologies to capture emotion in design inspiration research. This is illustrated through a specific design inspiration scenario. It must be noted that demonstrating a comprehensive application of the core affect model in data collection and analyses is beyond the scope of this paper.

6.4.1 A Sample Graphic Design Inspiration Scenario

In this section, a specific instance of contrasting concurrent verbal protocols generated by two design students is presented. These instances are taken from a study which was conducted to understand how different visual inspirational stimuli were perceived by design students engaged in a graphic design task and whether emotion played a role in such perceptions. In this study, the students were given a closed context graphic design problem: to develop conceptual ideas for a landscape poster to be used in web/digital platforms to promote the ponds of Kerala as a national/international tourist attraction. Such a problem in graphic design was chosen because of its rhetorical aspects [29]. Rhetoric implies the arrangement of elements such as visuals and text to persuade an audience through arguments [30]. One of the integral components of rhetoric is emotion or pathos. Targeting an audience, designers embed emotion into communication artefacts to induce action, to educate or to create an experience [30]. Therefore, designers themselves may engage in an 'emotional' mode of inspiration, when they generate ideas, as compared to cognitive modes like analogical transfers in engineering domains such as bio-inspired design [14]. For this task, the participants were given images which served as cognitive aids (photographs of ponds of Kerala) which could be used to express ideas specifically related to the given design problem [9]. They were also given visuals which constituted the aesthetic of the market (sample posters and promotional videos of the Kerala tourism department). This represented the visual style and language used in competing designs to engage target audiences [9]. A contrasting verbal utterance of two participants, as they saw a promotional video representing the aesthetic of the market, is discussed within the framework of the core affect model in the next section.

6.4.2 Applying the Core Affect Model: Delineating Emotion and Relevance for Methodology

The following are contrasting excerpts from the think aloud transcripts capturing the responses of 2 design students to the promotional video (duration: 34 s). While Participant 5 (P5) said "this looks very exciting. The music is exciting, and it is showing all the animals and people…", Participant 8 (P8) said "okay so these are the celebrations of the culture of Kerala…and they have actually blended the music…".

The various constituents of emotion delineated in the core affect model can be used as a guiding framework to analyse these excerpts. These transcripts show that the same inspirational stimulus was processed very differently by the two design students which could have influenced their ideations. While P5 finds the music and the accompanying visuals to be "exciting", P8 simply describes what he/she was seeing as the video was played. In other words, the use of the word "exciting" by P5 could be interpreted as an instance of perception of affective quality, one of the primitive elements of emotion in the framework of the core affect model. Additionally, If P5 experienced "felt" excitement while watching the "exciting" video as compared to P8, the components of the core affect model can be applied further to guide a detailed analysis of emotion in design inspiration as shown in Table 6.2 (the methods

Table 6.2 Aspects of emotion in design inspiration mapped to the core affect model

Aspect of emotion in design inspiration	Mapping to component of core affect model	Relevance for methodology/Method
Excitement of P5	Core affect—a blend of positive valence and high arousal	Experimental/physiological measures like GSR (for arousal) and EMG (for valence) can capture this component. Self-report questionnaires may also be used
Perception of promotional video as “exciting”	Affective quality/perception of affective quality	Qualitative methods such as descriptive phenomenology, semistructured interviews could capture the subjective nature of perception of affective quality. Rating scales with valence and arousal values may also be used for more objective measurements, depending on the research context
Excitement of P5 due to visual perception of promotional video	Attributed affect	This may be inferred from combinations of verbal protocols, physiological data, self-reports, etc.
Promotional video	Object	In design inspiration contexts, the inspirational stimuli constitute objects. Different kinds of stimuli (visual, auditory, tactile, etc.) may be used to understand the relationship between design inspiration and emotion

mentioned are only indicative and are not to be used as an exhaustive/prescriptive list).

As shown in Table 6.2, P5’s feeling of excitement is taken to be core affect which can be measured physiologically, through self-reports or other means [31]. P5’s verbal protocol which refers to the promotional video as being “exciting”, is interpreted as perception of affective quality. Methods such as descriptive phenomenology which focus on subjective experience of participants can be used to capture this. Ratings scales may also be used for objective measurements in well-defined problem spaces. The feeling of excitement which P5 experiences, possibly as a result of perceiving the “exciting” affective quality of the promotional video, is attributed affect, which may be inferred from data such as verbal protocols time-synced with GSR peaks/eye-tracking heat maps. The object of attributed affect could be the promotional video in this instance. Therefore, the core affect model could enable researchers to clearly delineate the various components of emotion in their data. The interactions of emotion and cognition in design inspiration and design ideation could be understood more comprehensively by taking this approach.

6.5 Discussion

Design researchers have been taking an interdisciplinary approach to link cognitive aspects of design with various theoretical, methodological and ontological frameworks [22, 32–34]. Aligning with these efforts, this paper proposes an ontological approach to study emotion in design inspiration, which brings terminological clarity and guides methodology. The adoption of the core affect model could also lead to new research avenues, some of which are discussed here.

To integrate various aspects of design creativity, researchers have proposed the adoption of the dual process theory [35]. The dual process theory gives a framework of human thinking by positing system 1, which is intuitive and rapid, and system 2, which is slow and procedural [36]. Therefore, aspects of design creativity such as fixation, which denotes the unconscious reuse of examples without consideration of alternatives [37], can be understood as a kind of automatic system 1 process. So, a dual process theory-driven approach could develop a holistic picture of design creativity. This approach shows that aspects like fixation need not be treated as isolated phenomena, but as a component in the various system 1 and system 2 thought processes related to design creativity. The core affect model of emotion, when linked to the dual process framework [38] places emotion in conjunction with such other aspects of design creativity like fixation and association. This could lead to new avenues in design inspiration research. For instance, rich and immersive inspirational stimuli such as virtual reality could trigger core affect and perception of affective quality through system 1 whereas heavy symbol systems such as language, descriptions, or poetry could instantiate core affect and perception of affective quality in a reflective manner through system 2. This might significantly influence fixation and ideation trajectories. For instance, a stimuli automatically (system 1) perceived as appealing could fixate the designer to that stimuli, as compared to a stimuli perceived as appealing after deliberate interpretation (system 2). Also, new affect-based classifications of inspirational stimuli could be developed to complement semantic classifications such as inter-domain/intra-domain stimuli. This could calibrate tool supports like inspirational databases. Another implication is related to cognitive dissociation [38]. That is, when activated by associative or system 1 processes, emotions could intensify even when the triggering stimuli are not real. But when activated by system 2 or reflective processes, emotions be could be weakened by the knowledge that the triggering stimuli are not real. Therefore, real inspirational stimuli such as artefacts or representational stimuli such as photographs may be used in design inspiration scenarios to regulate the designers' emotions and their subsequent ideations.

6.6 Conclusion and Future Work

This paper identifies the need to properly understand the construct of emotion, given its importance in design inspiration. This need is addressed by proposing a mapping of the core affect model of emotion to design inspiration contexts. The paper also outlined how the core affect model could potentially enable detailed measurements and analyses of emotion in design inspiration. Future studies may review aspects of emotion in existing design inspiration literature and map them to the technical terms of the core affect model. To define emotion and its components as variables, more descriptive studies [39] can be done. Conceptual linkages with constructivist theories of emotion [40] and other models of emotion may also be established to refine the emotion construct in design inspiration and conceptual design contexts.

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Chapter 7
Role of Prototyping in Insight Generation for Product Development in Healthcare

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Abstract In the process of developing a healthcare product, it is significant to consider the insights from all the players affiliated. Right from the patients, caregivers, doctors, nurses, and even the manufacturers, they help in the evolution of the product, making it feasible, viable, and desirable. Their role is of great importance to the patient to use it in their abnormal or normal or both period and help the healthcare professional to get the information needed for better diagnosis and treatment of the patient. Understanding comes through prototypes as they are eminent in generating insights and help assess the designer and developer to what to deliver. Prototypes in each stage help are pivotal to set the features and get to know what works and does not. This paper is an attempt to understand the pros and cons of generic linear prototyping patterns and to assess the effect of parallel prototyping, which allows the team to be more explorative and divergent.

7.1 Introduction

7.1.1 Impact of Prototyping

Prototyping can drive the team toward the final product with evolution, and the team discovers the dos and do nots of the product for the target audience and its specification. The prototypes are a reflection of the thought process the team undergoes to develop a product that delivers the best to its consumers. As said, prototypes in

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A. Chakrabarti et al. (eds.), *Design for Tomorrow–Volume 3*,
Smart Innovation, Systems and Technologies 223,
https://doi.org/10.1007/978-981-16-0084-5_7

design thinking are "A simulation or sample version of a final product used for testing before launch, i.e., before spending lots of time and money into creating the final version of the sellable product." Prototypes play a significant role in solving usability issues before the launch [1].

Prototypes impact the final product, but on observation it is found that not all prototypes impact the final product or have a minimal impact, some insights lead to wrong paths, and hence the team ends up wasting time and money for the same. By impact, this paper means that the prototypes' influence gets weak, or those insights are no longer relevant as the area of innovation might change. It is quite necessary to understand the concepts of linear prototyping and parallel prototyping.

The team worked on a year-long project on a comprehensive and non- specific problem defined as follows—"*How might we use connected sensors to make Healthcare accessible for the masses of India or other developing countries?*" [2].

The team then researched various health issues the Indian population dealt with and tried to understand the viability, feasibility, and desirability. To reach the final concise problem definition, considered a subpart or a smaller version of the above problem, the team followed the following linear prototyping approach. The final prototype on the problem "*How might we provide physical home care for an ACL injured patient post-surgery?*".

The journey of prototypes from a wide brief to a concise brief was set within the following stages of prototype as coined by D. school design thinking phases [3] (Fig. 7.1).

The final prototype is delivered by the team named EXOR. It is a device that can be put on the knee sideways. This device can check the range of motion and speed, which could be detected by several sensors, and this data, when sent to the doctor, can be further analyzed to check the patient's progress. Thus, accounting day-to-day and real-time progress of the patient.

General set of touch points and Quadruple aim.

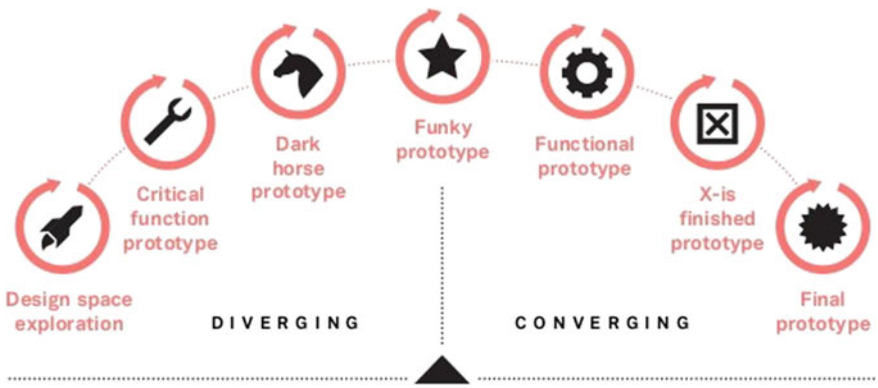

Fig. 7.1 Design thinking phases-prototyping

Table 7.1 General set of touch point to gauge a medical product

Patient should have	Exists (√/–)
Self-management	
In situ coaching	
Caregiver engagement	
Progress reports and appointment schedules	
Helpline and emergency responses	
Medication compliance	

Table 7.2 Doctor's checklist for the product designed

Doctor he/she should be able to	Exists (√/–)
Tracking the patients activity	
Risk stratification	
Care path customization	
Remote consultation	
Instant connection	

Table 7.3 Quadruple aim

Patients experience	Staff satisfaction	Productivity level	Clinical outcome

To assess the success of the product, the following set of general touch points are used.

In the gauging of the parameters, four criteria are put forth by the team to know if the product can deliver the following attributes as required in a healthcare product/device.

The rating for the above four points is to be given by team members as per Tables 7.1 and 7.2. Where the level of its purpose served (Table 7.3)

0—Poor 1—Good 2—Better 3—Average 4—Best 5—Excellent

Patients experience

On studying users' feelings and noting responses on the product, the looks and usability are on the test verge.

Staff satisfaction

To make sure the team delivers the required information to the healthcare professionals and ease up their detection of any symptoms and improve treatment procedure.

Productivity level

To make the product perform every necessary detail with proper co-ordination and sync. To ensure that the product performs various activities with different modes and delivers versatility with minimalism simultaneously with enhanced user interaction.

Clinical outcome

To abide by the medical regulations and provide necessary medical output, to smoothen doctor's work timely.

7.1.2 Research Question

How will the explorative and divergent prototyping approach affect the outcome and help the team generate insights, to add value to the final product deliverable evolution?

7.2 Methodology

7.2.1 Assessing the Impact of Each Prototype on the Final Prototype

To understand the impact of each prototype on the overall product at the end, the team assessed the prototypes in the parameters mentioned in Tables 7.1 and 7.2. Based on this checklist, the team decided to use the points gained in Quadruple to understand the level of impact and insight each prototype brought in (Tables 7.4 and 7.5).

Figure 7.2 depicts the final product's impact derived from the results seen in Table 7.6. Each checkpoint has taken into account, and as seen, the insights generated by DH2, DH3, and Funky prototype have been less impacted, whereas the CFP has a

Table 7.4 Assessment of each prototype using above Tables 7.1 and 7.2

Patients checklist	CFP	CEP	DH1	DH2	DH3	Funky	Functional	X
Self-management	–	–	–	–	√	–	√	√
In situ coaching	–	–	√	–	√	√	√	√
Caregiver engagement	√	–	√	√	–	–	√	√
Progress reports and appointment schedules	√	√	√	√	√	√	–	√
Helpline and emergency response	–	√	–	√	√	–	√	√
Medication compliance	–	–	–	√	–	√	√	√

Table 7.5 Checklist from the doctor's perspective

Doctor should be able to	CFP	CEP	DH1	DH2	DH3	Funky	Functional	X
Tracking the patient's activity	√	√	√	√	√	-	√	√
Risk stratification	–	–	–	–	–	√	√	√
Care path customization	√	–	√	√	√	√	√	√
Remote consultation	√	–	–	√	√	√	–	√
Instant connection	–	–	√	√	√	–	–	√

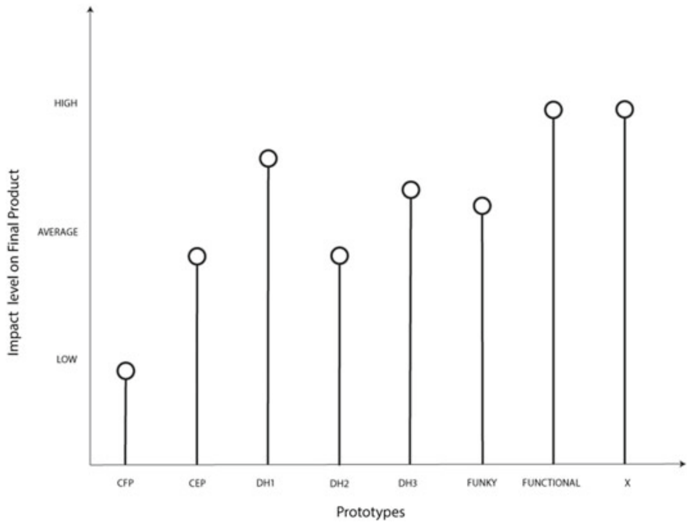

Fig. 7.2 Impact level on final product

Table 7.6 Quadruple aim

Prototypes/Q.A	Patients experience	Staff satisfaction	Productivity level	Clinical outcome	Total
CFP	2	1	3	1	7
CEP	2	1	3	4	10
DH1	3	5	4	3	15
DH2	2	2	2	2	8
DH3	3	4	3	4	14
Funky	1	5	5	2	13
Functional	4	3	4.5	5	16.5
X	4	4	4	5	17

shallow impact on the final. The attributes in the patient's view and doctors have covered how each prototype evolves with the features.

7.2.2 Considering the Research Question for Discussion

Is it beneficial to adopt exploratory and divergent approach in prototyping?

7.2.2.1 Discussion on Linear Prototyping

Before going further on the topic of parallel prototyping, it is necessary to understand the pros and cons of the linear prototyping.

Advantages and Disadvantages of Linear Prototyping

Advantages:

1. Since it is a linear approach, it can be time-bound where the team needs to deliver the products over a defined timeline, thus delivering the product for further process.
2. Scope of quick prototype and dirty prototype becomes much higher as they are easy to deliver by the team, and all insights are extracted from them.
3. The scope of a product derived becomes limited; thus, the team remains focused, and the delivered product is specific in its features, thus avoiding extra detailing over features.
4. Scope of the product being concise and precise, it becomes easy to create or address the target audience.
5. Can save minimize cost of production at point of manufacturing and keep away any error [4].

Disadvantages:

1. As the product delivered remains time-bound, the evolution further depends on the manufacturer and the design team.
2. Some points (features) to be addressed do not get specific attention and may loose its identity.
3. Over the period insights generated lose their value and thus remains as just an idea or disregarded insight.
4. The potential product features and concepts idea racks are just overlooked in the view to fulfill the criteria to attain goal.

7.2.2.2 Discussion on Parallel Prototyping

In selecting a brief under a head brief to move on with its specific target audience and innovation, it is essential not to get inclined toward any specific concept. Apart from this, it is a human tendency to get the work done and achieve what is required quickly. While there is nothing wrong with making things easy, it is vital to choose the course of action in design thinking. Linear prototyping is a time-bound process and entails a few limitations, which pressurizes the team to follow the steps rather than take the required and demanded steps of the design thinking process. The design itself being exploratory right from the beginning. The prototyping stage can be linear until the problem is well defined, but if the problems are ill defined, it is equally essential to search for the right problem and its solution to address.

In this manner, the concepts would be reasonably discarded and integrated into due process. From studies, it is evident that parallel prototyping emboldens designers to think generatively, using their work in the past as inspiration for new ideas whereas, in serial prototyping, it is mostly refining existing prototypes. The team observed a few points that could help prototypes to be insightful and have an impact on the final design [5]:

- Prototype does not represent the complete functionality or low-level details.
- Prototype is supposed to be flexible and such that it can be merged in the future based on the requirement.
- Prototype might be a throw-away deliverable but it is the only way to make sense and useful ideas turn into reality. It is a maturing process.

Since it is not expected a prototype to be wholly functional or have every minute detail covered, it is about trying to get insights. Via parallel prototyping, the team can have a more exploratory approach [6]. Parallel prototyping can be adopted, keeping in mind the stakeholders' requirements and the insights we gather in the process. The central part of parallel prototyping is to throw several options in front of the users to critique them. Multiple prototypes lead to a new amalgamation of the prototype. Also, the stakeholders could choose from multiple prototypes. This could be achieved by the following proposed model of prototyping where the insights, the parameters, and the attributes of the concepts on paper could be put to test by parallel validating the prototypes.

It promotes individual exploration, feature sharing among multiple prototypes and promote team work and promote a general agreement among prototypes, which is unable to configure at the initial stage of designing. Parallel prototyping encourages us to have questions early and find the gaps in the complex systems. Once we are set on filling the gaps, we build better prototypes and thus insights generated are way more efficient and fruitful for an overall output of the efforts [7] (Fig. 7.3).

Example:

Considering the first brief in the process, "How might we use connected sensors to make Healthcare accessible for the masses of India or developing countries?"

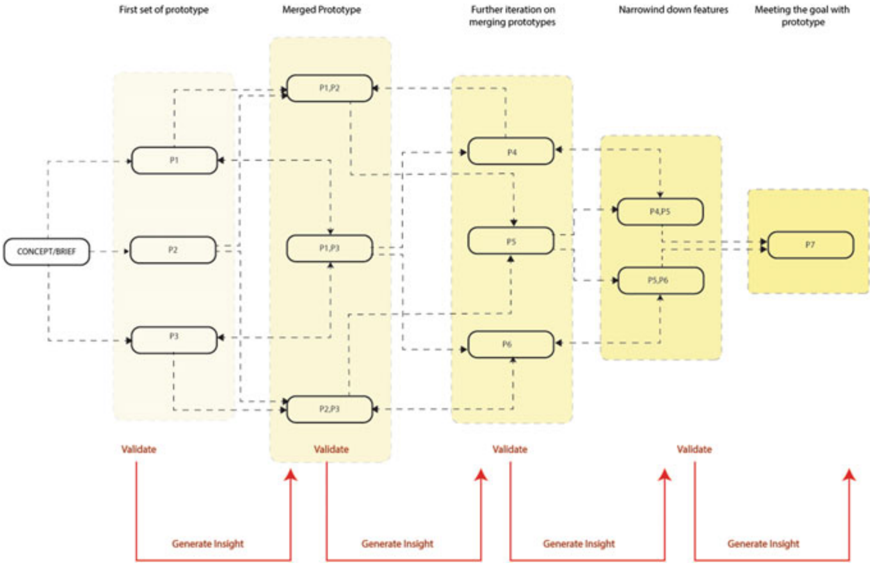

Fig. 7.3 Parallel prototyping

On further ideation and deep diving, the team narrowed down to three major areas as followed: (1) In-home monitoring, (2) Diabetes, and (3) Primary care. On further narrowing down. At home, monitoring opted as a space of innovation. Once the ACL injury area opted in, the team came up with an enhanced post-operative care experience. There are many relapses taking place due to non-compliance, irregular visits to the physiotherapist, and traveling.

The first three prototypes are as follows (Figs. 7.4, 7.5 and 7.6).

Fig. 7.4 Range of motion detection

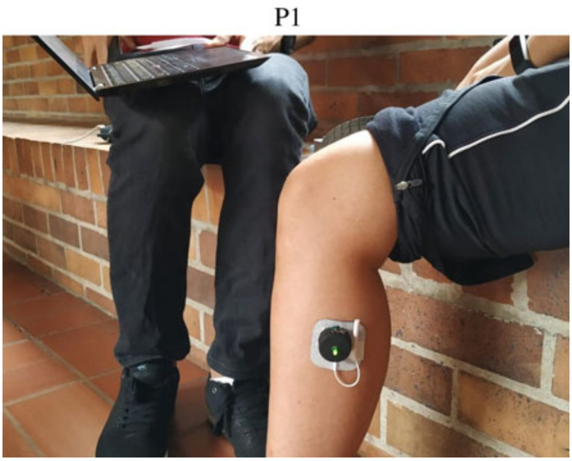

Fig. 7.5 Exercise guidance bot

P2

Fig. 7.6 Portable scanner

P3

Table 7.7 Quadruple aim analysis of the prototypes 1, 2, and 3

Prototypes/Q.A	Patients experience	Staff-satisfaction	Productivity level	Clinical outcome	Total
P1	4	2	3	2	11
P2	3	2	4	3	12
P3	3	0	1	1	5

In Table 7.7, as seen that the prototypes fail to fulfill specific criteria due to the lack of attributes required. The attributes do not need to be excellent, scoring five, but a balance of features and usability should be maintained. From Table 7.7, prototype 3 fails to fulfill the criteria of staff satisfaction as the scanner only provides the X-ray, and every other detail is to be diagnosed by the doctor while it serves incomplete information. The product does not provide any other medical information about the patient/user. Insights generated are as follows:

P1—It is inconvenient for the patient to apply anything on the skin as that could be a place of injury or would be sensitive evident in Fig. 7.4. However, at the same time, a tracking device helps them to determine their records. It is being tracked by a healthcare professional, which is a two-way benefit to the doctor and the patient in tracking and acting on the records. Thus, doctors need medical information from the device, and patients to need something unobtrusive to do this.

P2—The ratings are average for this prototype, which indicates that a little improvement in it would be acceptable. While doctors find the prototype to be an enabler to make their patients comply with their exercise routine, doctors are also worried that there is assistance in how these physical exercises are done at home.

P3—This prototype does not fulfill staff satisfaction as the scan will not be live and might hinder the patient's diagnosis with its improper information.

Step 2: Applying Parallel prototyping.

Merging the prototypes to see the results and impact on insight and gathering the outcomes from the quadruple aim with higher score, it was clear that the team has to be able to keep the good points and the one with lower score needs to be addressed. Thus, the process followed as per Fig. 7.3 was to merge the insights of each prototype and deliver a product maintaining the qualities required in a product.

P1, P2: On merging the insights, the team found that it needs to have a product that provides an interaction surface to the patient and an activity tracker but only for exercising.

Features of the merged product would be:

Two interconnected devices; one tracks the range of motion at the time of exercising, and the other gives guidance; now, this could be audio or visual or both.

The healthcare professional could use this data to guide via the visual guidance.

The best possible way to reach the patient is their mobile phones. Thus, an app-based activity tracker was coined as a prototype.

P2, P3: On merging the insights, the team found that the tabletop device while exercising is not effective as the patient has to reach the device for every interaction with it, thus needing guidance while exercising. Whereas from the third prototype, it was evident that the patient needs constant professional guidance when following up their physiotherapy session in prototype 3. Thus, the merged product would be

- a device with proper guidance with constant medical guidance by the physiotherapists.
- a device which could be something that need not be handy as the scanner but should be easily in the reach of hands when required.

P1,P3: As observed from the insights, where tracking is necessary, it is also important for the patient to have professional guidance during the activity, which could be provided by real-time feedback within the device you wear.

Thus, the merged product would be:

- a device with ability to guide the patient throughout his/her exercise regime and be able to track the patient's moment and provide useful data of range of motion and the sensitivity of pressure on movement.

Thus, in the example above, the insights gathered can be used to fill the gaps each prototype lacks and note down a critical takeaway from even the failed prototype. In the case of linear prototyping, the team has to discard it. A slight shift in proportions can make a world of difference in how someone perceives the appearance, function, and value of a product [8]. Impact of prototypes when merged and conducted tests parallelly:

To assess the impact of prototypes on final prototype based on the insight with doctors and patients' point of view, let us observe the table below.

Thus, the quadruple aim needs to be checked to know whether the parallel prototype proves to be beneficial to extract and deliver the best making use of the insights gathered.

Thus, after studying Tables 7.8, 7.9, and 7.10, the team infers that the insights have a remarkable impact when they prototyped parallelly and used the insights for merging the prototypes forming a more insightful prototype. This way, they got their doubts tested and also generated insights which work in the interest of both doctors and patients, while Table 7.10 is evidently saying that one prototype can help fill the gaps of other prototype by some minor improvement.

Table 7.8 Assessment in patients' point of view

Patient should have	P1, P2	P2, P3	P3, P1
Self-management	√	√	√
In-situ coaching	–	√	√
Caregiver engagement	–	√	√
Progress reports and appointment schedules	√	–	√
Helpline and emergency responses	√	√	–
Medication compliance	–	–	√

Table 7.9 Assessment in doctors' point of view

Doctor he/she should be able to	P1, P2	P2, P3	P3, P1
Tracking the patient's activity	√	√	√
Risk stratification	√	√	–
Care path customization	–	√	√
Remote consultation	√	√	√
Instant connection	√	√	√

Table 7.10 Quadruple aim checklist

Doctor he/she should be able to	P1, P2	P2, P3	P3, P1
Patient's experience	4	3	3
Staff satisfaction	3	4	4
Productivity level	4	3	3
Clinical outcome0	4	4	3
Total	**15**	**14**	**13**

7.3 Conclusion

The researchers found that the parallel prototyping approach helps create insights more efficiently, produce better design results, has diverse design ideas, and increase the team's productivity to be effective on the final product. In linear prototyping, the evolution of a product is dependent totally on the iterations done that ensure details in features of the product. Nevertheless, in parallel prototyping, each prototype's insights on merging forms a much more practical insight. Furthermore, designing has always been an exploratory journey to improving the lives of the people. In order to accomplish this, it becomes essential to be exploratory. It is in favor of developers to let the prototypes and the insights decide where it leads. Thus, parallel prototyping in this scenario become a crucial part which helps generate insights and thereby help the team to deliver their best.

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Chapter 8
Brassiere: Modern Approach to an Age-Old Problem

Tushar Amin, Tanmayee Puntambekar, and Dyuti Ravisankar

Abstract **Introduction**: The need to have a form fitting garment that provides support to the breast tissues has been around for a very long time. Brassieres are also known by its shorter-term bra; earliest documented date backs to seventh-century India. **Need**: Although the brassiere has been around and in use for such a long duration it has gone through a large evolution from being just a length of cloth to the sophisticated, complicated garment, the design still has quite a few shortcomings. Brassieres that are currently available all have the same issue of manufacturing defects and inaccurate measuring techniques. This leads to most women wearing ill-fitted bras their entire life. **Method**: Interviews were conducted to understand the difficulty level of wearing the bras, choosing the right size, type and problems faced with regular usage. The data collected was analysed qualitatively–quantitatively with grounded theory approach. It was found that most women faced physical discomfort due to the issues with imprecise fit of the apparel when adorned. Moreover, the availability of numerous types in the market further confused the user. As the garment is being used on a daily basis it's significant that it be redesigned for the woman of today. **Purpose**: This study explores the need for an accurate fitting bra which is comfortable and supports breast movement. **Conclusion**: Throughout history, women have been made to feel insecure about their bodies, not accept it for what it actually is and further inculcating self-doubt. Hence, there is pressing need to develop a product which is supportive and empowers the user.

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A. Chakrabarti et al. (eds.), *Design for Tomorrow–Volume 3*,
Smart Innovation, Systems and Technologies 223,
https://doi.org/10.1007/978-981-16-0084-5_8

8.1 Introduction

Regardless of the period in time, there have been various versions of bras that have been used to cover and support the breasts [1]. At the dawn of civilization, women were bare chested. It was with societies moving forward that it came to be considered uncivilized to have women not cover their breasts. In eighteenth-century British India, the ruler of the southern Indian state of Kerala in Thiruvananthapuram had imposed a breast tax on lower caste women which prevented them from covering the upper part of their body and were heavily taxed on disobedience [2]. Therefore, discrimination based on clothing was prevalent allowing the rigid caste system to continue up until a lower caste woman rebelled, on the arrival of the tax collectors sliced her breasts in protest. This was the turning point were the then ruler was forced to abolish the practice and women of all classes began to cover their breasts with securely wrapped clothing [2]. In today's world, women wear different forms and types of the bra. But when it comes to the fit and functionality of the undergarment, the users are in much trouble [3]. A study conducted by Doctor Pechter showed that 7 out of 10 women wore the incorrect bra size their entire life [4]. This was further proven by Jenny Burbange, a sports bio mechanist who showed lack in standardization, different measuring techniques for bras and its variance according to each manufacturer caused further problems with reference to fit for women [3]. The breast tissue inherently lacks the internal structural support to help displacements which in turn leads to breast pain in women. Thus, the need for an externally supportive garment is crucial [5]. This study aims to delve into the problems faced by the user when buying, using the apparel on a diurnal basis and importance of a well-fitted undergarment.

8.2 Literature Review

Over a century ago, in the western world, the modern bra came into being, designed by Mary Phelps Jacob; two handkerchiefs were stitched together with ribbons being used as the straps [6]. This was to break free from the corset, a contraption having a steel frame to shift the weight of the breasts to the rib cage. But with World War II, the need for metal increased which indirectly liberated women from this contraption. The corset took many forms in the hopes that it would help women attain the "perfect" physique [7]. The modern bra has had its own evolution from a tight bandeau tops which made breasts look smaller, a bullet-shaped bra and a push-up bra which helped enhance the bust size, but with fitness and exercise becoming popular, the first sports bra hit the market in the late 1970's to help support women with physical training [1]. Sports bras are supposed to be the most supportive kind of undergarment for women as it was designed to help women exercise at ease but breast displacement is a common concern during quick walking, exercising, running and jumping as this triggers breast pain. However, very little research has been conducted though it is suggested excessive motion causes the pain. The breast motion cannot be reduced since there is no structure anatomically. The sports bras that have been developed don't address this issue completely [5]. Moreover, this causes women to feel discouraged from wearing them. A study conducted in Australia with 267 women participants between the ages of twenty to thirty-five it was understood that the shoulder straps slipping, cutting into the shoulders and tightness around the chest further caused problem to the user in terms of comfort [8].

During the literature study on bras, the sports bra has been looked into the most as it is theoretically the most effective of all the available kinds of brassieres. Regular bras have not been taken into consideration in spite of its daily usage which indirectly cause most women to wear bras that are wrong sized and suffer in silence. This paper looks further into the cause, need for an accurately fitting apparel and its benefits.

When women wear bras that do not fit them properly, musculoskeletal problems arise and make them body conscious while participating in physical activities [9]. A research was conducted on 104 women to understand their method on choosing bras when left independently. It was found that 85% of women were wearing the incorrect-sized undergarment even though they had several self-fitting arrangements. This reflected the need to educate women on the method to choose by themselves a well-fitted bra [9]. It was once again proven when conducted on 1324 female horse riders that they too had difficulty in finding a well-fitted cup size for their bras due to which 40% reported breast pain during their riding session. 21% reported breast pain while trotting which caused underperformance. Large-breasted users found more difficulty than the small-breasted individuals [10].

Bra manufacturers and designers need to understand the root cause for most bras being of the wrong size and must accommodate the errors that occur due to breast volume with respect to breast size in large women. In a study that was conducted on 50 women with large ptotic breasts, when scanned three dimensionally, it was found that when the participant was in prone position, visualization was a complete success. In the prone position, the breast volume increased compared to standing. The difference in standing and prone position was 7–10% [11]. In reduction mammaplasty or breast reduction surgery, it was again found that ill-fitting bras played a major role in their discomfort. A study conducted in 103 women before surgery showed disparity between the sizes worn by the women against the actual measurements when taken. This problem of fit further aggravated their problems which made them elect for surgery for a better quality of life [12].

In the current market, an algorithmic lace bra was developed by Lisa Marks which helps women who have undergone mastectomy due to breast cancer. A three-dimensional lace was made with mathematical calculations which fit women who had one breast or both breasts removed. It made the bodies look symmetrical because of the mathematical modelling [13]. EVA bra made by Julian Rios Cantu, helps detect early breast cancer with two hundred bio-sensors that when placed on the breast helps track the changes in temperature, blood flow, weight and shape. This logged information in the bio-sensors can be viewed on its app. Cancerous tissues are said to rise the body's temperature due to increase of blood flow in the body. By wearing the product for a little over an hour every week, it helps track the symptoms easily [14]. In a sports bra, by compressing the breast against the chest wall, the vertical movements of the breasts are controlled within the breast. This makes the user feel uncomfortable while wearing it during exercising which leads to decrease in physical activity. Electro material sensors and artificial muscle technology are capable of detecting the breast motion. This bra by itself is made of sensors that can automatically respond according to the breast motion. Depending on the physical activity the fibres relax but this is still a concept design [15].

The current market consists of several high-tech bras but the need is to have a simple bra that helps the user function and get through the day easily without discomfort which designers loose focus off. Even before the British brought the then modern bra into British India other garments such as the Choli and Kanchuka, both were tight garments that eventually lead to tight blouses being worn underneath sarees by the women of the time to support their breasts whereas the current generation has shifted to the western wear [6]. So, the need for a well fitted bra is a must. Hence to support the breasts, a brassiere has to be developed which does more good than harm.

8.3 Methodology

The study conducted was to thoroughly understand the evolution of the bra, its need, usability, current structure and problems faced while using the existing kind. The data was analysed qualitatively–quantitatively through triangulation. Quantitatively research was conducted to gain people's knowledge as well as experience and qualitatively to see patterns and numbers through grounded theory approach. The research was conducted through interviews and an online survey that was circulated among 145 women of a socially diverse-mixed age group keeping between thirteen-to-seventy years of age. The primary research data was taken from the interviews and survey that contained eleven multiple choice and short answer questions aimed at acknowledging the issues while using, wearing and buying the modern brassieres. It was constructed with questions in regard to the brands women opt to buy from, brand loyalty, the types of bras that they do purchase, measuring techniques applied when purchasing the apparel, comfort level of the product, problems faced by them while wearing the garment and the after use of the product.

The secondary data was taken from online journals and research papers to understand the types of surveys that had been conducted, its findings and implications. The types of errors in manufacturing and fit were made evident from this analysis. Through Simple Random Sampling, Convenience Sampling and Snowball Method of Sampling the survey was able to travel which helped in a diverse audience to write in their feedback. This really helped understand the deep-rooted issues that the bra causes and the silent pain women suffer when wearing it on a daily basis. All participants were made aware that their data would be used for research purposes and consent was taken in regard to that.

8.4 Result

The survey made it clear that women above the age group of thirteen owned several types of bras to make up for the problems caused by each bra. Moreover, the availability of various styles, fits and sizes of brassieres further confuses the consumer from choosing the right fit for them. Usually, they buy multiple brassieres for several occasions which is evident from (Fig. 8.1). On daily usage of the apparel for a long duration, it is found they face multiple difficulties where 40% of the women have straps cutting into their skin, 23% with the cup sizes not fitting and 11% with issues of support with the garment. Less than 9% of them claim to not have any problems with the apparel (Fig. 8.2). These issues in fit and structure cause multitude of physical problems for the user which manifests in breast, neck and back pain to mention a few. This causes women to feel conscious and not be at their best. The expense of the bra needs to be kept in mind when purchasing and it not functioning as per its need is a disservice to all its users. 92% of the participants felt that bras are an expensive commodity owned by women (Fig. 8.3). The high cost of the brassiere makes women use and reuse until it is completely worn out in spite of it causing pain to the user.

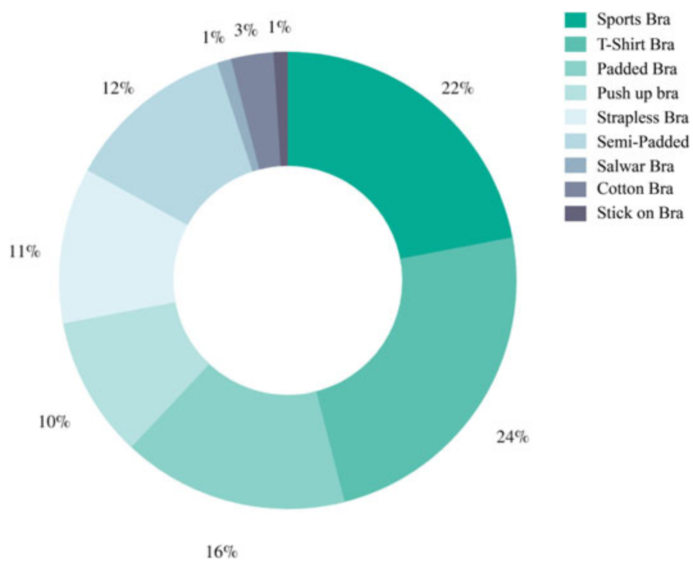

Fig. 8.1 Types of bras owned

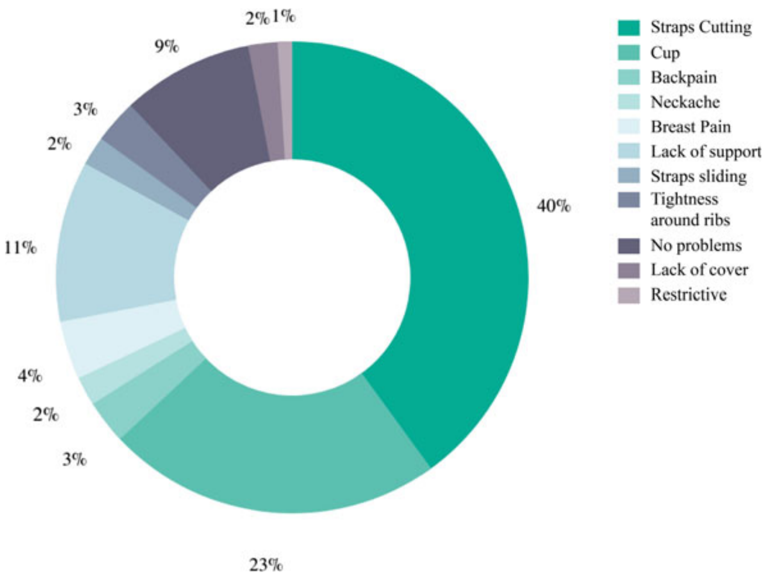

Fig. 8.2 Problems faced

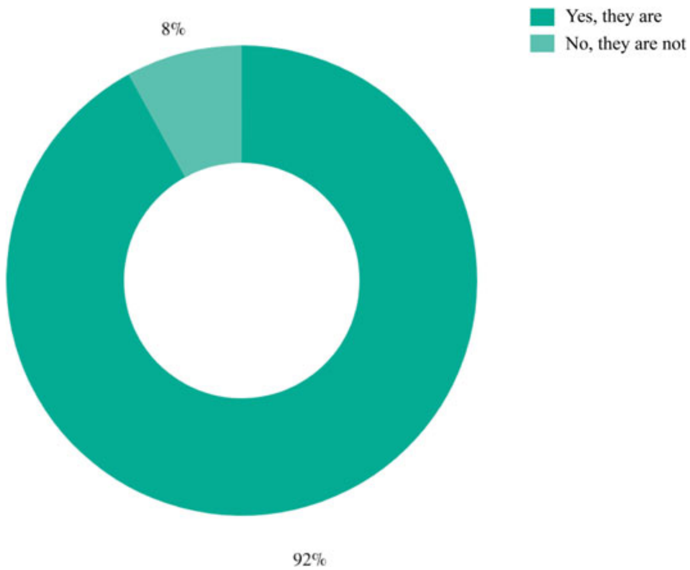

Fig. 8.3 Expensive

8.5 Discussion

From the results, it is evident that bras cause much discomfort to the user during use. An inner garment that is supposed to support instead is the cause of pain and that needs to be addressed. The purchase of a bra begins at the sale point which is the sales counter [3]. The woman depends on the experience of the saleswoman to help her choose the right size. By taking the correct measurement starting with the cups, such that it covers the entire breast, then the bust and chest gives the correct size of a bra needed by a woman. Even if the bust and chest size is right, some manufacturer's defects that are present in bras also cause women to wear the wrong size [11]. The issue in fit causes further problems to the user as it leads to breast pain, back ache, neck pain and can even lead to other musculoskeletal problems [9].

In India, brassieres have been around from the period of King Harshavardhna but yet as a product it's not user friendly for long periods of time [6]. Thus, in this case, there is a need for having brassieres where the cups mould according to the user's form, helps keep the breasts intact and adapts to the user's body changes as well, thereby providing sufficient support to the movements of the body. Additionally, it should be machine washable making the user experience easier. When the product can mould itself to take the shape of the individual's physique, the measuring tape becomes redundant and hence margin of error becomes less. Due to this, it is imperative to look into fabrics that offer more in terms of functionality than just basic support. The material should react to movements and tackle stress–strain. It should accordingly provide localized stiffness to support when and where the breast tissue requires. For this reason, the fabric should be dynamic in nature which reacts to stress by increasing the material thickness around the breast area. This will ensure that the garment provides sufficient support by reacting and adapting in real time to movements of the breast tissue. Auxetic materials lend themselves very well to this need. These materials work contrarily where normally a material that is stretched would become narrower under tension and would expand under compression. Auxetic materials have a negative Poisson's ratio and are those that possess the ability to become plumper when subjected to a stretching stress and finer when subjected to compressive strain. These forms of materials can be woven into the fabric of the bra along with currently available elastic materials like lycra. This will allow the bra to latently provide support and also be comfortable since it will adapt to the form of the body of individual users [16].

The comfort level of the user can be enhanced due to the cups ability to react to the physical motion of the user's body, thus avoids the hassle to get multiple bras from the market. By providing the user with the much-needed support, it will help prevent physical pain and mental fatigue that brassieres cause currently [12].

Further research has to be done into redesigning the straps and cups of the bra to elevate the user experience and comfort of the product. This concept however, does not guarantee that it will work, it's merely a solution to help free women from wearing the currently flawed design that is available. The research shows that the root cause of this issue is the lack of awareness when designing and choosing the apparel.

Previously conducted researches have mostly focused on sports bras not regular ones, over looking the needs, implications and importance of having a well-fitted garment for daily usage.

8.6 Conclusion

An immediate need for a proper supportive system which physically and emotionally makes women feel confident about themselves is required generating body positivity for themselves. On future studies regarding brassiere design, the researchers must take into consideration the physical changes associated with women's body. This should include her menstrual cycle, pregnancies if any and medication that she could be on. Even today, the bra lacks support to counter women's breast motion and this leads to back aches and physical discomfort with the straps cutting into the shoulders of the user. The problems identified in this research can be overcome by the right design intervention. This research paper hopes to create an awareness in women that selecting the right-sized bra needs to be customized from woman to woman.

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Chapter 9
Investigating the Use of 3D Solid-Modeling Tools in the Early Idea Generation Stage of Product Design: An Exploratory Study

Purba Joshi and Battula K. Chakravarthy

Abstract The vast intervention of CAD tools and ubiquitous availability of computers has changed the culture of product design and has given birth to a new generation of engineers and designers. It has become a necessity in today's fast moving technology-driven world and an integral part of the designer's work environment. Initially, the application of CAD was mainly restricted to later stages of design, but in recent years, it has seen increased attention in the idea generation stage. The paper illustrates an exploratory study conducted with five professional product designers who were given a design task to be performed in limited time. The data used for the analysis was the visual data recorded during the design exercise and verbal data from the interviews. The visual data was recorded with the help of video camera and desktop recording software. Semi-structured interviews were conducted with participants to collect supportive data for the analysis and were audio recorded. The video recording of the whole activity was transcribed and tabulated, and occurrences of study parameters were mapped visually. This also helped establish a method to analyze a design activity with the visual mapping of study parameters. Supportive verbal data from the interview helped qualify some of the findings and cover the missing points that were difficult to identify in the time-bound exercise or through observation. The qualitative analysis of the study helped identify visualization as the strongest enabler offered by the use of CAD in the early idea generation stage. It also indicated the other enablers as confidence building, faster process and ease of prototyping. The most evident barrier identified through the study was circumscribed thinking. Circumscribed thinking occurs when ideas get limited or affected by the skill level of the designer (Robertson and Radcliffe in Comput Aided Des 41:136–146, 2009 [1]). The study also throws light on how CAD is used in the process when the design brief requires functional or problem-solving exploration

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A. Chakrabarti et al. (eds.), *Design for Tomorrow–Volume 3*,
Smart Innovation, Systems and Technologies 223,
https://doi.org/10.1007/978-981-16-0084-5_9

versus formal exploration. It was observed that during formal explorations, considerable time was spent on exploring how to model, leaving lesser time for design exploration and decision. The study helped understand how designers accommodate CAD in their exploratory process in combination with other tools like sketching and physical modeling. It strengthens the view that CAD has become an integral part of the design environment and is extensively used even in the idea generation phase of design.

9.1 Introduction

The design process for new product development has seen enormous changes since the introduction of CAD [2]. Designers today are well acquainted with the new age tools and have adopted them as an essential part of the design process. This has affected how designers are working today.

Widespread adoption of CAD by designers had led to a range of views on the consequences that it could bring for individual design ability, efficiency, and quality of the output. Stappers and Hennessey [3] emphasize that "we must better understand the contribution that CAD makes to the design process and be careful that its implementation does bring changes in the awareness and capabilities of participants that may be regarded as central to capability in design."

Many researchers [3–6] have argued the suitability of CAD when the ideas are crystallized and not for idea generation stage. CAD is well accepted as the drafting, visualization, and detailing tool but not as an exploration tool.

Hanna and Barber [7] mentioned that the conventional design process has a well-established formal structure of analysis–synthesis–evaluation– presentation. However, the computerized design process does not have any such established structure and is more like an added activity. They also emphasize the need to identify the changes to the nature and structure of the design process that need to be made if CAD is to be used as a design tool in the early phases of design. As the role of CAD is well established in the later stages of design [8, 9], its role in the early idea generation stage in the context of product design was identified as a gap.

Creating ideas is a continuous process of finding possible solutions and refining those. It is not something that takes place at the beginning of the project [10]. Searching for ideas requires many diverse activities and an open and free mind, and it is crucial to understand how the tools used by the designer can affect this.

9.1.1 Aim of the Study

The broader aim of the study was to understand how the use of CAD affects the early idea generation stage of product design. The objective of this particular study was to understand the advantages CAD offers and limitations it imposes in the said context.

9.2 Methodology

The qualitative approach for the study was adopted to strengthen the understanding of the context. Qualitative research facilitates producing in-depth information and knowledge from a small number of cases or participants.

Since observing a designer in their actual work environment while working on a live project involved many copyright and privacy issues, the study was conducted in a separate setup away from their offices. The methods used for the study were observation and semi-structured interviews.

9.2.1 Participants

SolidWorks 3D modeling software was used for the study. It allowed the collected data to be comparable. Five participants selected were the product designers with 3–5 years of working experience and users of the same software. Three of the participants were the certified *SolidWorks* professionals and proficient users, and other two participants were competent users. They rated their proficiency based on the criteria provided to them. The proficiency criteria were derived based on the Dreyfus model of skill acquisition [11].

9.2.2 Procedure and Task

The study setup was arranged with a desktop computer pre-installed with software, loose papers, pen, pencil, ruler, and water in a separate room. The participants were made comfortable and briefed about the study and the data collection method. A declaration was given to them, stating that the data collected will be used for academic purposes only by the researcher. Their consent for recording the task and using data for analysis was taken. A video camera to capture their activities was installed behind their seat, and free desktop recording software *Webinaria* was installed on the computer.

The printed brief was provided to them, and time was given to understand the same and clarify any doubts. Two separate design briefs were used for the study. The first design brief given to three of the participants was to design a bread toaster for visually impaired users. This brief allowed the ideation toward the problem-solving activity. The second brief was to design a spoon for a five-star restaurant based on which the remaining cutlery can be explored. This brief focused more toward formal exploration. The participants were given a limited time of 180 min to explore their ideas with a tea break in between.

All the participants were scheduled on different dates, and the design session was conducted with one participant at a time.

9.2.3 Data Collection

The overall procedural data were collected through the video recording, and visual data specific to the CAD session was collected through the desktop recording software *Webinaria.* After the design task, semi-structured interviews were conducted with the participants, where they could reflect on the session, explain their idea/s, and share their views and experiences. The interviews were voice recorded and transcribed.

9.3 Analysis

The qualitative analysis of the design activity involves an attempt to interpret and describe the designer's thinking, act, and behavior while using CAD. Video recording of the design activity facilitated microanalysis of the complete activity. The videos were reviewed and transcribed. The interview transcribes provided supporting data.

9.3.1 Research Parameters

The literature review had helped identify various study parameters and their co-relations as shown in Fig. 9.1.

By keeping the tool as *SolidWorks* and employing only proficient and competent users as participants, tool limitations, proficiency, fluency, and time could be eliminated as variables. The occurrences of study parameters—fixation (F), circumscribed thinking (CT), effective visualization (V), size perception (S), and design changes (DC) were mapped onto the transcription. Any observations apart from the study parameters were noted separately.

Circumscribed thinking is caused when tool or proficiency limitations cause the design decisions to change from what is intended to what can be made [1]. CAD facilitates 3D visualization of ideas and is acknowledged as one of the most significant advantages of CAD [1, 6, 7]. Fixation occurs when a designer is reluctant to make changes in design either because of the efforts gone in making the model or due to attachment to the certain design or detail [1]. 3D visualization on one hand can cause fixation due to realistic representation, and on the other, it allows the designer to interact with the idea and create alternatives. Many design refinements and intermediate design decisions can be taken visually while developing idea in CAD. This was defined as design changes due to visualization (DC) or visual triggers. It was noted in the previous studies that it is difficult to gauge the size of a grip or handle or overall form, looking at the screen. This was defined as size perception (S).

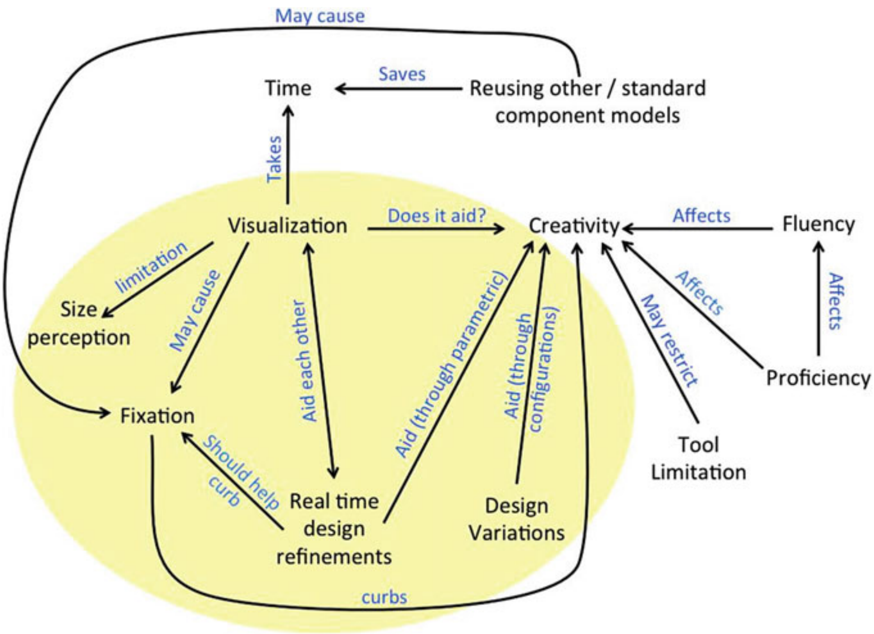

Fig. 9.1 Study parameters

9.3.2 Visual Mapping of the Parameters

All the five design sessions were transcribed and broken in 5 min intervals. The occurrences of the study parameters were mapped visually as shown in Fig. 9.2. Apart from the study parameters, time spent on designing (D), modeling (M), and exploring how to model (EM) were also mapped. The codes were visually mapped in the table. The visual mapping of study parameters helped achieve the understanding of various effects in a fast and comprehensive manner and facilitated qualitative analysis of the data. The method is similar to coding of data but has a more visual approach and is worth exploring further specially in the field of design. Robertson and Radcliffe [1] mentioned that occasionally time pressure forces designers to generate intended designs in the easiest possible way. CAD tools may never match the imagination of designers, and they might, in turn, limit their designs to what is easy to make [1].

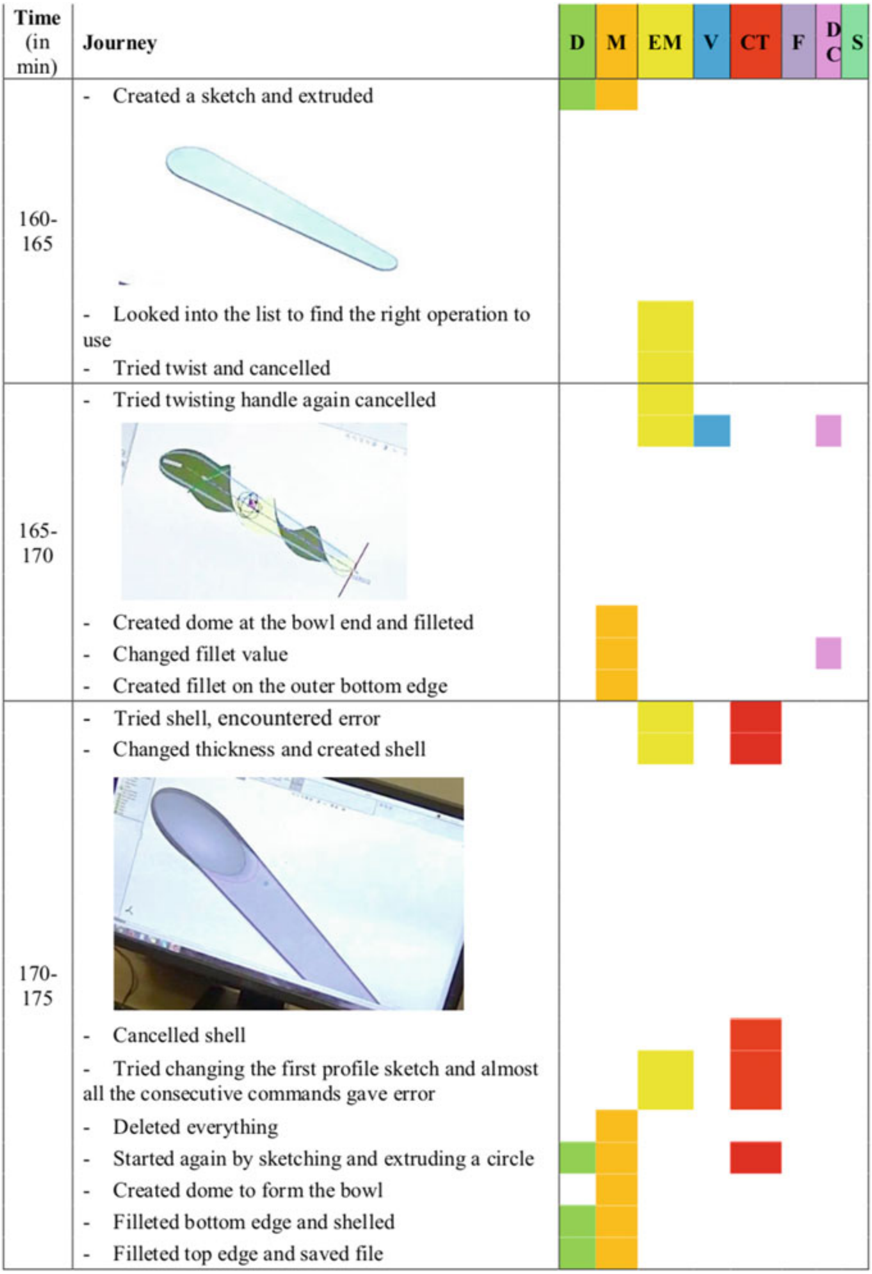

Fig. 9.2 Example of the visual coding of the study parameters on the transcribed data: D: time spent on designing and design decision, M: time spent on CAD modeling, EM: time spent on exploring modeling strategy, V: effective visualization, CT: circumscribed thinking, F: fixation, DC: design changes, and S: size perception

9.4 Findings

9.4.1 CAD in Product Ideation Phase

All the participants acknowledged using CAD in the initial design phase to understand proportions, volume, and scale. This is contrary to recommendations found in the literature suggests that CAD should be used only when concepts are finalized. CAD aids spatial visualization and allows the usage of standard parts, making the process faster.

The inclusion of CAD in the process also depends on the scope and stage at which the design brief is received. A redesign project can start directly from the existing model. However, for new projects, designers prefer to register their thoughts through words and sketches.

In the initial exploration phase, CAD modeling is used as a 3D rough sketch. It helps designers comprehend their ideas better. Keeping them in the background and sketching further on top of basic block models help the participant achieve better representations and overcome the limitations of their sketching skills.

It was observed that the use of CAD modeling in the initial phase may support vertical exploration and formal refinements but might not be supportive of lateral exploration. The point needs to be probed further. Lateral thinking is an essential requirement in the early idea generation phase.

9.4.2 Advantages of Using CAD in Ideation Phase

Visualization

Visualization was identified as the most important advantage by all the participants. CAD software incorporates multiple tools to aid visualization like zoom, pan, rotate, section, color, background environment, transparency, texture, and even magnifying glass. It allows the user to observe the geometry from different angles and supports for focusing and developing even the smallest details.

During the design session, all the participants used various visualization tools extensively. One participant also enacted role-play in the assembly file and took the design decision based on the interaction of components. It was realized that the interaction in 3D space and design iterations were the outcome of effective visualization, and hence, it were considered under the same heading.

Communication

A participant mentioned, “Sketch is like a shadow of what I have in mind, whereas a 3D CAD model is closest to what I am thinking.” All the participants prefer rough CAD models to sketches for communicating with the clients and other people. CAD helps them comprehend their ideas better and communicate without ambiguity. One participant even mentioned that the CAD rendered images and animations are used for catalogs and other communication purposes even before the actual product is made.

Presenting the ideas through CAD models aids their confidence levels. Since the idea is better comprehended and can be checked for fits, interferences, and other detailing aspects, CAD modeling brings in more clarity in communication.

Other Advantages

CAD models can facilitate 3D printing and rapid prototyping, saving a lot of time and effort in model making.

The usage of standard components and models from other files can facilitate faster development of the product and reduce the chances of errors.

It builds the designer's confidence level while presenting the idea to others and helps them overcome the limitations of their sketching skills if any.

9.4.3 Limitations of CAD

It was interesting to note that 3 out of 5 participants could not think of any limitations imposed by CAD during the interview and emphasized that CAD has become an integral part of their design process and is inevitable. All three of them are certified *SolidWorks* professionals and proficient users. As their proficiency levels are high, the limitations faced by them are low.

Circumscribed Thinking

Circumscribed thinking occurs when a designer compromises on the intended design feature due to tool or proficiency limitations [1]. This was most evident during the formal exploration brief. During the interviews, participants shared their previous experiences on how they changed their designs for the ease of creating the CAD model.

The form exploration exercise was carried out by competent users. Both of them rated themselves as competent users of *SolidWorks* software and had been using the same software for five years. However, they faced difficulty in creating their designs and could not achieve the desired results. This illustrates that the number of years does not ensure proficiency, and users do not attain the next level of proficiency unless they are pushed or are motivated. The participants had created their comfort zone and a certain approach to model making. The task required them to produce forms they were not used to making regularly. The time spent on designing (D) (time where design decisions were made), modeling (M), and struggling or exploring how to create the intended form in CAD (EM) were mapped on the timeline. Figure 9.3 illustrates the time map for one of the participants who struggled during the formal exploration design task. It is visible that he spent considerable time exploring the ways to create the desired form.

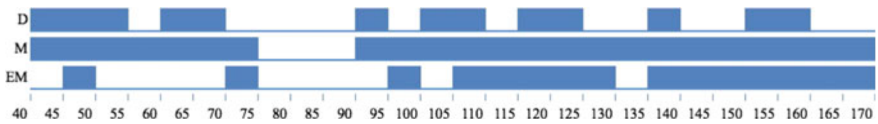

Fig. 9.3 Time map for one participant showing time spent on design decisions (D), modeling (M), and exploring modeling methods (EM)

When the proficiency levels are low and a challenging task is faced, much time was spent trying to explore how to create a particular model. If the efforts and time spent on this are more, it can create frustration and boredom, further hampering the motivation and creative exploration. As a result, the user may subconsciously start exploring the designs that they are comfortable in modeling.

Size Perception

Perceiving the sizes, flexibility, textures, softness, or hardness by looking at the screen is difficult. While designing, participants were continually referring back to the ruler to define dimensions. Participant 4 and 5 also shared their experiences, where they need to have a rough mock-up made in Styrofoam or 3D printed to ensure the sizes. Sometimes, the CAD model is zoomed closer to actual size on the screen to understand its dimensions in reality.

Cognitive Load

A participant shared his experience about how once he was working on a challenging design and he struggled to model the same. It took him so long that he eventually forgot the details which he was thinking about and wanted to workout.

Proficiency has a significant impact on the cognitive load that any tool can cause. Further study to understand this limitation needs to be conducted.

Fixation

Small evidence of fixation was noticed with the two participants who first created the model of a basic toaster and started exploring around it. They did not move away from the existing toaster image until the end. However, it was realized that this study could not probe deeper into the effect of fixation due to realistic 3D visualization and would require further study.

9.5 Conclusion

The paper presents an exploratory study conducted with product designers using 3D CAD modeling tools in the idea generation stage of product design. This study helped understand how designers today have adopted CAD as a tool in their design process and its advantages and limitations. It also throws light on how the approaches toward introducing CAD modeling in design process differ based on the design briefs. This helped establish the guidelines for future studies.

The study also helped establish a systematic way of analyzing the design activity and drawing qualitative observations from audiovisual data by visual mapping of study parameters. This can help future design researchers to develop ways to analyze and understand the designer's thought process and design activities.

Today, it is essential to consider CAD as an integral part of the designer's tools, along with sketching and physical modeling. Designers today do not use CAD in isolation and are developing new design methods involving all their tools in conjunction. This indicates that contemporary research needs to move in the direction of mixed media environments considering all the new age tools available to designers, and how design processes are changing or need to change with advances in technology.

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Chapter 10
A Case for Intuition-Driven Design Expertise

Natrina Toyong, Shahriman Zainal Abidin, and S'harin Mokhtar

Abstract The role of intuition in decision making is widely recognized in many fields, which saw a strong network of an intuition-based research community in this early turn of the century. However, it is poorly studied in the design field and notably little has been published on its role in design decision making, especially on the early concept stages of the design process. Reviews of previous studies reveal that task uncertainty and creativity have a positive and significant impact on expert intuition. This makes it a more convincing case for studying the highly unstructured mode of problems that are typically found in design. The case study on intuition-driven design expertise was done as a triangulation of data source from the in-depth interview of ten expert and six senior-level designers, followed by four sessions of focus group involving thirty-two participants made out of novice-level designers. Working around the common theme of "Future Workplace for Designers in the Year 2050," the result produced a rich comparative and descriptive attributions of intuition-driven decision making between experienced and novice designers at three different types of intuition. These findings later inform the three decision-making models for training design expertise based on (1) affective intuition which draws on emotion, heart and feelings; (2) heuristic intuition which draws on logic, theories, facts and hunches; (3) holistic intuition which draws on abstract thinking, big ideas and big picture.

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A. Chakrabarti et al. (eds.), *Design for Tomorrow–Volume 3*,
Smart Innovation, Systems and Technologies 223,
https://doi.org/10.1007/978-981-16-0084-5_10

10.1 Introduction

Previously, mainstream understanding of intuition links it to a local and non-local form of knowing that are misconstrued as illogical, irrational or lacking in proof. Luckily, over the decades, intuition is often associated with trend forecasting ability at various types namely gut intuition, expert intuition and strategic intuition [1, 2]. In strategic decision making, forecasting ability is more commonly discussed as management or entrepreneurial foresight. The most significant learned skill in foresighting among designers is more closely related to trend study or forecasting [1]. However, even that, as branch of knowledge, has a marketing-field origin. Meanwhile, a growing academic research group have begun to relate it to evidences through cognitive sciences within the premise of neither left-brain nor right-brain thinking, but a combination of both. Exploring closer to the domain of expert intuition, Pretz and Totz [3] citing Jung [4] characterized intuition as *a primary mode of perception which operates subconsciously* with Pretz, Brookings [5], later, introducing the types of intuition scale (Tints) as a new measure for intuition which outlines the three type (a) holistic, (b) inferential and (c) affective. Here, the intuition measured, form a part of the commonly accepted categories of intuitions summarized by Sinclair [6]. This various combination of instances is the threshold of the three type of intuition; intuitive expertise (professional domain/practice), intuitive creation (creation, innovation and invention) and intuitive foresight (future opportunities). It may appear that there are varied labeling for the different type of the intuition studied but they do in fact correlate to describe similar if not the same sub-phenomenon within the intuiting process.

This current study looked at the premise of all three intuition type with discovery of intuition in the creative industry by employing a partial fore sighting ability of expert-level designers. The discussion for design expertise is based on the definition as prescribed by Liem et al. [7] adapted from Popovic [8] which defined design expertise based on the years of experience in the field. Working within the scoped description, experienced designer is composed of senior level (either educator or practitioner with 8/10 to 15/18 years working experience in industry) and expert level (either educator or practitioner with more than 18 years working experience in industry). Meanwhile, non-experienced designer refers to novice level (either student, educator or practitioner with less than 5 years working experience in industry).

Within the understanding of design thinking field, the study also looks at the term designerly coined by Cross [9] to describe a third way of knowing in education that are at parity with the already established fields of sciences and humanities domain today. In short, the term designerly in this study is used to describe expertise in design. Designerly thinking, therefore, refers to the thought process of an expert designer, which sets them apart from that of lower level of expertise.

10.2 Background

10.2.1 Domain Expertise as Expert Intuition

Jung [10] has defined intuition as the psychological function that transmits perceptions in an unconscious way. Since then, intuition as a potential trained and developed skill was earlier suggested by Koestler [11] citing Fichte (1962), describing it as "conditions of preconscious existence the true consciousness must be explained and developed step by step." Hohler [12] later expanded on this understanding that an individual's reflective awareness on "being aware of himself" and "being aware of himself investigating and being investigated," is a *self-returning activity and* that is also the first characteristics of an intellectual intuition. This conscious effort to be aware of an individual's unconsciousness is fundamental to learning to trust the *gut feeling* [13]. In line with that, a recent study, closer to the design field, drew a correlation of gut feeling as the synthesis of causal and effective knowledge [14], which correlates with previous narrative of the three types of intuition.

Additionally, Pretz and Totz [3] studied the distinctive difference between heuristic and holistic aspects of intuition and its link to tacit knowledge and expertise. It is also revealed that since tacit knowledge is acquired without awareness and often difficult to articulate, tacit knowledge can be considered intuitive in nature. The study also concluded that for tacit knowledge to be measured effectively, and it should be measured using a task that relates specifically to the domain in which intuition is being used. Complementing this, a study by Klein [15] revealed that having more experience contribute to more accurate intuitions compared to that of novices.

10.2.2 Designerly as a Form of Design Expertise

The concept of a designerly way of thinking can be traced back to the concept of design thinking which alludes to the reliance on ability *to be intuitive, to recognize patterns, and to construct ideas that have emotional meaning as well as being functional* [16]. The earliest usage of the term design thinking was coined by Arnold [17]. It was initially used in the context of engineering studies where Clancey [18] previously aligned his view on the interdisciplinary approach in support of Arnold's concept of creative with focus on personal growth of intellect and emotion linked to other fields.

However, as both design thinking and designerly way of thinking begin to garner more practical and scholarly following, a clear difference is established. Whereas the designerly narrative seeks to develop the thinking within the design practice, and design thinking undertakes a generalist approach. In making a case for designerly ways of knowing, Cross [19] proposes that the design practice has its own strong and appropriate intellectual culture with clear demarcation from other sciences or the arts, offering the development of a rich design research paradigm committed to investigating the particular human ability to design. Therefore, it is not overreaching to consider that the designerly ways of knowing are synonymous to the best practice that are sought in design abilities. For this reason, it has been revealed that experts show a tendency of making quick decision using affect heuristics and are more committed to their own previously developed design concepts which they carry through the next stages in their design process [20].

10.2.3 Designerly Concepting

There are three known intuition processing types and styles, two of which, intuitive expertise and intuitive creation are clear in its role in design. Empirical findings establish that intuition is instant responses with little or no conscious deliberations as a result of many years development of new mental model from accumulated, experience using reasoning and rational thinking processes to structure and evaluate information [21]. Meanwhile, literature and empirical research evidences on intuition and creativity has long been studied, some measurable using Myers–Briggs type indicator (MBTI) which assesses the preference for an intuitive thinking style [22]. These two types of intuitions are commonly studied. The third type, foresighting intuition, however, is least explored in the design field as an empirical study as compared to other fields such as entrepreneurship [23], with claims that this non-local processing may be closely linked to intellectual, emotional, and spiritual intelligence [24].

Later, Eling et al. [25] developed a conceptual framework to outline the conditions in which intuition is beneficial toward product development. It is built on underlying dual processing theory on intuition (system 1—unconscious) and it is parallel with rational argumentation (system 2—conscious). This present study adapted their model where during the unconscious; the individual is *having intuition* followed by the conscious process of *applying intuition*. Building on that, the following image (see Fig. 10.1) provides findings of intuition framework by Sinclair [6] and definitions and measurement of intuition by Pretz and Totz [3] to propose conceptual framework for intuitive designerly thinking at conceptual design stage.

As discussed earlier, intuitiveness is highly domain specific. There is satisfactory correlation to describe that intuitive expertise, and creation is closely related to trained skilled set, as well as core competency expected of a designer. Based on current understanding of intuition in design, the following conceptual framework indicates that intuitive creation is a sub-set of intuitive expertise in design when the process and outcome attributes are paralleled accordingly. Intuition foresight however is poorly connected within the overall framework due to its weak position as a necessary skill of a designer. Therefore, taking everything into consideration, this conceptual framework visually argues the positioning of intuitive foresighting as the third type of intuition as it illustrates the reasoning to scope the study toward uncovering "early concept decision making in design."

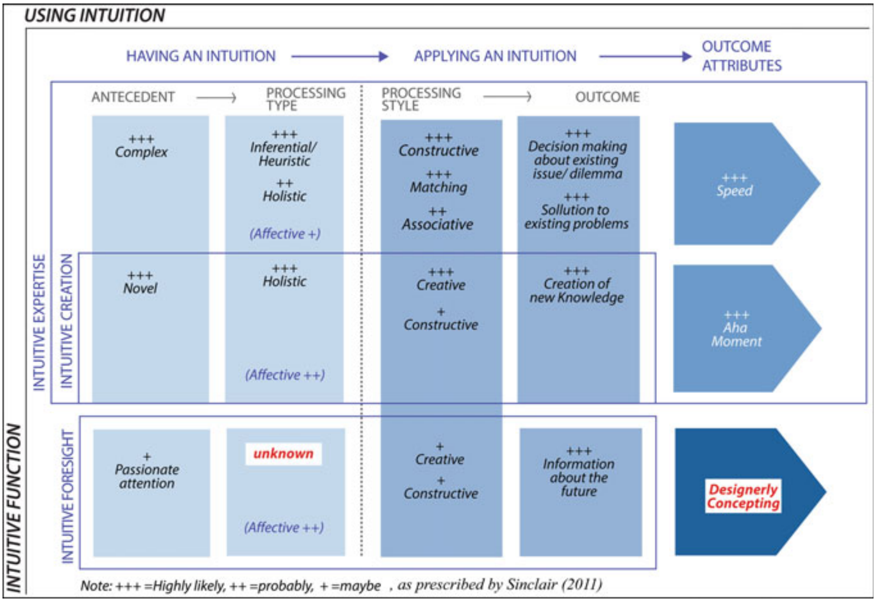

Fig. 10.1 Conceptual framework for intuitive designerly thinking at conceptual design stage, adapted from Sinclair [6], Pretz and Totz [3] and Eling et al. [25]

10.3 Method

10.3.1 Sampling

Intuition studies often present arguments that decision makers are not free of bias tendencies, among which are cultural in nature [26–28]. Intuition relies on a priori knowledge, with high sensitivity to affective and emotion triggers. Therefore, in minimizing the impact of external factors influencing the effectiveness of the data collecting method employed, the study has decided on keeping a homogenous samples of similar if not identical background in their design knowledge acquisitions which sets the foundation for their domain-specific knowledge. Therefore, in-depth and focus group interview recruited respondents and participants who are graduates from the same institution which is University Teknologi MARA (UiTM) or formerly known as Institut Teknologi MARA (ITM). The justification is based on the fact that it was the first tertiary learning institution to offer the course thus has produced the most numbers of experienced designers in the industry to date. It should be noted also, as reported by Tamyez Bajuri [29], an analysis of the curriculum structure received by ITM or UiTM graduate revealed a common learning environment that is still relevant today. Keeping to the criteria, the in-depth interview sampled ten of expert-level designer and six senior-level designer, whereas, the focus group interview was conducted as four sessions with eight novice-level designer per session, totaling up to thirty-two participants.

10.3.2 Instrumentation

The in-depth interview is designed to collect data from two data sources; senior-level practicing designer and expert-level practicing designer. This activity gathered rich narrative of actual practicing designers that are later triangulated with findings from focus group discussion of novice designers. The structure of the interview design is adapted from existing known measurement of intuition: Types of intuition scale (TIntS) [3], which measures three identified types of intuition; holistic, inferential, and affective. These empirical studies have contributed to various measurements conducted as quantitative analysis in other fields. For the present study, inquiry guideline is developed based on the keywords gathered from reviews on literature, specifically adapted from the main structure of qualitative study on measures of intuition [3, 5].

The focus group was conducted as two-phased, research collection activities in which a total of four sessions were conducted with eight participants per session. At every session, phase one required each participant to complete an individual reflective sketching activity. A partial verbal protocol analysis approach is applied where captured sketching activities are matched with retrospective verbal account. The premise for this approach by Zainal Abidin et al. [30] established the adaptation of some aspect of the "in vivo" approach into verbal protocol analysis in humanity-domain focused studies where technical content is not critical. Phase two of the focus group uses the sketches to centralize the group discussion where the design concepts are discussed, argued, defended, and brought to conclusion as a team.

Both data collection method share a common reflective activity with a common theme, which is to reflect on *Future Workspace for (Industrial) Designer in the Year 2050*. The main reason for the specific topic is to provide a reflective base that is shared by all forty-eight respondents. In order to trigger foresight intuitiveness, discussion must accommodate room for familiarity, close subject matter as well as room for emotive affect to reasoning. Befitting this, the theme is familiar for both novice and practitioner with opportunity for predictive reasoning. Figures 10.2, 10.3, 10.4 and 10.5 show the partial verbal protocol analysis through cross-referencing sketches with focus group transcript and video of reflective sketch exercise.

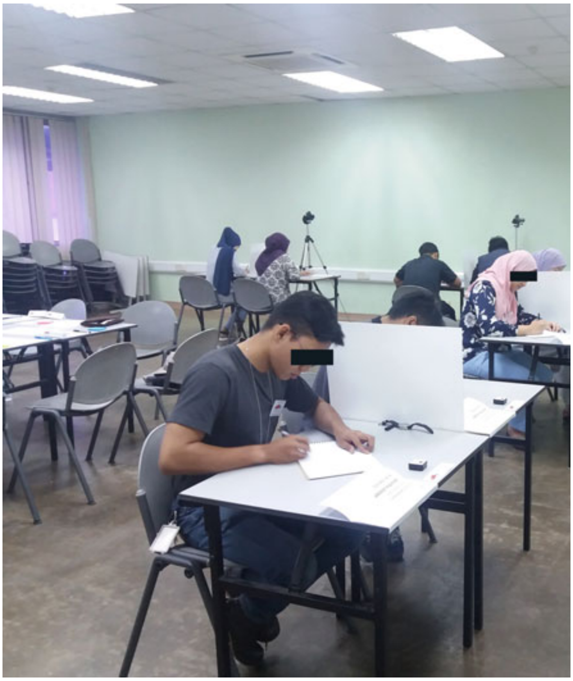

Fig. 10.2 Reflective sketching session as a controlled environment in focus group interviews

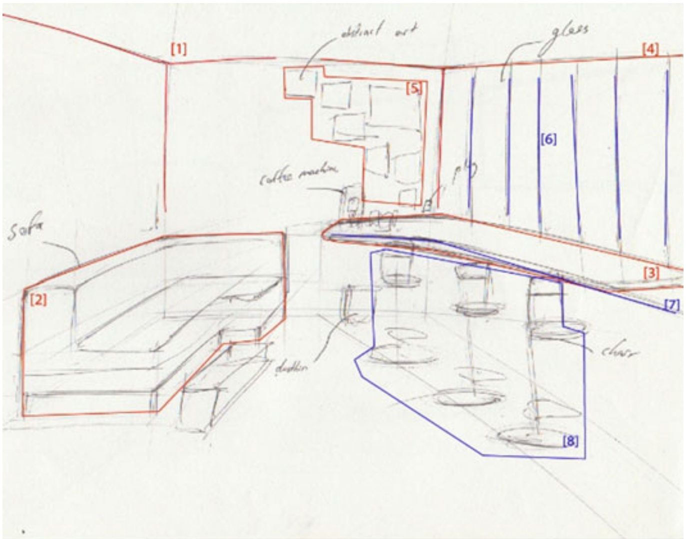

Fig. 10.3 Sample of activity analysis of sketch at step 8 by participant 1 of focus group session 1 (F.G P1.1)

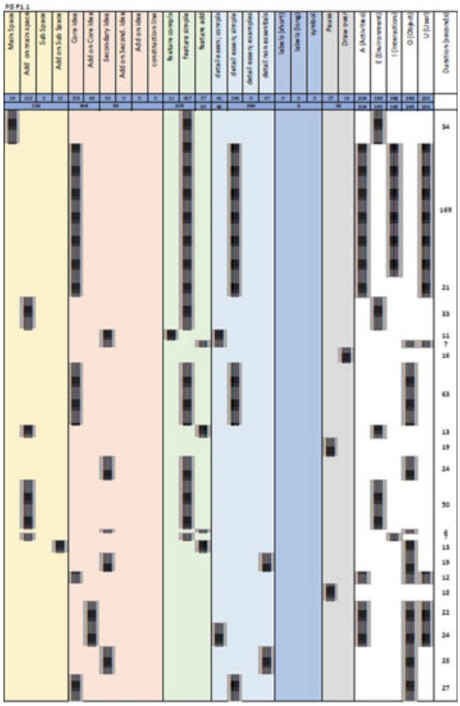

Fig. 10.4 Time stamped analysis of sketches by F.G. P1.1 based on time (in seconds) spent per sub-concept

10.4 Results and Discussion

10.4.1 Initial Themes

Analysis of result was conducted as a thematic review using the keywords from the guiding themes derived from literature. This process was conducted to ensure multiple meaning and interchangeable descriptions of the same keyword are all accounted for. The documentation of this process is presented in excel table format with care to include respondent's unique identification and the line numbering of the document. Later, a detail quantification was also done to reveal usage within case and across different cases. The analysis also took into account the sum of the different type of context in which it is used and aided by hierarchical cluster analysis which is a result word frequency query using Pearson correlation coefficient similarity matrix in NVivo. Table 10.1 shows the initial themes based on interviewers note and NVivo text search.

The recorded interviews are transcribed verbatim. Respondent and participants conversed in the language that they are most at ease with, allowing for a comfortable and rich narrative required for qualitative data. English and Malay language are widely spoken in Malaysia, so it is also common for a sentence to have both language in them. No translation to either language was necessary because the

FG. P1.1

	Accumulative (seconds)	Single activity duration (seconds)	Main Space (creative)	Add on main space (associative)	secondary Space (creative)	Add on secondary (associative)	Main idea (creative)	Add on Main Idea (associative)	Secondary Idea (creative)	Add on Secondary Idea (associative)	suplemnetary idea (associative)	construction line (constructive)	feature complex (constructive)	feature simple (constructive)	(add.) feature (associative)	detail, essen; complix (matching)	detail, essen; simple (mathcing)	detail essen; examples (associative)	detail non essen (de-associative)	labels (short) (matching)	labels (long) (matching)	symbol (matching)	Pause (de-creative)	Draw over (de-constructive)
1	34	34	34											34										
2	169	135					135							135			135							
3	190	21					21							21			21							
4	223	33		33										33										
5	234	11							11				11			11								
6	241	7							7						7	7								
7	257	16																						16
8	320	63					63							63			63							
9	333	13		13											13									
10	352	19																					19	
11	376	24						24						24										
12	426	50		50										50										
13	430	4							4						4									
14	437	7		7										7										
15	450	13				13									13									
16	469	19							19										19					
17	481	12					12																	
18	499	18																					18	
19	521	22						22																
20	545	24						24								24								
21	573	28							28										28					
22	600	27					27										27							

Fig. 10.5 Time coded analysis of sketches by F.G P1.1 to be represented as a graph on percentage of time spent per sub-concept

Table 10.1 Initial themes of designerly foresighting attributes based on interviewers notes and NVivo text search of in-depth interview

No.	Guiding theme	Keyword	Interviewers notes	Initial theme
1	Affective	Emotion, heart, feelings	Confidence, validation	Confidence, acknowledgement, winning, established, validation, personally, competition, commitment
2	Heuristic	Logic, theories, facts, hunches	Budget, cost, limiting choices, stakeholders, experience	Budget, cost, limiting choices, stakeholders, process, habit, schedule experience
3	Holistic	Abstract thinking, big ideas, big picture	Trend	Trend, expectation, current and existing, users, prediction, problem

result revealed that NVivo was still able to pick up significant words as context. This is because, despite conversing in the Malay language, designers used design terminology descriptive structures and attributed meaning in the English language.

10.4.2 Expert and Senior Designer Intuition Attributes

The in-depth interview transcript is sequentially analyzed to produce hierarchical clusters to uncover themes of intuitive decision making within and between expert, senior and novice designers. The subjectivity of the codes was reduced by decreasing the amount of raw data using data analytic software. The decreased data are presented as hierarchical structure that are then analyzed by two coders. The coding activity was conducted as a week-long coding workshop which included discussion and agreement on the final codes before the code book is used for all the transcripts. Table 10.2 summarizes the sequential order of the analysis as well as the emerging themes.

10.4.3 Novice Intuition Type

The reflective activity for the focus group was conducted as a 10 min sketching exercise with the same theme provided for expert and seniors. The sketches were then analyzed based on the concept attributes and dimension. The movement between ideas area encoded based on duration of time spent for each different attributes and dimensions. The coded events for each designers are later presented as graphs (see Fig. 10.6), which provided five groups of similar decision-making patterns by novices during early concept design stage and attribute description most similar to the pattern represented in experienced designer (see Table 10.3). The attributes of sub-concepts coded include designer's representation on main/add-on space/sub-spaces, core/add-on of idea or secondary ideas, construction line, complex/ simple product features/sub-features, as well complex/simple essential/non-essential detailing.

It should be noted that the sub-concepts are determined based on cross analysis with the transcript of focus group interaction. When participants mention and defend a concept attribute or dimension, it is coded as main space or core ideas, while non-mentions are considered sub-space and secondary ideas. Meanwhile, simple or complexity of features or detailing is coded based on the depiction of high technology and part feature on the concepts in the sketches.

Table 10.2 Emerging themes of designerly foresighting attributes and scale definition based on sequential NVivo text analysis of in-depth interview

No.	Guide. theme	Code	Emerging themes	Attribute scale definition	Apply. intuition
1	Affective	A.con	Confidence	I trust judgment	Constructive
		A.ack	Acknowledgement	I receive projects	Constructive
		A.win	Winning	I receive award	Creative
		A.est	Established	I am in leadership role	Creative
		A.val	Validation	I get support from others	Creative
		A.per	Personally	I do it for myself	Constructive
		A.cmp	Competition	I can compete	Constructive
		A.cmt	Commitment	I follow through my decision	Constructive
		A.tec	Tech skill	I don't worry about technical ability	Creative
				I have technical skills	Constructive
		A.div	Diversification	I appreciate diversity	Creative
		A.tru	Truth	I know the reality	Constructive
		A.ddc	Deduction	I conclude	Constructive
2	Heuristic	H.num	Numbers	I care about the budge t	Matching
				I care about the cost	Matching
				I care about the sales	Associative
		H.lim	Limiting choices	I limit the choices for others	Constructive
		H.stk	Stakeholders	I know my stakeholder	Associative
				I know my stakeholder's concern	Associative
		H.pro	Process	I know processes	Constructive
		H.hab	Habit	I have my own way of doing	Constructive
		H.sch	Schedule	I know the schedule	Associative
				I keep to the schedule	Matching
		H.exp	Experience	I have experience	Associative

(continued)

Table 10.2 (continued)

No.	Guide. theme	Code	Emerging themes	Attribute scale definition	Apply. intuition
		H.per	Persuasion skill	I convince people	Associative
		H.led	Leadership	I lead	Constructive
		H.sol	Solution	I know the solution	Matching
3	Holistic	Ho.trn	Trend,	I know trend	Constructive
		Ho.exp	Expectation	I know what is expected	Creative
		Ho.cur	Current and existing	I know the situation	Constructive
		Ho.use	Users	I empathize	Creative
		Ho.pre	Prediction	I guess	Creative
		Ho.prb	Problem	I understand the problem	Constructive
		Ho.img	Images	I know how it looks like	Constructive
		Ho.ins	Inspiration	I know how it should look like	Creative
		Ho.big	Big picture	I see the big picture	Creative
		Ho.ind	Industry knowledge	I know the industry	Constructive
		Ho.the	Academic theories	I learnt it in school	Constructive

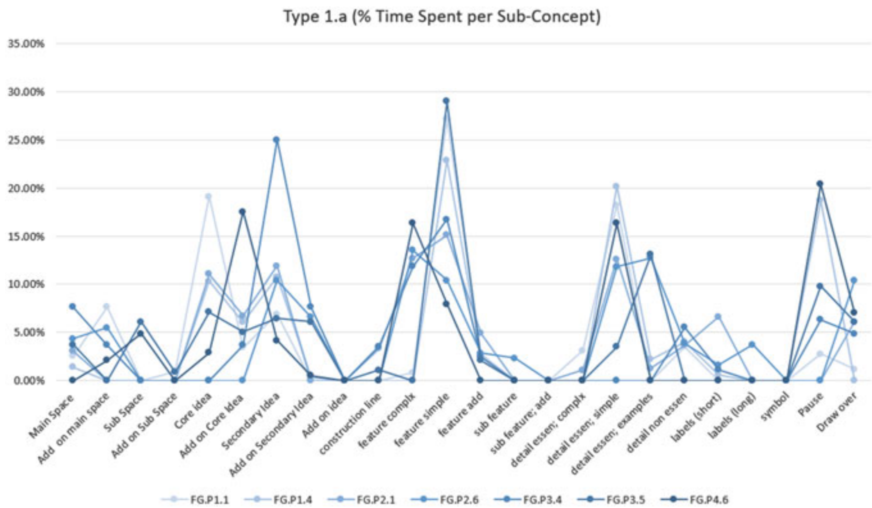

Fig. 10.6 Type 1.a designers with similar event patterns presented as graphs

Table 10.3 Novice intuitive decision-making patterns at early design concept stage

No.	Type	Description
1	Type 1.a	Novice type 1.a provided a big picture view of concept by illustrating space and environment. They spend most time (average 18.46%) on depicting simple features and building on secondary ideas on their sketches. Once their core and secondary ideas are depicted, novice type 1.a do not continue to add any more ideas, instead focus their time (average 11.81%) on simple yet essential detailing on existing ideas
2	Type 1.b	Novice type 1.b is almost similar to 1.a but less emphasis on the larger space. Instead they illustrate smaller more detailed space in the environment, they spend a balanced amount of time between core ideas (average 10.94%) and secondary ideas (average 8.43%). They are also focus on depicting spaces in the environment with great concern for sub-spaces (average 6.15%). However, very little time is spent on detailing out additional features to item that were sketched
3	Type 2.a	Novice type 2.a has a focused concept with a lot of detailing on secondary features. They basically focused their effort into two main concept ideas which are (1) depiction of core ideas with higher emphasis on secondary ideas (average 12.53%), (2) detailing out complex feature (average 7.83%) and simple feature (average 12.07%). Between sketches, they also took a lot of time pausing (average 19.94%) and drawing over existing lines on sketches (10.40%)
4	Type 2.b	Novice type 2.b is almost similar to 2.a with more spread out emphasis on depicting ideas on add-on and simple, non-essentials details They spend an amount of time on core idea (average 8.75%), simple features (15.28%) and its detailing (7.97%), secondary ideas (10.59%). The rest of the time is then spent on pauses (average 7.51%) and drawing over existing lines on sketches (16.11%)
5	Type 3	Novice type 3 do not have a focused concept. They have multiple non-connected smaller ideas that are often sketched out halfway They spend a balanced amount of time on drawing concepts of secondary ideas (13.44%), simple features (17.53%) and non-essentials detailing (15.65%). A significant amount of time is also spent on pausing (average 5.50%) and drawing over existing lines on sketches (12.58%)

10.4.4 Intuitive Thinking in Experienced and Non-experienced Designer

Although the initial and later complete coding was derived from the transcript of expert designers' interview, the study does not prescribe specific type as purely a senior or expert type. It merely extracts a shared interpretation of attribute dimension that can be used to assess the unique pattern of thinking that designers have established in their career. The development of intuitive skills is also dependent on the area of expertise they have acquired throughout their profession. Although there was no clear pattern to suggest a consistent type of intuition in decision making and preferred reliance to any one type, the manner which attributed to the indication of decision-making event was quite evident. This is what allowed the synthesis of a general attribute dimensions of experienced designers as presented in the findings.

On the other hand, the five types of novice intuition describing the varying ways that novice designers approach early concept decision making is not presented in any scale order of good or bad. It should be noted also that the samples although kept homogenous are only a reflection of a group of designers who are trained in a specific and consistent environment [29]. The present study is able to form the five pattern based on the similarity of the graph based on the dimensions and attribute. It is possible that in future research, there will be outliers that will not fit into these five categories or contribute to the discoveries of new category(s), based on other factors such as program type as well as social and cultural learning environment.

10.5 Conclusions

The study provides descriptive interpretations of attributes of senior and expert-level intuition style as well as an overview of the different types of novice intuition-based decision making. Opportunely, the interpretation of internal and external skills in intuition can be presented as value-laden training for novice designers and a good foundation as a focused training guideline toward foresighting intuition for novices that are otherwise more readily evident in experienced designers' early concept decision-making skills. This will provide a strong case for the trainability of foresighting intuition as a form of designerly skill supported by prior studies which have indicated that in essence, intuition precedes insight, therefore, is best for decision making at early design concept, herewith presented as "designerly concepting" attributes.

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Chapter 11
Recreating the Past Methodology to Design a Better Society for the Future

Natasha Narendrasingh Turkar

Abstract With the omnipresence of design, our future is a visualization of further convergence of the world with technology as its nucleus. Professionals across all disciplines have been envisioning a future dependent on technology, where artificial intelligence, Internet of things (IoT), and big data form a multifaceted design universe. However, this paper challenges the notion of the future design methodology relying heavily on technological advancements and proposes the question of how design can borrow from the past and harness the power of reflective nostalgia to build a better society in future. The research discusses how design creativity and synthesis, driven by societal necessity in the past and customized user-centric exclusivity in the present, will rely on empathy, reassurance and security on a social level once again, in future. The research methodology and study conducted have been summarized to highlight how any product we have designed, became a part of an environment larger than us, taking up an intangible behavioral form, which came back to redesign us. Thus, reflecting on this past methodology and taking the traditional wisdom forward is paramount. The directions for further research have also been discussed.

11.1 Background of the Study

With the evolution of design over the years, there is no denying its perpetually progressive nature. As the world is faced with major challenges such as a global pandemic, societal unrest and the resulting economic slowdown, it is vital for designers to refocus their attention. Modern designs provide user-centric solutions based on personalization for target consumer segments. While the practice of empathic design to understand the latent emotions and expectations of the users has been adopted since the last few years, are technocentric and user-centric design solutions enough for sustenance in the constantly changing terrain of society? What

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A. Chakrabarti et al. (eds.), *Design for Tomorrow–Volume 3*,
Smart Innovation, Systems and Technologies 223,
https://doi.org/10.1007/978-981-16-0084-5_11

designers of the future will need more than ever is a methodology to design not only for individuals, but responsibly design for communities altogether. Design has a deeper impact on society than we can fathom. It adds up to a double movement—we design our world, while our world acts back on us and designs us [1]. An example of this is the introduction of Internet to smartphones, revolutionizing communication forever. The authors of a study published in the August 2011 issue of "Science" conclude that persistent access to information via search engines—Google, in particular, which fields more than 1 billion search queries per day—is changing how the brain catalogs knowledge. Internet-connected devices such as smartphones have become a kind of "external memory source" [2]. Thus, while designing a product or service, thinking about the behavioral and cultural impact of the design on social evolution is extremely essential.

In order to effectively design for the society of the future, analyzing culture studies and design methodology of the past can aid creativity, ideation and synthesis in future. This paper presents a historically grounded approach that suggests the thoughtful recreation of the past as a fundamental step in moving forward to design the societies for the future, while keeping in mind the revised reality we are living in today. The goal of this paper is to reflect upon both the design approach adopted in history and how the application of the same is relevant to the fickle nature of society today.

11.2 Research Methodology—Analyzing Design in Past Societies

This section describes the systematic approach or research methodology. First, as background research for this study, an analysis of the past has been carried out through historical text to understand the cultural and anthropological aspects of civilizations, moving forward to see the correlation between design, art movements and their impact of society and vice versa, to get an idea of the social design in the past. The section then explores the evolving nature of technology and society, in relevance to TRIZ-based anticipatory and environment-based design. Then, through unstructured interviews with the elderly, the study is narrowed down to homes and personal spaces as an attempt to gather qualitative data from the personal histories shared by them. Further specifying the study, a small qualitative experiment called, 'would you throw this away?' was conducted to determine the impact of nostalgia when it comes to products. Finally, popular media of the past, precisely advertisements, have been used to analyze the intent of designers and brands to take the study a step further, beyond tangible design of products (Fig. 11.1).

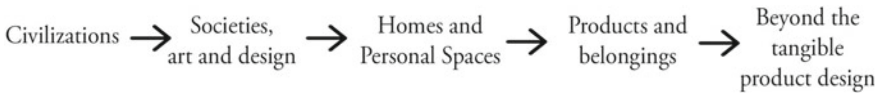

Fig. 11.1 Flow of the research methodology

11.2.1 Analyzing the Past Through Literature

History is the study of past events, particularly, in human affairs. As a designer, one can study patterns or recurring themes in history to forecast the expectations from design or the market in future. As described below, the historical text from literature and previously published works were reviewed to identify relevant trends in social design that give a clear insight into the design methodology of the past. Since history is not universal and varies regionally, the data collected is a general overview of the ancient societies with specific examples. Other cultural contexts would need separate data.

Historical text. Civilizations in the past flourished due to a structured social design, strategically planning their settlement, even if mostly based on a survival instinct. Ancient cities were well aware of nature's resources, offerings and limitations and humbly adjusted to the land's geography and orientation to the sun. Earliest societies and had an exploratory approach fueled by their nomadic lives.

In ancient Mesopotamian civilization, beginning around 6000 BC, people of the region began digging simple small-scale canals for irrigating small plots of land. By 3000 BC, canals had become enormous in scale, even being used for transportation between cities. From symbolically decorated vases to the nature of some of their gods, these people recognized at a practical and even spiritual level how fundamentally important reliable access to clean water is [3].

Another key component of ancient civilization was shared communication which included spoken language; numeric systems; cave paintings, signs and symbols and so on. The Egyptian civilization took this a step further, through hieroglyphs. Hieroglyphs, meaning "sacred carving" or "the word of God," use an arrangement of symbols and pictograms. They realized that languages can differ through regions but a symbol is universally relatable, meaning that the interpretation of the symbol will remain the same throughout, much like the miniature emoticons in our phones today [4].

In ancient India, the Gurukul system of education was a residential schooling system which dates back to around 5000 BC. Gurukuls were located at picturesque places enmeshed in serenity, far from the hustle and bustle of city life. The environment of study played a crucial role; ensconced amidst nature, devoid of any worldly distractions and it was most conducive to learning. Greater emphasis was laid on the mental, cognitive, spiritual and physical wellness of students, ensuring a mindful ambience for better learning outcomes.

A common observation in ancient civilizations is the innate nature of humans to solve problems. Decorative arts were secondary, mostly used as a medium of self-expression. But as evident through art movements, art proceeded in history to become a central driving force of society.

Art movements. Impact of art and design on society. Art movements are zeitgeists of society—living, breathing embodiment of the philosophy and ideology of the past. Art has a social dimension to it and artists who have drawn inspiration from global events have brought about social revolutions. Society inspired art and art and design shaped the society.

One of the most notable societal changes was the industrial revolution. At the start of the Industrial Revolution, the main painting style was Romanticism, which referred to a pre-industrial life. Scenes from classical mythology and rural backgrounds were used as inspirations, as artists showed an appreciation for a romanticized life before industrialization. But after the Industrial Revolution, the mass production saw realism as the new face of art. Some people were not in favor of new change in production methods and used their roles as artists to rebel against the new trend in mass production. Artists now chose to depict more realistic view that did not avoid unpleasant or uncomfortable aspects of how people lived at the time.

The world war-torn society leads to the creation of designs with a more pragmatic approach. Luminous accessories to be used as SOS signals for the stranded people, divided bottoms and overalls for women working in industries as opposed to corsets and bulky gowns and specially designed bags to hold gas masks are a few examples. There was a clear shift from aesthetic art to design-centric production during the world wars.

In a post-world war era, society once again experienced complex changes. As a result, movements like pop art challenged traditions of fine art by including imagery from popular culture such as advertising, news, etc., making it relatable to the masses. They drew inspiration from banal subjects in everyday life, assigning them the same value as high culture. It was grounded in the philosophy of unconventional art and bold consumerism. Pop art evidently succeeded in bridging the still deep chasm between demanding art and wide popularity [5].

Technological Revolution in Society. Technology has altered the face of society and revolutionized the entire process of design and development. Product development organizations redesign their products to incorporate new technology to adapt to changes in consumer preferences and to anticipate (or react to) the actions of competitors. During redesigns, organizations seek to increase the functionality of their products. Functionality includes all valuable results of a product's behavior in its use environment such as specific features, ergonomics and capacity [6]. This technological evolution is also the history of mankind in an eternal fight to dominate his surroundings as part of his own evolution. Genrich Altschuller, the father of TRIZ methodology, a creative and systematic problem-solving methodology, discovered that systems do not go randomly, they grow based on patterns of evolution. The idea that technological systems tend to go forward in a way analogous to that of biological systems has been supporting the research of the evolution of several system designs [7]. These objective patterns can be identified based on the analysis of historical development of technology.

11.2.2 *Unstructured Interviews—In Conversation with the Elderly*

This section aims at gaining effective data into the lives of people in the past through verbal testimonies. After studying societies in the past, the following topic will narrow the study down to homes and personal spaces. Although the results of these unstructured interviews that cannot be generalized beyond the sample group, they give an in-depth insight into the very specific demands, emotions, perceptions and motivations of individuals.

A determining factor in this study was the selection of participants. A group of elderly people were chosen for this study. The age range was 47–63 years old with a mean age 55 years. People in this age group have spent their earlier phase of life without technology, witnessed the digital advancements first-hand and are now also living in a digital era and were thus deemed appropriate for interviews. Specifically, the study was performed with 6 males and 8 females, who have experienced both the rural and urban life.

Where we stayed—An analysis of homes and spaces. The participants were asked to reminisce their earliest memory of a home. Since most of the participants hailed from rural areas, they recalled large and open spaces in the form of C or L-shaped houses for cross ventilation of air, with a central yard. Popular color choices for the exterior of the house were green, white and blue. White kept the houses cool in the soaring temperatures of summer, whereas the green and blue colors created a visual harmony by blending with the natural colors of trees and sky, respectively. For temperature regulation, they recalled their parents asking them to sprinkle water in the front yard to naturally keep the homes cool.

Talking about the *pooja ghar* or the prayer room of the house, they described it to be located in such a spot of the house that every member could see it from anywhere in the house—like a physical reminder to pray every day! It was always constructed on the ground floor of the house to give accessibility to the elderly, ailing or those with physical disability. It was made to be a peaceful setting, complete with fresh flowers from their garden, incense sticks, *Rudraksh mala* (textured beads strung together for meditation purposes) bells hung on the entrance and *prasad* or food offering served at the end of prayer.

About kitchens, the ladies said that the stove was made by them using cow dung and clay mixture and they customized it accordingly—single top or double top where the second stove got its heat supply from the first one, thus, acting as a top with medium-low heat. The vegetables used in cooking were mostly home-grown organically in their backyards. Although the smoke from the stove irritated the eyes was difficult to deal with on a daily basis, which is why they prefer modern kitchens. Domestic work also took a toll on them due to the large sizes of the houses and their maintenance. Most male members recalled large living rooms, where the whole family crowded around the television to hear what was happening or catch a weekly program, but now everyone has the liberty of viewing any content at any given time, losing the essence of family coming together, in spite of living in the same house.

Fig. 11.2 Glimpse of a storeroom, part of the "would you throw this away?" study

"Would you throw this away?" An experiment on preservation and nostalgia. For this specific experiment, it was requested that the elderly individuals allow us to be a part of the annual cleaning of the storeroom that takes place in their house. The participants were given the freedom to go through all the contents of the storeroom for as long as they like and decide what they would throw away and which items would they keep, eliciting reasons for the same. The aim of this qualitative experiment was to extract the significance of nostalgia by evoking memories using objects and understanding how the course of life has changed since technology, whilst keeping it informal to obtain raw and honest opinions. This study enabled us to find anecdotes and stories more than opinions and facts. The findings of this study have been presented in Sect. 3.3 (Fig. 11.2 and Table 11.1).

11.2.3 The Design Intent—Popular Media of the Past

Popular media like magazines, catalogs and advertisements are a window to not only the design intent, but the brand philosophy and ideology. With the evolution of media, power dynamics have changed in the marketing climate. This section provides an opportunity to learn how the consumer culture has evolved through the years and how products and brands were perceived by the public, typically using advertising across different media, to elicit information. This study further narrows things down from products to understanding the design intent beyond tangible design.

Understanding design methodology through the evolution of advertising. In the middle ages, most people could not read, so stores would use an image associated with their trade such as a boot, a suit, a hat, a clock and a diamond. A Londoner printed

Table 11.1 Systematic observations of the two groups in the social experiment

Age (in 2020)	What did they discard while cleaning?	What did they insist on keeping?	General observations
45–55-year-old	Old Documents and bills, newspapers, appliances that were broken or no longer in use (DVD Player, large MP3 players, sewing machines etc.) clothes, broken footwear	Old books that were passed down to their generation, few magazines (not printed now), broken radio from 1970s, cloth bags and sweaters knitted by their grandparents on the spokes of bicycle wheel	This group insisted on throwing away things that occupied more space in their urban apartments and were no longer in use, which mostly included documents, bills, newspapers, for which they have an alternative digital archive. They wanted to preserve what they believed arc future heirlooms and arc aware that these are rare pieces not be spotted easily anymore, like the radio and knitted bag. They also kept old magazines for pictures and advertisements in them, which sparked a memory of products they used as children
56–65-year-old	Clothes that were used to maximum capacity, broken footwear, old utensils (broken and unbroken), newspaper bundles	Things that belonged to their children like their baby clothes and old stationery from their school days, old luggage, especially trunks, appliances like sewing machine which was no longer in use, old pieces of rare wooden furniture	This group's capacity to upcycle was tremendous. A pair of denims no longer being worn were made into a tote bag for groceries and hanging stand for planters, then used as a cloth piece for dusting before being thrown away at last. They retained most things from the past, especially those reminding them of their children's childhood and their own, which reminded them of the simpler times without technology, where "everyone was a 100% physically present in the room and not checking beeping devices every minute"

the first English newspaper in 1622 and the first ad appeared in 1625 [8]. In the end of the 1800s, products became more commoditized during the industrial revolution, and manufacturers now had to advertise to thousands in order to sell the inventory. That is when large-scale advertising began. At the time, ads were often in black and white, line-art and text. Fast forward to the 1920s, color printing of magazines had progressed. Large illustrations, art-deco style, were capturing readers attention all over the world. Then, brands started introducing emotion to their product advertising. They were amazing because they got you laughing, smiling, curious and open to a new viewpoint [9].

Audio advertisements came in when people listened to their favorite programs on the radio. It was always “brought to them by” whatever company was advertising during that program. People associated the advertiser so deeply with the content that they believed the advertiser was the author of it. Television advertisements that followed were widely welcomed because, in a sense, everyone saw the commercials as an opportunity to learn about what was available for them to buy, without actually having to step out of their house [10].

But in the 1990s, it was Internet that revolutionized advertising. One could simply search for a certain product and get multiple related advertisements, thus, giving the user the power to choose what they saw. This started a wildfire in advertising. Social media and promotional campaigns online are ever-increasing. Brands are also incorporating humor and witty taglines to grab the attention of the millennials. Advertising through collaborations with bloggers and micro-influencers is becoming widely popular. Currently, with audio advertising back on music-streaming platforms like Spotify and brands opting for a ‘less is more’ minimalistic approach to aim for greater impact, the question that rises here is whether we have saturated the market with a plethora of designs and advertisements to such an extent that we are resorting to simpler ways. This brings us to the next section, a case study of Muji, a brand completing the circle of design and advertising.

Not a brand—the story of Muji. Launched as a private brand in 1980 to counter the increasingly brand-conscious consumer in Japan, Muji offered beautifully designed, fairly priced quality goods. The once modest private label brand with 40 products had expanded significantly by 2019 to more than 7000 products with more than half its 975 stores outside its home market in Japan [11]. Their full name Mujirushi Ryohin stands for “no brand quality goods,” a philosophy they have kept to this day. Muji is a “no brand,” in the sense that their products have no logos or other obvious markings on them indicating the brand. The items are not made to stand out; they are very plain and minimalistic but not for the purpose of making a style statement. They do not believe in keeping up with the trend, but rather deliver simplistic and functional products that are made to last. Muji focuses on quality while material selection streamlines processes to include just what is necessary and their packaging is simple. They once sold U-shaped pasta after buying the ends of spaghetti that is cut off when it is manufactured. Thus, in spite of having “no brand,” Muji has strategically built a strong one.

11.3 Findings from the Study

In this section, four organized sections present findings from the study, including questions asked and the resulting design implications.

11.3.1 Design for Everyone

The findings from the historical texts unsurprisingly revealed how civilizations lived in harmony with nature, in contrast to the modern cities, where nature has to accommodate our special demands. Inhabitants of ancient societies utilized natural resources thoughtfully. They designed for their tight-knit communities rather than for personal use as they moved in groups, courtesy the nomadic culture and relied on each other for sustenance. While communication is ever-evolving and we might resort to minimal pictorial communication like emoticons, for universal understanding at times; with a society as advanced as ours, it is unlikely that we will rely purely on symbols to communicate, like Egyptians did. It is evident that earlier societies paid attention to creating dedicated mindful surroundings to boost productivity, like in Gurukuls. The clever use of space design to promote self-learning through tangible, real-time experiences might be the next step in social design.

It was noted that mass production changed and resulted in mixed viewpoints regarding handmade design, but successfully increased accessibility to design. The Industrial Revolution, however, introduced a separation between the designer (the person who conceives an object), the maker (the person who produces it) and the user (the person who experiences it). As a result, the direct feedback loop between experience, design and making is interrupted [12].

Another observation was that whenever there was societal unrest, art and design displayed a sense of nationalism and adopted a pragmatic approach. With movements like pop art, a drastic shift of subjects in art, from portraits of royalty to a can of soup, which shows how art and design philosophy changed from elitist to art and design for everyone.

While technology has revolutionized the way design and society function, a sustainable approach and the greater impact of design and product development on the environment must be taken to account, where the future is an endeavor to remind human beings of their physicality as well. This could lead to a paradigm shift of design methodology to be more tangible and experience-based, focusing on mindfulness, rather than adopting a linear technological approach.

11.3.2 Thoughtful and Long-Lasting Homes and Systems

Homes of the past were clearly built to last, as the designs are relevant to this day. The residents put a lot of thought into design and used solutions which were derived from nature, evident from the selection of natural materials to build their homes in rural areas and matching the exteriors to blend with nature. People grew their own vegetables and fruits in the backyard and liked being self-reliant, trusting their own methods. The designs of the prayer room are an excellent example of sensory ecosystem design, where different elements come together to function as a system which engages all your senses. There was something for each sense—striking flower garlands for visual sense, bells for auditory sense, incense sticks for olfactory sense, the *rudraksh mala* for the sense of touch and the sweet offering at the end for taste.

11.3.3 Nostalgia and Physical Presence

To better convey the results of the experiment, “would you throw this away?”, the results have been divided into two groups—the younger age group of 45–55-year old and the older age group of 56–65-year old.

New dimension. The second elderly group firmly believe that things used to be better in the past and longed to relive it, without the interference of technology. They are unable to fully comprehend and keep up with the technological developments and believe that they are losing people to cyberspace. This was restorative nostalgia, stemming from an emotional longing to relive the good old days. The other group (45–55-year old) recalled childhood memories of being in closely-knit circles of family and friends, and increased human interaction, where physical things and experiences were valuable, but also agree to the importance of technology and how it has made life so much easier for them. Observed here was reflective nostalgia, dwelling on the ambivalent nature of human longing and belonging, while also acknowledging the contradictions of modernity.

11.3.4 Back to the Basics

Through advertising, it was evident how the design of products extends beyond the tangible aspects. When mouth-to-mouth referral was not enough, brands decided that advertising was the solution. Through print ads in newspapers, magazines and billboards, brands were only convincing consumers to purchase their product. Audio and television advertisements enabled users to see and choose products from the comfort of their homes and Internet took it a step further. But this form of media created a wave in the advertising industry, and as a result, there is a plethora of advertisements being bombarded on the consumers. The method of enabling bloggers and micro-influencers to promote and advertise for the brand serves the purpose as social media has become a platform for everyone to freely voice their opinions, and thus, recommendations do not go unnoticed. However, this is reminiscent of the mouth-to-mouth referrals which existed before advertising. Similarly, audio advertising has made a comeback through music-streaming platforms. We also notice that since millennials want to see something different in a saturated market, brands have resorted to bite-sized minimal content for the impatient generation and also incorporate humor to make it relatable. Through the Muji case study, the success of the "no brand" and impact of value addition makes it clear that as consumers become more aware of the harsh reality we live in, and they appreciate honesty and transparency in the design process.

11.4 Discussion and Future Work

The present scenario is that of global unrest and the future is more uncertain than ever—an indicator for designers to use creativity and innovation to tackle major issues on a societal level.

People are reaching out to help each other cope with the impact of a global pandemic, economic crisis and political unrest in the long run, fueled by the search for connection, familiarity and intimacy. As a result, there will be a rise in tight-knit community groups like in the past societies. Design in future will shift paradigm to human-centric services which would help people rediscover intimacy and emotional connection. This can include spaces, projects and curriculums that encourage human engagement, breaking down the boundaries between disciplines.

With communities coming together largely, universal and empathic design on a social level are necessary now more than ever, taking into account the sensitivity and heightened emotions of consumers, who are aware and raising voice against human rights, gender bias, racism and so on. We need to create safe spaces and environments which are inclusive, forming a tangible network-driven design philosophy for the future—"design with" instead of "design for."

Recreating mindful surrounding in public spaces, especially space design in offices and schools will increase productivity and will have great potential. Imagine, not products, but spaces inside your homes and offices that will teach you! As remote working breaks conventional four-walled classrooms and brings education to home, there will be a focus on recreating thoughtful spaces at home, where self-learning and specialized, asynchronous educational curriculum will be paramount.

To progress further, as mass-customization describes the design scenario today, where personalization and convenience of the user are highlighted, it is not enough for the future. The next step could be a possible democracy in design—customization to such an extent that the user feels like they are completely in charge of the design. It is human nature to like something the best when done by themselves. How designers can be more relevant in future is by providing the consumers with means to create and customize their own design, giving them a sense of self-reliance and independence like in olden days. For instance, designing and providing them with a 3D printer that prints out food for them so they will have endless possibilities with them.

While modern consumers feel the need to be in control of design processes, they also appreciate traditional wisdom, labor and craft that go into producing goods, and thus, look for long-lasting products, with the intent to keep them as future heirlooms. Local organizations will be empowered, as opposed to an individualistic and fragmented society now. A revived respect for the past will give valuable insights into the intricacies of ancient systems, from sustainable design to nature and wellness. Indulging the past and revisiting childhood memories is becoming increasingly comforting as the future is so uncertain. A trip down the memory lane is a coping mechanism for many people ever since the new norms of social isolation have emerged. As designers, we can tap into this nostalgia to be more reflective and harness its power to create balanced and ambivalent systems for the future that use technology as a medium to advance, but at the same time, are reminiscent of the nostalgic physicality and intimacy of the past.

11.5 Conclusion

In the recent years, designers have looked into the past for inspiration and constantly borrowed from it to create futuristic designs. But given the fickle nature of the present society, simply borrowing from the past is not enough, but recreating their methodology by combining design and technology effectively can have a monumental impact. Design philosophy is coming a full circle as we go back to basics—value-adding designs that are driven by simplicity, necessity and functionality. We need social design now more than ever; design that is universal, inclusive and most importantly empathic to cater to a society where fear and uncertainty is heightened. As the changing terrain of society is challenging, we must change the way we see and talk about design. Design should not be limited to solving problems or fulfilling necessities, but it shoulders the responsibility of socially and psychologically reassuring the consumers, providing them with a sense of social security. This can be achieved by not just merging the cyber and physical, but reminding the society through reflective nostalgic designs, of its existence as a unified community—recreating the past, using the advancement of the present to build a balanced society for the future.

Acknowledgements I would like to thank the Organizing committee of ICord'21, IDC School of Design, IIT Bombay, Powai and CPDM IISc Bangalore for giving me the opportunity to write this research paper and be able to contribute to the design fraternity and also thank my faculty, Dr. Pallavi Rani, Ph.D., who provided me with guidance in my research. I would like to extend this gratitude to all the kind people who let me interview and converse with them, sharing their personal histories and supporting the study. I am grateful to my family, friends and faculty members for their constant support and motivation.

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Chapter 12
Narrative—A Vehicle to Generate Product Form

Suresh Sethi

Abstract The paper focuses on the aesthetic assessment and evaluation of the designed product forms. The emphasis was on whether narrative improved the expressive qualities and the unity of the designed artifacts. The story seems to be the condition that guarantees the unity of the object, and at the same time, gives the product form its structure by connecting and merging lines, colors, shapes, and volumes of the experience into a new form. This merging is what philosopher John Dewey called aesthetic experience. Aesthetic experience has a central focus, in which attention is upon intensity and unity of the object, where unity is a matter of coherence and completeness. The study results confirm that using narratives at the design process's conceptualization phase structured the perception and organized designers' own experience to generate the product form.

12.1 Introduction

Design involves feelings, and narration helps to instill meaning and emotion in design. Metaphors, analogies, and narratives are powerful tools that help to bring concepts to life. Designers create objects not only as a set of logical propositions but often as a pattern of experiences. Designers link unconnected links to create new designs. Visual experiences are based on the features of the visible world. These experiences are stored in the unconscious and are manifested through the ideas they generate. Designer's direct experiences and perceptions of the everyday environment play a crucial role in the generation of design ideas. Designers create new patterns and new relationships that once may have seemed obtuse, unrelated, or even inappropriate. Moreover, they do this by deliberately blurring the lines between fact and fiction. Narratives provide a way in which designers can explain what they do in an understandable and informal style.

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A. Chakrabarti et al. (eds.), *Design for Tomorrow–Volume 3*,
Smart Innovation, Systems and Technologies 223,
https://doi.org/10.1007/978-981-16-0084-5_12

"Design is metaphorical, just as language is metaphorical, the design is informed thought or emotion" [1]. Language organizes much of our experience. Language enables us to conceptualize, manipulate, and invent new forms [2]. "The typical form of framing experience (and our memory of it) is in narrative form" [3]. "Storytelling, after all, does nothing, except shuffle words, and yet through the arrangement of the words, new worlds are built filled with an imaginative wealth" [4]. The designer organizes and constructs the events' excitement and emotion into the product form by framing experience as a narrative. Narratives bring the inert material, processes, and product form to life.

12.2 Aesthetic Assessment

This study assumes that the narrative helps the visualization process result in more desirable product forms. The product form visualized using narratives is preferred to the ones designed without narratives regarding aesthetic appearance to which unity—coherence and completeness—is essential. Here, aesthetics is the "essence" of the narrative or the "feel" of the object at first glance. Dewey also noted that "essence" could also mean the indispensable "gist" of a thing. All artistic expression moves toward the organization of meaning to capture the essence in this sense. According to Dewey, there are no standards for critical judgment, but there are criteria of judgment. These criteria are a means of discovering the aesthetic dimensions of product form [5]. When people look at objects, the objects are experienced sensually, objectified rationally, and realized as a synthesis. They use language to express their feelings, whether the object was pleasing or not. Dewey proposed that language provided a way of sorting out our thoughts about the world.

Research through design approach was adopted to investigate the value of the proposed design framework. This approach focuses on embodying emotion and personality in product appearance, as Don Norman put forward in 2004, and Ortiz et al. in 2008 [6, 7]. During the study, different sets of products were designed with the aim of visualizing the form with and without narratives. However, this paper focuses on the evaluation of these sets of stimuli.

12.3 Designing the Assessment Scale

The systematic aesthetic evaluation of the product form generated with narratives has several stages. The first step is to define what is to be measured. In this assessment, we are interested in what the object looks like, focusing on what the form of an object "appears or feels." In this aesthetic assessment, besides evaluating the designed object (the logical outcome of the process), the research also intends to determine if narrative use creates a positive effect regarding the expressive qualities and the unity of the designed artifacts.

As the aesthetic point of the design is communicated through the precise use of language, we started investigating what terms and words designers use when defining a product aesthetics. The development of the product personality scale followed the general steps of the scale development proposed by Pascalle Govers. "Firstly, we formulated a definition of product personality and established its defining components. Then we determined the format measurement, and an initial item pool was generated. Next, this item pool was reviewed with respect to defining components of product personality and reduced to manageable number. A final stage in the development concerned the unequivocalness of the items" [8]. However, in this study, the main focus was not on the product's personality but more on the unity of the product form and whether the linguistic approach can help assess the aesthetic appeal.

12.4 Format of Measurement

Designers more or less consciously strive to create a coherent unity of three factors—"instrumental," "affective," and "preference." Each of the three applies to different functions and qualities of the artifact. Narratives facilitate the right kind of cues in the visualization of the product form and help in communication. Moreover, the narrative is the key to a coherent design or an integrated matrix within which one can sense the visualized form [9]. The "essence" or the "emotion" of the narrative is communicated with adjectives. Although researchers could use only one emotion on a practical level, we can capture the full construct of the aesthetic assessment of a product form [10]. Therefore, the three-factor model would be an appropriate way to assess the visualized form's completeness and coherence of the visualized form to assess the narrative's effectiveness to create the product form.

We decided to use adjective pairs representing two opposites (e.g., strong-weak) as "aesthetic impression may be defined as the sensation that results from the perception of attractiveness (or unattractiveness) in products" [11]. There are different theories regarding contrast, light and dark, and dominant and subordinate qualities in creating a product form. According to Kostellow (1947), "balance, not the symmetrical equalization of weight or median lines, but the dynamic distribution of it to achieve livingness; tension, the awareness of the drama of existing relationships in space between widely separated parts; integration of positive and negative volumes…; opposition, the forceful relationship of the heterogeneous elements in the design structure" [12] are all essential in the perception of the product form.

Johannes Itten, the famous instructor of the Bauhaus school, favored teaching students about contrast. "Light and dark, material and texture studies, form and color theory, rhythm, and expressive forms were discussed and presented in their contrasting effects. Finding and enumerating the various possibilities of contrast was the most exciting lesson because they realized that a whole new world was opening up. The students had to study the contrasts in three ways: to experience sensuously, to objectify rationally, and to realize as synthesis" [13]. For Itten, this opposition was one of the most expressive and vital means of design, as the gradation between the poles of contrast contains life and serves as an emotional quality, that is, the essence of the product form.

12.5 Selection of Aesthetic Terms to Form the Concept Scale

The study's primary aim was to select aesthetic dimensions that show a particular pattern of relationships, to indicate a coherent unity of the three factors—instrumental, affective, and preference. Several steps (see Table 12.1) led to a shortlisting of the aesthetic dimensions. Table 12.2 depicts the final list of the nine pairs of opposites.

Table 12.1 Steps of shortlisting aesthetic dimensions

Words listed to describe the aesthetics of product form	
Study 1: Industrial design students ($n = 30$) list 20 words they use to describe designed artifacts	Simple, functional, innovative, aesthetic, modern, sustainable, unique, elegant, dynamic, ergonomic, minimal, fashion, durable, and smart were the only words repeated more than five times
Study 2: Literature search: Sibley's aesthetic concepts	Sibley's approach to aesthetics uncovers the richness and range of language applied to the everyday world. According to Sibley, aesthetic terms come in an almost endless variety and span a vast range of types and sub-types (Sibley, Aesthetic Concepts, 1959)
Mugge, Govers, and Schoormans's product personality scale (2009)	The original list of 1142 words was reduced to 78. From these 78 words, a manageable set of 20 words finalized, and the verbal description of the words developed
Ortiz Nicolas (2014)	Ortiz Nicolas came up with a set of twenty-five positive emotions, including ones that are highly preferred by designers: e.g., curiosity, joy, confidence, inspiration, fascination, and pride
Blijlevens et al. (2017) expert shortlisting	Blijlevens et al. found 86 words based on extensive literature research that include "clear, dynamic, varied, powerful, beautiful, distinctive, moved, and novel"
Study 3: Industrial design students ($n = 57$) list five words from the experts 24 words	Two experts helped create a list of 24 words that were found most appropriate for the current research The shortlist was compiled by the experts reduced to five words. This list was discussed with the experts to get the final list of nine words relevant to the current research

Table 12.2 List of nine pairs of opposites

Clean–Messy	Delicate–Rough	Desire–Disgust
Dynamic–Static	Elegant–Not elegant	Formal–Casual
Strong–Weak	Surprising–Boring	Varied–Monotonous

These dimensions were then used to describe the product form visualized with narratives. This study's artifacts were from the pool of items collected from design practitioners during this fieldwork. We recruited thirty design students. The preference for recruiting only design students was their training in color, line, three-dimensional volume, spaces, and to notice or discern expressiveness and unity in an object. Each participant received a set of questions based on the adjective pairs for each aesthetic dimension—the set compiled for rating based on each of the nine dimensions for nine artifacts. The photograph and the narrative of each artifact are individually illustrated. Two experts selected these nine artifacts from the pool of 81 artifacts collected during the fieldwork—three versions of the questionnaire made in a randomized order. Before the participants got started, test procedures were explained, the narrative read aloud, and the artifact's high-resolution color image was projected on the screen. Each participant completed the test individually and rated nine products based on each for the quality dimensions.

The study was set up to test the reliability of the aesthetic assessment scale. Most importantly, the main focus was on the role of narratives in generating the product form. The scale could be considered reliable if each stimulus's dimensions were perceived consistently by the thirty participants, who assessed the nine dimensions allocated to each artifact collected during fieldwork. The mean scores of the product dimensions are depicted in Table 12.3. The results show high-reliability values for all nine stimuli. The alphas are all high (0.79–0.88), and the r_1 values are all significant. These results indicate that the product dimensions profiles of all stimuli were perceived consistently by the participants.

Table 12.3 Reliability of the scale calculated for each artifact variant ($n = 30$)

Artifacts from fieldwork	α	$r1$
Artifact 1	0.79	0.30
Artifact 2	0.84	0.36
Artifact 3	0.88	0.47
Artifact 4	0.84	0.38
Artifact 5	0.85	0.41
Artifact 6	0.79	0.30
Artifact 7	0.81	0.33
Artifact 8	0.87	0.42
Artifact 9	0.79	0.34

12.6 Concept Scale

The aesthetic assessment scale consists of adjectives that could be interpreted differently by each participant. It is also clear that these nine dimensions, which may not be present in all the products, influence the product form through their particular arrangement. One way to create a scale is to address these values would be to broadly group them into three sub-groups—instrumental, affective, and preference. These sub-groups are at a higher level of abstraction than piecemeal dimensions and therefore allow a holistic judgment.

Instrumental—utilitarian/functional—Is the design grasped as a general whole; is it complete and coherent? Is the representation of the narrative strong? Is the articulation of the visual sketch and drawings clean and formal? Do the instrumental components—formal, strong, clean—describe the quantitative, measurable aspects of the designed product form.

Affective/Expressive—emotional—Is the solution (the product form) elegant/delicate/dynamic/varied/surprising? What are its regional qualities, and how intense are they? According to Beardsley (1958), an aesthetic object has certain obvious and emphatic features—its dominant patterns or qualities—that stand out clearly and can be perceived without much effort. "The features which make something delicate or graceful are combined peculiarly and uniquely; the aesthetic quality depends upon exactly this individual or a unique combination of just these specific colors and shapes so that even a slight change might make all the difference" [14].

Preference—Is the product likely to be purchased? The deliberate choice of making a preference relies on understanding the design attributes of both instrumental and affective and of how the elements of color, material, volume, texture, patterns come together coherently to evoke the intended aesthetic experience. An ideal choice of object is both sufficient (functionally) and satisfying (emotionally/experientially).

All three qualities are considered when making a value judgment on design regarding its coherence. To what degree is the design coherent with the subject? Coherence is a matter of having elements connected appropriately, and an orderly accumulation of energy toward a climax should be present to an unusual degree [15]. The concept scale is depicted in Table 12.4.

12.7 Testing the Three-Factor Scale

The final step in scale development is testing the concept scale concerning validity and reliability. The aesthetic dimensions grouped around three factors, and the following questions needed an answer:

Table 12.4 The three-factor aesthetic assessment scale

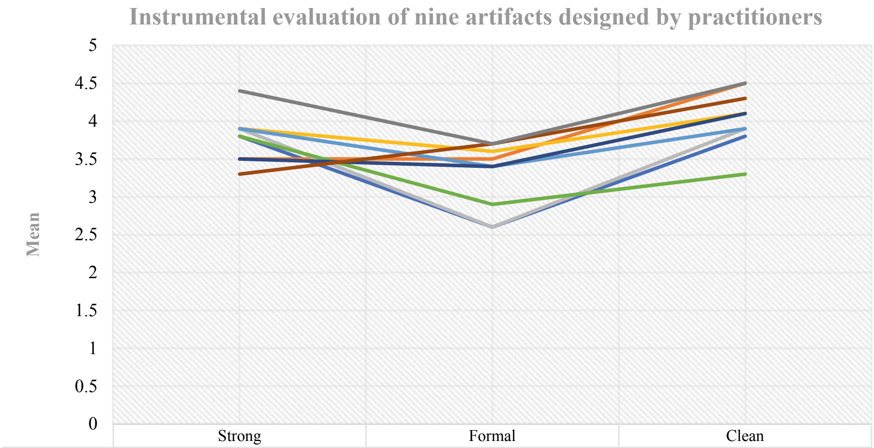
Three-factor model	Dimensions	Evaluation
Instrumental	• Strong–weak • Clean–messy • Formal–casual	• How well does the narrative work in creating the product form? • Is the narrative clearly translated into visual form? • Is the output strong regarding visualized drawings and product form?
Affective	• Elegant–not elegant • Dynamic–static • Delicate–rough • Varied–monotonous • Surprising–boring	• Is the product form elegant/delicate/dynamic/varied/surprising? • A beautiful object has a specific dominant quality that we are likely to notice. Is such a quality present? • What are its regional qualities, and how intense are they? Are they balanced?
Preference	• Desire–disgust	• To what degree does the design cohere with the subject? • Is the design complete and coherent?

Is the narrative clearly translated into visual form? Is the visualized output strong and coherent? Coherence is promoted by focus, balance, and equilibrium and the similarities between the parts of the design. If the narrative process was meaningful, there should be a degree of agreement between the participants about the instrumental dimensions of a particular artifact, even though they had rated the product independently. The outcome of the test (Fig. 12.1) gave strong support to the idea that participants found that the artifacts designed with narratives were meaningful.

Is the product elegant? Do the participants prefer elegant products? The Collins Dictionary defines the adjective "elegant" in the following way: "if one describes a person or a thing as elegant, they mean they are pleasing and graceful in appearance or style." An elegant solution is one that has maximum effect for minimum means. Elegance is a unique pairing of two often contradictory qualities: extreme simplicity and surprising impact. The results (Fig. 12.2) showed how the participants found the artifacts elegant and strongly supported the idea that people prefer elegant products. The test outcome supports the general idea that design students found products created with narratives meaningful.

12.8 Experiment Design

The project in which workshop participants was asked to design cool boxes with and without narratives. The experiment followed a mixed method with three artifacts designed with narratives and three without narratives. Therefore, the participants



	Strong	Formal	Clean
Object 1	3.8	2.6	3.8
Object 2	3.5	3.5	4.5
Object 3	3.9	2.6	3.9
Object 4	3.9	3.6	4.1
Object 5	3.9	3.4	3.9
Object 6	3.8	2.9	3.3
Object 7	3.5	3.4	4.1
Object 8	3.3	3.7	4.3
Object 9	4.4	3.7	4.5

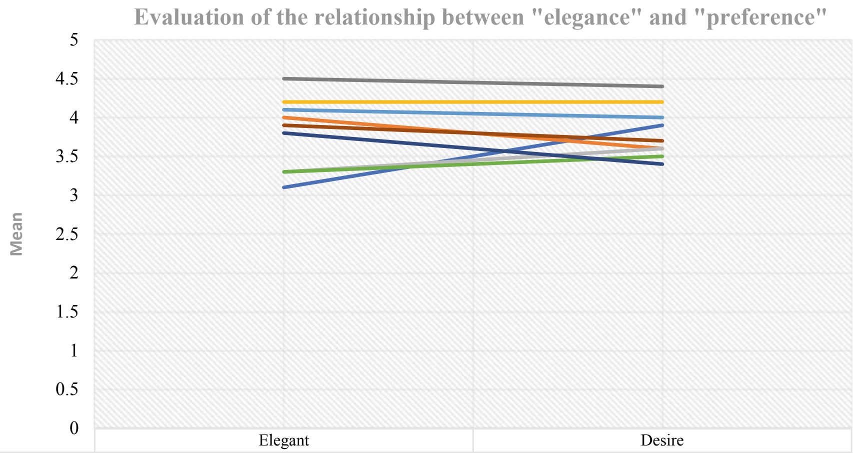
Fig. 12.1 Mean ratings for "instrumental." The results are for the dimensions of "strong," "clean," and "formal"

were split into two groups: first investigating the artifacts with narratives and the other the artifacts without narratives.

Participants: We recruited the same thirty design students who had taken part in the previous study. All students were from the industrial design program, twenty of them were women (67%), and ten were men (33%). The participants' age ranged from 21 to 28 years, with an average of 23 years. Participation was part of their studio class.

Questionnaire: Each participant received a set of questions based on the adjective pairs for each dimension—the set compiled for rating based on each of the nine dimensions for six artifacts. The photograph and the narrative of each artifact are individually illustrated. Three versions of the questionnaire were in a randomized order.

Procedure: Before the participants got started, test procedures were explained, narratives were read aloud, and high-resolution color images of the artifacts were projected on the screen. Each participant completed the test individually and rated three products based on each of the quality dimensions. The artifacts with and without the narratives are illustrated in Fig. 12.3. The stimuli were presented on two sets of three



	Elegant	Desire
Object 1	3.1	3.9
Object 2	4	3.6
Object 3	3.3	3.6
Object 4	4.2	4.2
Object 5	4.1	4
Object 6	3.3	3.5
Object 7	3.8	3.4
Object 8	3.9	3.7
Object 9	4.5	4.4

Fig. 12.2 Evaluation of the relationship between "elegant" and "preference"

A4 sheets. The study conducted in a design studio setting and the rating items took participants 20 min to complete.

Stimuli: Color pictures of the artifacts were projected on the screen. A survey was created for rating based on each of the nine dimensions. Each participant in the two groups individually rated the three refrigerators from the aspect of the quality dimensions.

Results of the Experiment: The results of a one-way analysis of variance (ANOVA) [16] are summarized in Tables 12.5, 12.6 and 12.7.

The study results confirm that using narratives at the conceptualization phase of the design process structured the perception and organized designers' own experiences to generate the product form. In design, words, images, and shapes—in combination or independently—are used to communicate the concepts and represent the understanding of the physical world of artifacts. These are the most common media that designers use to interpret and reformulate design concepts. Stories and lived experiences are fundamental building blocks of design.

For the students, every new design is a risk, as it brings the possibility of failure. When asked to describe their inquiry methods, they speak of experience, trial and error, and intuition. Using narratives gave them the freedom to pursue their own

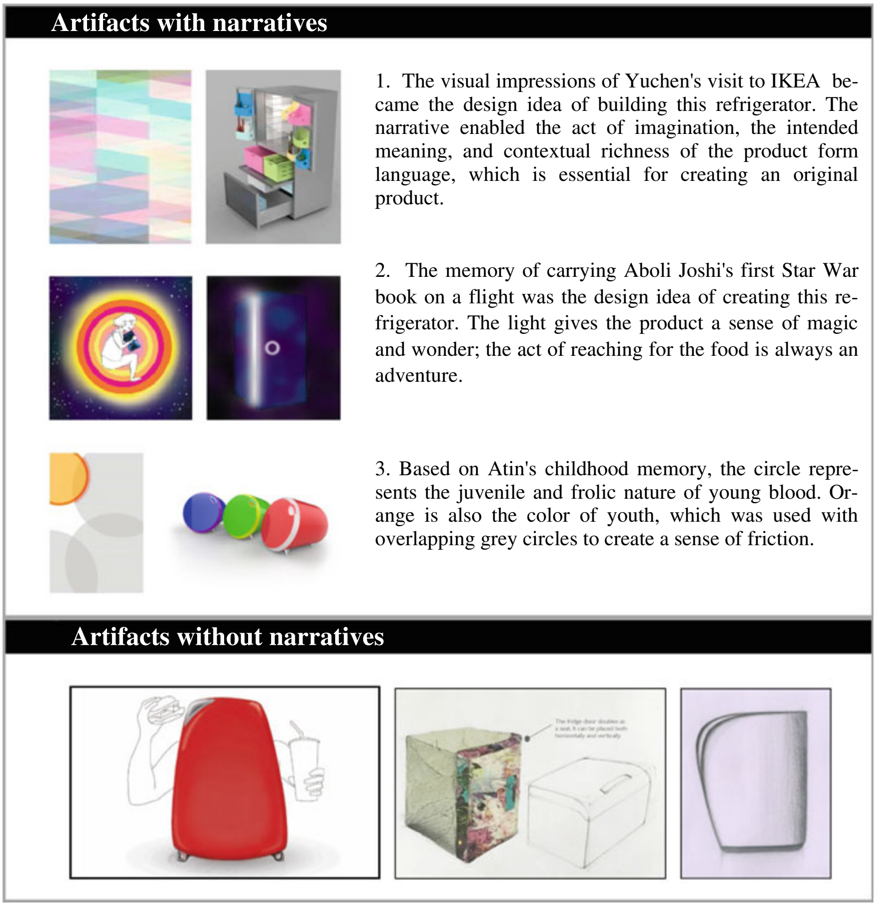


Fig. 12.3 Artifacts are designed with narratives and without narratives

Table 12.5 Results for "instrumental" with and without narratives

Source	S.S.	df	M.S.	*F*
Between treatments	16.8056	1	16.8056	11.26606
Within treatments	265.5222	178	1.4957	
Total	282.3278	179		

The main effect of the narrative treatment ("instrumental") was significant with $F = 11.26$ and $p < 0.05$

Table 12.6 Results for "affective" with and without narratives

Source	S.S.	df	M.S.	*F*
Between treatments	9.72	1	9.72	5.92796
Within treatments	488.6267	298	1.6397	
Total	498.3467	299		

The main effect of the narrative treatment ("affective") was significant with $F = 5.92$ and $p < 0.05$

Table 12.7 Results for "preference" with and without narratives

Source	S.S.	df	M.S.	*F*
Between treatments	3.2667	1	3.2667	4.50396
Within treatments	42.0667	58	0.7253	
Total	45.3333	59		

The main effect of the narrative treatment ("preference") was significant with $F = 4.50$ and $p < 0.05$

sense-making goals to formalize the form's character and elements. The emergence of coherent information from a narrative became the guiding principle that created a meaningful and integrated form. The students found that the narrative was a very positive way for them to go about their work. Most students said it "was a new way to visualize" and "it gave us a tool to create and communicate clearly." Narratives helped the participants in planning and navigating the process, as well as in decision making. They discovered that design was not set apart from daily life but sprang forth from our experiences' visual impressions. All students expressed an interest in exploring this way of designing and further investigating the narrative approach. Most students also suggested using narratives again when developing their concepts as they felt it helped build their confidence. "Narratives give the designer a pair of wings to transcend limitation and do original work" [17].

12.9 Discussion

According to Ossi Naukkarinen (2010), the study has some inherent limitations, aesthetic judgment cannot be proven right or wrong by scientific methods, and aesthetic qualities cannot be directly measured. The method of both making and analyzing aesthetic judgment is a discussion. Naukkarinen believes that aesthetic issues have to be discussed to be defined, explaining that aesthetic judgments may vary with evaluators and that no scale exists for aesthetic judgments. The point of aesthetic judgments is to get others to agree rather than find the absolute truth [18].

Designers seek, express, confirm, and ascertain a sense of being through their creation. Design students take the category of a product form for granted—when they have to design, say, a lamp—they look at all the “lamps” and design a “lamp”—the challenge is to make an ordinary object extraordinary. The use of narratives captures the essence of a designer’s experience, which helps conceptualize product form. Narratives forge links between function and emotions. The function and the use of the product are the elements we take for granted—we do not question, for example, why a lamp lights up. In contrast, when one encounters an exception to a given function and wants to grasp what is happening, they will always come up with a narrative that gives reasons. This narrative’s function is to find a story that makes a deviation from a canonical cultural pattern comprehensible. Narratives interpret form and what form means to them. It mediates between the object’s functional world and the expanded world of beliefs, desires, and hopes. It renders emotions comprehensible; it frames the experience and provides the means to construct the product form.

Most research on product personality has focused on consumer preferences and behavior, and products designed in a short period (e.g., three products were created during a 45-minutes session; for details, see Govers, Hekkert, and Schoormans, 2004). These stimuli were used to test whether personality embodied in product appearance was recognized as such by the consumers. The Govers et al. research relied on designers’ skills to embody selected personalities in three products by using their approach, and thus it is not reported how designers created the stimuli. This raises important questions regarding stimuli creation for research on product appearance. How the designer interprets the emotion he or she embodies in the visualized form is also worth considering. To assess the stimuli, they should be complete and coherent—they should have the necessary information with which respondents can perceive the same meaning and references as those intended by designers. When we want to remember something, citing the work of Frederic Bartlett, Bruner quotes, “what most often comes first to mind is the charged ‘attitude’—that it was something… that was exciting. The effect is rather like a general thumbprint of the schema to be reconstructed. The recall is then a construction made largely by this attitude, and its general effect is that of a justification of the attitude” [19]. The designer’s capacity to render experience regarding narrative is an instrument for making meaning of the product form and is a reconstruction designed to justify.

These findings have clear implications for design education: teaching designers to use narratives as part of their concept generation, especially in the early stage of design when concepts are ambiguous, can produce new interpretations. “When designers are producing drawings entirely for their benefit instead of presenting information to others, this reflective process is almost the whole part of the drawing. It is these design drawings, sketches, scribbles, diagrams, and the like that most offer this conversational potential” [20]. Such drawings are done by the designer not to communicate with others but rather as part of the very thinking process enabling them to visualize product form. The process that starts with ambiguity and anxiety also makes the designer wonder, and when the solution is made visible, it is sheer surprise and astonishment for everyone.

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Chapter 13
Development of Design Heuristics for Furniture Design

Supradip Das and Amarendra Kumar Das

Abstract Innovation in design is positively influenced by the selection of successful concepts from the multiple and varied alternatives generated. Prior research explicated that design heuristics are the prompts, which allows novice designers to generate a number of alternatives and avoid design fixation. However, available design heuristics are industrial and product design specific. There are no heuristics available specific to furniture design. This paper presents the systematic development of design heuristics for furniture design (DHfFD), a concept generation tool for novice furniture designers. The tool has been developed from an analysis of the characteristics of 650 award-winning furniture (chair) designs and published compendium of well-known successful designs. This paper extends the research on the impact of DHfFD use by investigating the effectiveness of the tool through a pilot study. Initial testing has been done successfully with design students in the Department of Design, IIT Guwahati and has been enthusiastically adopted by students to create concepts that are more diverse. This study correlates DHfFD with more number of alternative concepts in furniture design. This research integrates evidence, methods, and perspectives from cognition and design correspondingly provide a pedagogical recommendation to use design heuristics for furniture design to overcome the issues in innovation in furniture design with the novice designers.

13.1 Introduction

Prior research explicates that major project termination in design innovation occurs at two points [1] (Fig. 13.1): (a) after the evaluation and selection process and at the beginning of the product development stage and (b) after the product launch. Thus, the success of the design innovation depends on the concept generation phase [2–4].

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A. Chakrabarti et al. (eds.), *Design for Tomorrow–Volume 3*,
Smart Innovation, Systems and Technologies 223,
https://doi.org/10.1007/978-981-16-0084-5_13

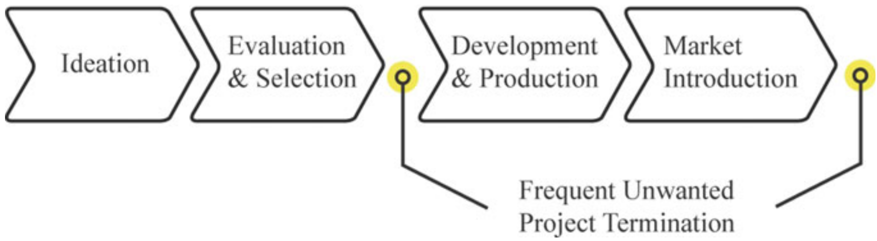


Fig. 13.1 Frequent unwanted project termination points

And statistically, the success of the concept generation depends on the quantity of the concepts generated in the early design phase [5]. But research on concept generation has revealed two serious cognitive issues [6]: (1) attachment with the early concepts and (2) unable to explore variety of designs. These are because feasible and efficient diverse concept generation by exploring 'problem space [7]' is difficult for novice designers [8] and novice designers fixate on the features of their initial concepts or available concepts [9, 10].

To overcome these issues, researchers suggested many formal methods (more than 172) for idea generation in the conceptual design phase [6, 11] and has been categorized as in Table 13.1.

Categorization of the idea generation methods aimed toward: (1) facilitation of idea flow, (2) stimulation of initial idea formation, and (3) transformation of ideas into refined ideas. Though there are existing tools available, there are many issues observed [11–13], such as:

1. Some of them provide very generic guideline, e.g., SCAMPER
2. Some of them need training and practice, e.g., Synectics, TRIZ
3. Some of them suggest ideas but do not evaluate ideas, e.g., Brainstorming
4. Many of them are not empirically tested for their effectiveness.

Research expounds that design heuristics are the empirically validated method for concept generation in the conceptual design phase and mitigate design fixation among novice designers [6]. Available design heuristics are industrial and product design-oriented [14]. This paper illustrates the effort of the development of 'design heuristics for furniture design' (DHfFD), which is a cognitive shortcut for novice designers to develop intentional variation in furniture design concepts.

13.2 Design Fixation and Design Heuristics

Design fixation is a phenomenon where designers adhere to (1) a limited set of ideas [15], which is considered as *conscious blocking* [16], (2) existing product feature [17], which is considered as *unconscious adherence* [16], (3) their own early design solutions [18], which is considered as *intentional resistance* [16]. Design fixation

Table 13.1 Categorization of methods for idea generation

Formal idea generation methods	Intuitive	Germinal	Morphological analysis
			Brainstorming
			K-J method
		Transformational	Checklists
			Random stimuli
			P-M-I method
			SCAMPER
			Lateral thinking
		Progressive	6-3-5 method
			C sketch
			Gallery method
		Organizational	Affinity method
			Storyboarding
			Fishbone
		Hybrid	Synectics
	Logical	History-based	Design catalogs
			TRIZ
		Analytical	SIT
			Forward steps
			Inversion

is also considered as cognitive fixation or mental block for novel idea generation during problem solving when designers are unable to think beyond, what they are exposed to [19]. There are multiple reasons, which contribute to design fixation: (1) experience [10], (2) domain knowledge [20], (3) personality traits, (4) awareness of recent advancement, (5) unawareness of the superior supporting methods or tools, and (6) self-imposed constrains. In quest of mitigating design fixation, design research explored and proposed many solutions [16], such as (1) short breaks, (2) physical prototyping, (3) use of design heuristics, and (4) use of computer-based design tool. Among all of them, design heuristic is a systematic idea generation tool.

Design heuristic is defined as scientifically validated [21], empirically tested [22], context-specific tacit knowledge derived from experiences [23], which are used as principles or methods [24] for improving the effectiveness of the problem solving [25], however, not providing direct and definitive answers, nor guaranteeing a solution for a problem [23, 26]. Heuristics are also considered as a *rule of thumb* [27], *cognitive shortcut* [12], *engineering strategy* [28], and *cognitive problem-solving tool* [29]. Notwithstanding the limitation of the tool, design heuristics are well accepted, as it helps in divergent thinking and supports two modes of idea generation: initiating novel ideas and transforming existing ideas [29, 30]. It is because design heuristics are helpful in stretching the paradigm of thinking [31] and it acts as an easy aid for finding complex problems by reducing the number of solutions to be searched for inspiration [32].

Previous research efforts have evidence of many design heuristics (DHs) or design heuristics sets (DHSs) for idea generation, which includes: SCAMPER [33], TRIZ 40 inventive principles [34], 121 heuristics [25], design Synectics [35], 77 design heuristics [14], transformation design theory [36, 37], portability design heuristics [38], and design heuristics set for X [39].

The design heuristics above are categorized into two [39]:

1. Design heuristics without pre-specified purposes, which are useful design knowledge across all domains. These are considered as 'comprehensive design heuristics' (CDHs). To use a particular design problem, a designer has to apply each design heuristic on a trial basis to get a solution, even if the problem is from a specific domain.
2. Design heuristics with pre-specified purposes, which are useful for addressing domain-specific problems. These are considered as 'design heuristics for X' (DHsfX).

This paper focuses on the later, which is 'design heuristics for X' and aims to develop *design heuristics for furniture design* (DHfFD) with special emphasis on the chair, a concept generation tool for novice furniture designers.

13.3 Design Heuristics for Furniture Design (DHfFD)

13.3.1 Existing Methods of Extracting Design Heuristics

This research draws upon the concept of *design heuristics for furniture design* (DHfFD) with special emphasis on the chair, which would help in furniture concept design for novice designers. Toward the development of a method for the same, a systematic study had been done to understand the method of the development of the existing heuristics. Systematic investigation of the existing design heuristics and their development elucidates that design heuristics are mainly developed based on the heuristics evident in successful innovative products.

The theory of inventive problem solving, which is also known as TRIZ, was developed identifying heuristics in technological innovations in patents in engineering [34].

77 design heuristics were derived from a detailed study and analysis of more than 400 award-wining products [14].

Design heuristics for transformation design theory, which describes the principles for transformation and facilitator for transformational design construct, were proposed based on the analysis of patents, analogies from nature, and existing products [36, 37].

Portability design heuristics were proposed by Hwang and Park [38] by clustering existing products and patent into groups.

Saunders et al. [40] investigated specific characteristics in innovative mechanical products from 197 major innovation award-winning products and identified 13 'innovation characteristics.'

13.3.2 Development of the Design Heuristics for Furniture Design

This research followed a three-step process based on the inductive approach [37] to study and analyze an extensive repertoire of furniture (chair) design analogy. The heuristics development schema is illustrated below (Fig. 13.2).

The process was initiated by searching repertoire of existing furniture design from independent award competitions (Table 13.2), published compendiums of furniture designs (Table 13.3), catalog of leading furniture manufacturer (Table 13.4), and online design magazine (Table 13.5). A total of 650 furniture were selected for analysis.

The details of the existing furniture were analyzed based on the form and structure and special features. The form and structure were further deconstructed into bar, body, and surface [41] and the orientation and dominance of the element were also analyzed [42]. After the analysis, existing furniture was grouped (Fig. 13.4a) according to the similarity, as suggested in the K-J method (Fig. 13.4b) [43, 44].

Analysis and heuristics extraction (Fig. 13.5) of the existing furniture has been done, as suggested by Yilmaz et al. [22].

The success of the heuristics extraction process and analysis was evaluated with the inter-rater agreement between three coders, which measures the degree to which they agree to each other. In this process, one Professor, one Assistant Professor and one Master of Design Student participated. The initial inter-rater reliability was 90%. The disagreement between the coders was resolved through discussions and 100% reliability was achieved. This process generated 66 heuristics.

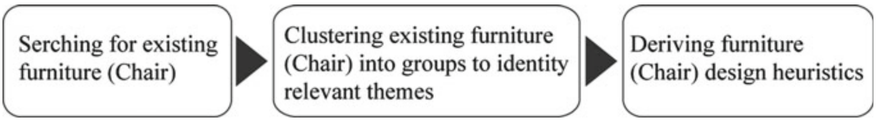


Fig. 13.2 Heuristics development schema

Table 13.2 Design award repertoire of furniture design (chair)

Award name	Organizing body
Red-Dot Design Award	Organized by Red-Dot (www.red-dot.org) It is the largest and most renowned design competition in the world
A' Design Award	A' Design Award is organized with the collaboration of many institutions, including MOOD-Museum of Design (www.competition.adesignaward.com) A' Design Award recognizes and endorses good design and emerging talents in design
iF Design Award	Organized by if Design Foundation (www.ifworlddesignguide.com)
The Good Design Award	The Chicago Athenaeum Museum of Architecture and Design and Metropolitan Arts Press Ltd. (www.good-designawards.com)
Elle Deco International Design Award	Organized by Elle Decoration International Network (www.edida-awards.com)
International Design Excellence Award	Organized by Designers Society of America (www.idsa.org/IDEA)
National Design Awards	Organized by Cooper-Hewitt, Smithsonian Design Museum (www.cooperhewitt.org)

Table 13.3 Published compendium of furniture design (chair)

Title and author	Publication details
Design Secrets: Furniture: 50 Real-Life Projects Uncovered, by Laurel Saville and Brooke Stoddard	Publisher: Rockport Publishers Inc.
Prototyping and Modelmaking for Product Design (Portfolio Skills), by Bjarki Hallgrimsson	Publisher: Laurence King Publishing
The Making of Design, by Gerrit Terstiege	Publisher: Birkhäuser Architecture
Process: 50 Product Designs from Concept to Manufacture, by Jennifer Hudson	Publisher: Laurence King Publishing
Furniture Design: An Introduction to Development, Materials and Manufacturing, by Stuart Lawson	Publisher: Laurence King Publishing
Scandinavian Furniture: A Source Book of Classic Designs for the Twenty-First Century, by Judith Gura	Publisher: Thames & Hudson

13.3.3 Design Heuristics for Furniture Design Identified

Table 13.6 presents the 66 design heuristics.

These heuristics are to be used by the novice designers based on the design problem, context and designers' predilections. Further, these heuristics will be grouped in future to develop a framework to lead to schemes that would assist designers conveniently.

Table 13.4 Leading furniture manufactures in the world

Organization name	Product range
Steelcase (www.steelcase.com)	Leading manufacturer of office furniture
Herman Miller (www.hermanmiller.com)	Researching, designing, and manufacturing innovative interior furniture
Knoll (www.knoll.com)	Manufacturer of office systems, seatings, and storage furniture
Vitra (www.vitra.com)	Manufacturer of the renowned designers
Cassina (https://www.cassina.com/en)	Manufacturer of high-end chair, sofa, and armchair
Artek (www.artek.fi/en)	Manufacture of furniture and accessories designed by Finnish masters and leading designers
Kartel (www.kartel.com)	Manufacturer of contemporary plastic furniture
Dovetail (www.dovetail.in)	Manufacturer of school furniture in India
Godrej Interio (www.godrejinterio.com)	Leading furniture manufacturer in India

Table 13.5 List of the online design magazine

Source name	Details
Dezeen	Architecture, interiors and design magazine Alexa Rank 3.7 K
Design Milk	Architecture to modern furniture and home décor Alexa Rank 40.9 K
Yanko Design	Design magazine covering international product design Alexa Rank 35.2 K
Designboom	Critique of art, technology, architecture and design Alexa Rank 6.7 K
Core77	Articles and discussion forum for product and furniture designs Alexa Rank 54.2 K
Fast Co. Design	Innovation and business stories through the lens of design Alexa Rank 11.5 K

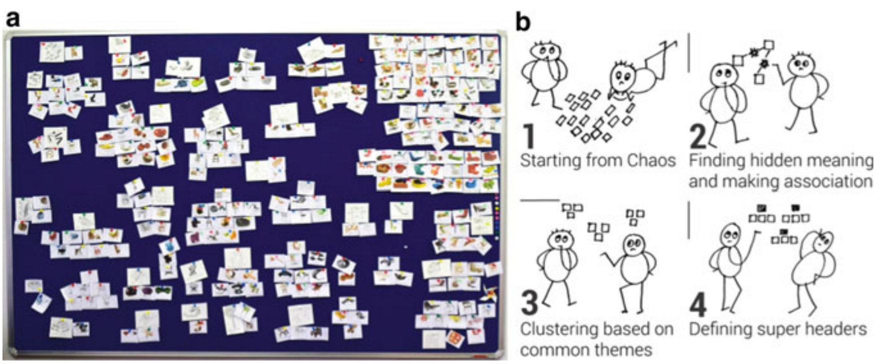


Fig. 13.4 **a** Grouping and labeling of the existing furniture, **b** steps of the K-J method

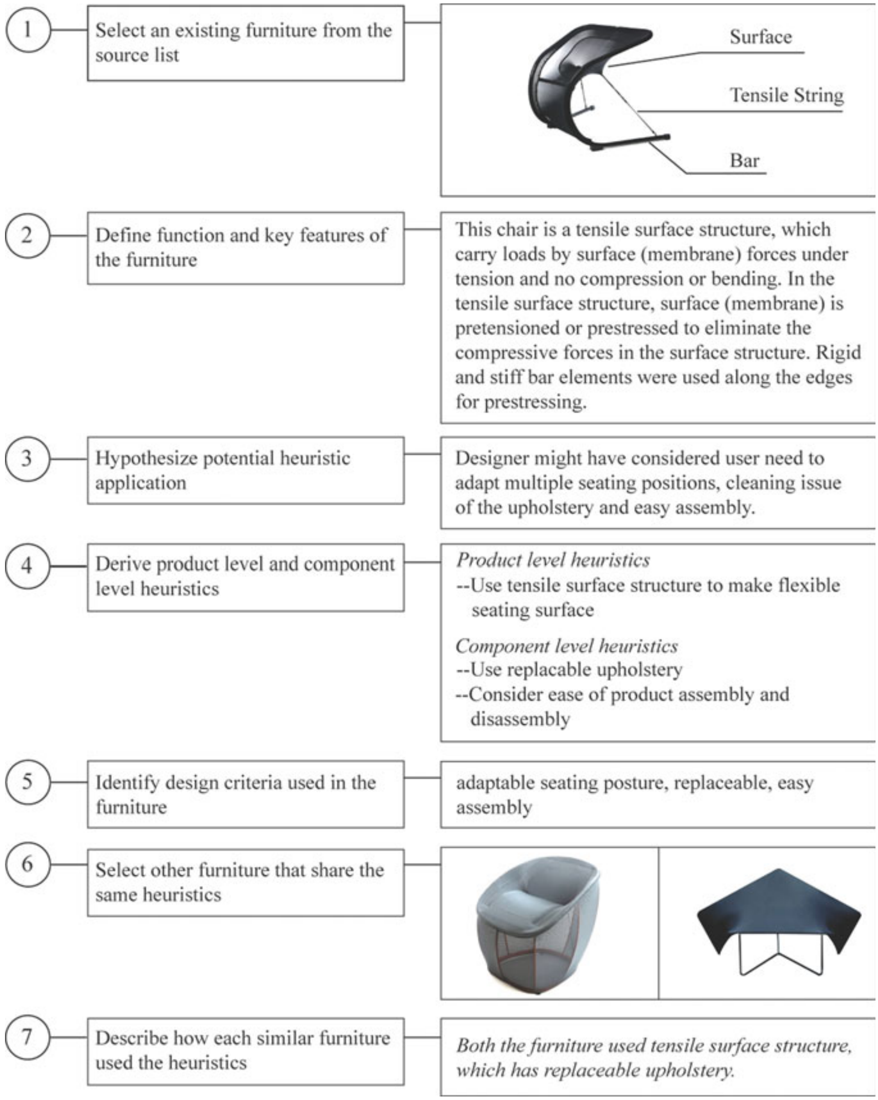


Fig. 13.5 Heuristics extraction and analysis process

13.3.4 Defining Design Heuristics Card for Furniture Design

All the design heuristics were converted into a design heuristics card set for the novice designers. The layout and the content of the cards are inspired by the design heuristics proposed by Daly et al. [12]. Design heuristics card for furniture design have the following content in each card (Fig. 13.6):

Table 13.6 List of design heuristics

Polyhedron	Bent surface	Bar and panels
Cantilever	Tensile Surface Structure	Bulge/Swelling
Collapsible	Comet Structure	Continuous Block
Hand Fan	Flat-Pack	Genealogical Tower
Hollow	Inflatable	Locked String or Rope (Knot/Knit/Weave)
Nervous System	Log Joint	Locked Cushion (Knot/Knit/Weave)
Cobweb	Peeled Surface	Bulge Surface
Revolving Bundle	Stack Body	Stack Bar
Stack Surface	Street Pattern Tower	Stud Surface
Swollen Bar	Transformed Uniform Grid	Transformed Non-Uniform Grid
Wiggle	Transformed Body	Wave Surface
Origami	Space Truss	Shaft to Blade
Reinforcement	Mobius Loop	Tensegrity Bar
Brush Stroke	Coil	Modular
Illusion	Spiral	Twist
Playful	Reduce-Reuse-Recycle	Multifunctional
Fiber	Myriapoda	Cocoon/Pod
Extension	Contradiction	Technology
Art and Craft	Roll	Sculpture
Posture	Cord	Nest
3D Print	Hammock	Grow
Spring	Grow	Suspended

1. Design heuristic number
2. Design heuristic name
3. An abstract representation of the design heuristic through illustration
4. Design heuristic description
5. Instructions for designers
6. Real examples associated with the heuristics.

13.4 Effectiveness of DHfFD

After the development of design heuristics for furniture design, the effectiveness of the heuristics was assessed in a controlled experiment with 18 sophomore design students (12 male and 6 female) in the Department of Design, Indian Institute of Technology Guwahati. It was a correlational study to check the impact of design heuristics for furniture design on more number of ideas generation.

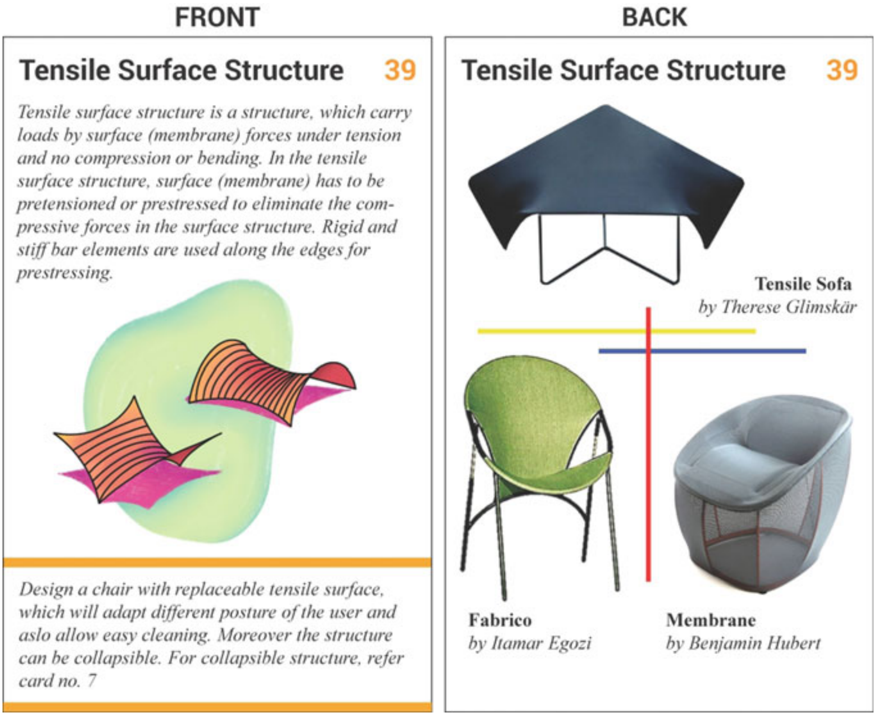


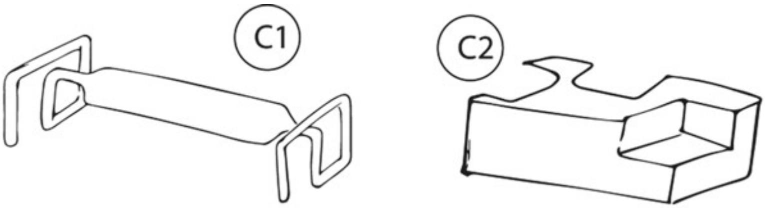
Fig. 13.6 Example: DHfFD card tensile surface structure

The session was initiated with a 15 min introduction to the design heuristics for furniture design followed by a task for 30 min for the experimental group. Both the experimental group and the control group had 9 participants (6 males and 3 females). The control group was not introduced to the heuristics card set.

An open-ended task had been given to the students and asked to generate as many concepts as possible within 30 min.

Brief: Design as many as possible indoor chairs for urban housing. There is no constraint of cost, material, and process.

In the allotted 30 min time, the control group produced an average of 4 concepts per participant, where the maximum concept generated by a participant is 6 and the minimum concept generated by a participant is 2. On the other hand, the experimental group produced an average of 8 concepts per participant, where the maximum concept generated by a participant is 12 and the minimum concept generated by a participant is 5. This difference is significant. The use of design heuristics was evident in the experimental group. Figure 13.7 shows two conceptual design, in which heuristic application is evident and claimed by the student.



The chair used a transformation of the shaft into flat blade like boat paddle. *Heuristics No. 36* *Heuristics Name: Staft to blade*	The chair referred in the image is a body transformed by altering more of its dimensions using the principle of addition, subtraction *Heuristics No. 32* *Heuristics Name: Transformed Body*

Fig. 13.7 Evidence of DHfFD in the design solution produced by students

13.5 Conclusion

This research study analyzed 650 existing chairs and extracted 66 heuristics developed a set of design heuristics for furniture design, with special emphasis to chair design. The main contribution of the study is the development of design heuristics card set for furniture design, which is one of its kind. As it is difficult to recognize for a designer their own implicit cognitive approaches to train novice designers, this heuristics card set would help novice designers to generate concepts in furniture design. The effectiveness of the heuristics card set in comparison with other concept generation tools would be checked in future. The testing for the effectiveness did not consider the creativity aspect of the concepts generated by the students. In future, creativity and functionality aspects also would be considered and a correlational study would be carried out.

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Chapter 14
Effect of Persona Stereotyping on Design Solutions: Observations from an Empirical Study with Novice Designers

Abhishek Dahiya and Jyoti Kumar

Abstract Persona is widely used in the design industry as a tool to understand and empathize with the users. Personas are intended to help designers by providing them useful user information and more importantly helping them remove the personal bias toward their users. However, without proper training and education, the information given in the persona could be misleading resulting in designers not appreciating the benefits of the tool. Such behavior could not only fail the actual purpose of creating a persona but can also be misleading to designers while taking crucial design decisions. With the increase in the number of young designers joining design academics and industry in India, it becomes important to investigate design behavior of novice designers while working with such tools in the design process. This paper presents observations from an empirical study done with 80 novice designers. The study aimed to investigate how user information presented in the form of a persona affects the conceptual design solutions produced by a novice designer.

14.1 Introduction

The advent of user-centered design has advocated the need to understand the users before designing [1]. Hence, user research has become a crucial part of the design process [2]. Various user-research tools and techniques have been developed that can help bridge the gap in mental models between users and designers [3]. Persona is one of the user research and design tools which is widely used in the industry. This tool is not only helpful in user-research and presenting user information but also reported as a useful tool to empathize with the users [4]. This important quality of

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A. Chakrabarti et al. (eds.), *Design for Tomorrow–Volume 3*,
Smart Innovation, Systems and Technologies 223,
https://doi.org/10.1007/978-981-16-0084-5_14

a persona helps designers to look and understand the design situation from multiple perspectives.

Design tools such as persona are also getting fair recognition in the design academics as various design courses are including these tools in their course content. Design students are also picking up to learn these 'quick tools' to include them in their design projects. However, in absence of proper training of using persona, designers could not appreciate the benefits of using persona to assist in the design process [5]. This paper aims to investigate the effect of information provided in persona to on design concepts. This paper reports findings from an empirical study done on novice designers to observe the effect of persona information on conceptual design solutions.

14.2 Background

14.2.1 Persona in Design

Persona is a brief description of a user that is created to help designers to get an idea about their users. The information given in a persona is based on user research. Hence, it is a cumulative representation of user data in the form of a fictional user. Literature defines persona as a "fictional, detailed archetypal characters that represent distinct groupings of behaviors, goals and motivations observed and identified during the research phase" [6] or "abstractions of groups of real consumers who share common characteristics and needs" [4]. Typically, a persona includes a user's demographic details like name, age, gender, photograph, etc., skills and knowledge, motivations, psychographic details like personality traits, values, and attitudes. Providing user information through persona helps designers in explicitize user data among design teams [7] and generating empathy among designers for their users [8].

According to Cooper [9], the ability of human beings to predict behavior and mental conditions of other human beings helps them envisage how people will behave and respond in any situation [10]. Persona as a user-understanding tool is based on the fact that people tend to characterize other people in terms of traits: these traits are broad dispositions that predict or explain much of people's behavior. It is further argued that "actions and behaviors are predicted by building an internal model of the person. This ability to engage with models of real people is also applicable to the models of fictional people" (in this case, personas) and, therefore, working with persona can be as realistic as working with real users [10].

14.2.2 Social Categorization or Stereotyping

Investigations in social psychology have reported that act of knowing or understanding the other is not simply adding the bits of information received about the person together. Rather, it involves constructing meaning based on their ideas about how different personality characteristics tend to go together [11]. Parkinson defines social perception as "a study which focuses on how we as social perceivers form impressions of other people, and how we combine information about them into a coherent overall picture" [11]. Social stereotyping occurs when we try to put people into categories based on our judgments or perception about the person. The judgments can be made through physical attributes like age, skin color, clothes, voice, or behavioral attributes like gestures, tone of voice, walking style, etc. [12, 13]. Stereotyping is helpful as it reduces the amount of thinking or processing that needs to be done in order to understand the other [14]. However, it is argued that stereotypes are a special case of interpersonal perception and are often inaccurate [15]. This is due to the fact that stereotyping is based on selective recall and reinterpretation of information from an individual's past experiences.

Fiske [16] explained how people categorize others on the basis of observed attributes. It is argued that, people first try to categorize a new person. Then the perceiver checks if the observed attributes of the person and the attributes of the category stored in his/her memory are corresponding or not. After this, the perceiver makes a judgement about the category and its accompanying attributes. "*The informational conditions under which categorization will be more successful are those in which (a) the available attributes cue an appropriate category in memory, (b) the available attributes fit a category label that is also available, or(c) the label is the only information available (and is presumed to be accurate)*" [16]. Hence, stereotyping is primarily accompanied by the attributes perceived about the other person.

14.2.3 Persona and Stereotyping

The authors posit that although persona in design is helpful in many ways, yet information presented in persona lead designers to attribute and stereotype their users [17]. Due to this, designers may unintentionally end up making false judgements about their users. This is due to the very nature of a persona that increases the possibility of stereotyping effect. Following are some reasons why presenting user information through a persona can present higher possibilities of stereotyping effect:

1. Information in a persona is never complete: According to causal schema theory, people take shortcuts to inferential conclusions when information about the other is limited. The missing information in the brain is mostly filled up by assumptions that are based on prior experiences. Persona presents very limited information about a user and so the chances for a designer to assume and make

judgements are increased [11]. For example, a personality trait like ambition provides a wide range of interpretation by the reader.

2. Nature of information in a persona: Typical information in a persona includes demographic details like name, age, gender, photograph, etc., skills and knowledge, motivations, psychographic details like personality traits, values, attitudes, etc. Literature reports that stereotyping effects are observed through visually perceptible sources like race, gender, and age, clothing style [13, 18]. Further, words used to describe personality traits like “warm”, “ambitious”, “competent”, “introvert” can help a person to make judgements about the person [11]. Hence, the type of user information presented in a persona acts as a favorable stimulus for stereotyping.
3. Emphasis on thinking about the person: The information presented in a persona never presents a complete information about the user. The designers are suggested to use the given information and try to think like their users. The emphasis on thinking more about the users with only limited factual data about the person may give rise to social attribution. Attribution is the process of inferring the causes of events or behaviors [11] Attribution is an integral part of human visual perception that uses information held in memory for making judgements [14]. Hence, a deliberate effort to find the causality of a user’s behavior is one of the frequent things that designers do with a persona.

This paper aims to investigate how novice designers use information in a persona in their design. The empirical study presented in this paper reports indication of stereotyping effect of persona that influences the conceptual design solutions produced.

14.3 Empirical Study with Novice Designers

14.3.1 Methodology

Participants were given two graphical design problems, one after the other, along with persona of the user for each design problem. They were first asked to thoroughly read the given persona. Then the participants were asked to create conceptual design solutions. Conceptual design solutions produced by the participants along with written explanations about their design followed by a questionnaire were recorded to analyze the effect of persona stereotyping on design solutions.

14.3.2 Participants

Participants were graduate students with different educational backgrounds like engineering, architecture, and fashion design. A total of 80 students participated in the study. Participants constituted 53 males and 27 females with age ranges between: 22–27 yrs. (average age: 25.3 yrs., Std. dev.: 1.23 yrs.).

14.3.3 Persona Description

Participants were given persona description before briefing them the design task. This was to ensure that participants should not carry prior biases or fixations in their design. Providing persona description after the design task might increase the chances that participants would carry their initial concepts and ideas forward into the design solutions. Persona description was made through several iterations on the contents to make it as realistic as possible. Persona included a text describing about the user's demographics, interests, hobbies, habits, work profile, and family background. The personas provided to the participants are given below. Two personas were used instead of one with an aim to cross validate influence of specific elements of persona on designers' design thinking. The two persona created were almost similar in their description structure, but different in content of information.

Persona 1: *Suchitra Basin is 29-year-old girl in Kanpur. She is a school teacher (6–8th class Mathematics) and stays with her husband, who is an entrepreneur, and her in-laws. Suchitra also takes evening tuitions at her home for children as a top up for her meagre salary. Suchitra enjoys reading and writing and she is also interested in cooking. Often she invites relatives for get together at her home and enjoys testing new recipes with them.*

Persona 2: *Pallavi Sharma is 32-year-old Delhi girl. She is a dietitian and part time gym instructor. She got married 4 years ago. She has a son who is about to be 3 in a month's time. She lives with her husband who works in an IT company in NOIDA (close to Delhi). Pallavi had been sports enthusiast since her childhood and won many state level prizes in tennis and basketball during her school and college years. Pallavi smartly balances her home and professional life. Pallavi is also passionate about travelling in general and off road biking in particular*.

14.3.4 Design Task

The participants were given design the design task on a printed slip. The task was to design a "graphical composition for smart phone back cover" for the given persona. For the composition, the participants were asked to use white stickers of basic shapes. Cutting, folding the stickers was not allowed. However, the participants were free to sketch over the stickers. The idea of providing limited number of shapes was to minimize individual differences in ability of sketching/drawing. All participants were given equal set of materials required for the task. Participants were instructed to use only the provided materials only for final solution. Materials provided to the participants were: (1) Persona description and design problem with instructions, (2) A4 size template of smart phone back cover, (3) Stickers: 24 circles, 12 squares, 6 rectangles, 6 rounded rectangles, 6 trapeziums, and 6 triangles of various sizes, (4) Rough sheets, (5) Sketch pens, (6) Pencil, eraser, and cutter.

14.3.5 Procedure

Participants were given an isolated desk in a room which was free from any visual cues relevant to problem at hand. It was ensured that the experiment room is free from visual and auditory disturbances. Participants were first given Persona 1 to read followed by design task followed by instructions. A total time of 30 min was given to the participants for completing the first design task. Next, participants were given a break of 15 min before providing them the Persona 2 and the second design task. The participants were not allowed to use of any sources of inspiration like pictures form Internet, magazines, books, etc., while designing the graphical composition. After the design task, participants were given 10 min to fill the questionnaire and explain their design concepts in a written paragraph.

14.3.6 Observations and Results

Figure 14.1 shows example of graphical compositions designed by the participants for Pallavi and analysis method. The compositions were generally graphical depictions of interests of the users and their nature. The graphical designs were analyzed using NVivo software. The designs were first coded on the basis of their graphical depiction. For coding in the software, various nodes (e.g., hobbies, profession, personality, etc.) and sub-nodes (sports, cooking, travel, writing, etc.) were created. Every design

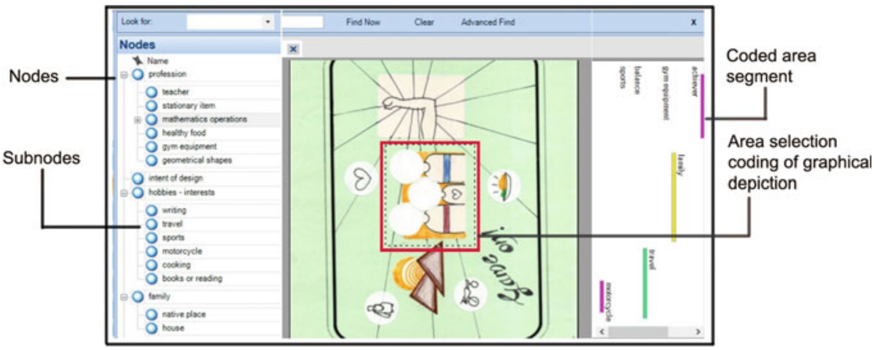

Fig. 14.1 Example of qualitative analysis method using NVivo

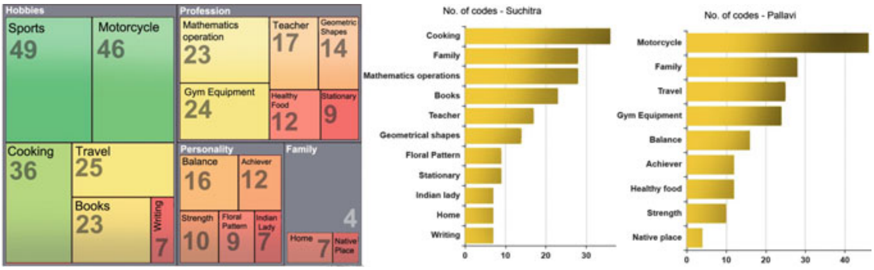

Fig. 14.2 Tree map for the number of coded elements in the design compositions for Pallavi and Suchitra (left), bar-charts for number of coded element for individual users (right)

composition was analyzed and coded against the respective node. The authors were interested in observing what type of user information do the designers use to create the design for their users and how do they use them.

Figure 14.2 (left) shows a tree map for the number of coded elements in the design. It was observed that designers were mostly (50%) interested in depicting hobbies that were given in the persona text. Another major area that interested designers to depict was user's profession and artefacts related to user's profession. Almost 25% of the coded graphical depictions were related to user's profession. Around 15% of the coded graphical depictions were related to user's personality. Figure 14.2 (right) shows bar-charts for number of coded element for individual users. Most of the graphical depictions for Suchitra included 'Cooking', 'Family', 'Mathematical operations', 'Books', 'Teacher', and 'Geometric shapes'. While for Pallavi the graphical depictions were mainly composed of 'motorcycle', 'Family', 'Travel', 'Gym Equipments', 'Balance', 'Achiever', and 'Healthy food'. The authors were also interested in knowing about what do the participants feel about their design. Hence, after designers were done with creating both design compositions, they were asked to fill a short questionnaire related to their design.

Table 14.1 shows questionnaire responses given by the participants. Most of the participants (67.4%) agreed that the persona given with the problem description reminded them of someone they know. This is important because it indicates that the participants already had an image of a person like the user and therefore attributes can have a basis from self-experience. Designers agreed that they are good in predicting what others will like (61.3%) and that they can tell the food preferences of the given users (60%). Most of the designers (61.3%) liked their work in their work and were confident that their users will not only like the design but also understand the thought that they have put into their design. Designers also indicated that their work is exclusive of their users which means that they are not comfortable with switching the designs among the users. The response corresponded with the last question where most of the participants (52.5%) agreed that both users were very different in their aesthetic taste.

Table 14.1 Results of questionnaire responses given by the participants

	Strongly disagree	Slightly disagree	Neutral	Slightly agree	Strongly agree
At least one of the given persona remind me of someone I know	2(2.5%)	5(6.3%)	1(1.3%)	18(22.5%)	54(67.4%)
I am not sure whether my users will like my design	20(25%)	45(56.3%)	3(3.8%)	9(11.3%)	3(3.8%)
I also like the designs that I have created for my users	4(5%)	5(6.3%)	1(1.3%)	21(27.5%)	49(61.3%)
If my designs are switched between the users, both will still like it	15(56.3%)	13(16.3%)	1(1.3%)	19(23.8%)	2(2.5%)
I am generally good at predicting what others will like	5(6.3%)	3(3.8%)	1(1.3%)	49(61.3%)	22(27.5%)
I don't think that my users will understand the thought that I have put in my design	46(58.2%)	22(27.8%)	1(1.3%)	6(7.6%)	4(5.1%)
I think I can tell the food preferences of the given users	4(5%)	6(7.5%)	4(5%)	18(22.5%)	48(60%)
Both the users are very similar in their aesthetic taste	42(52.5%)	27(33.8%)	3(2.5%)	4(5%)	5(6.3%)

Designers were asked to explain the thought behind design and how did the user information help them. The explanation was to be submitted in a paragraph format with not more than 200 words. Responses from all 80 participants were transcribed into text and were qualitatively analyzed in NVivo. The transcripts were analyzed to understand the personality attributes drawn by the participants from the persona and the subsequently what design approach did they used. The transcripts were coded and content was analyzed.

Figure 14.3 (left) shows an example of a word-tree diagram for one of the persona created using the software. The diagram is helpful in understanding what participants thought of the users. The highlighted stripes over the text of the diagram indicate

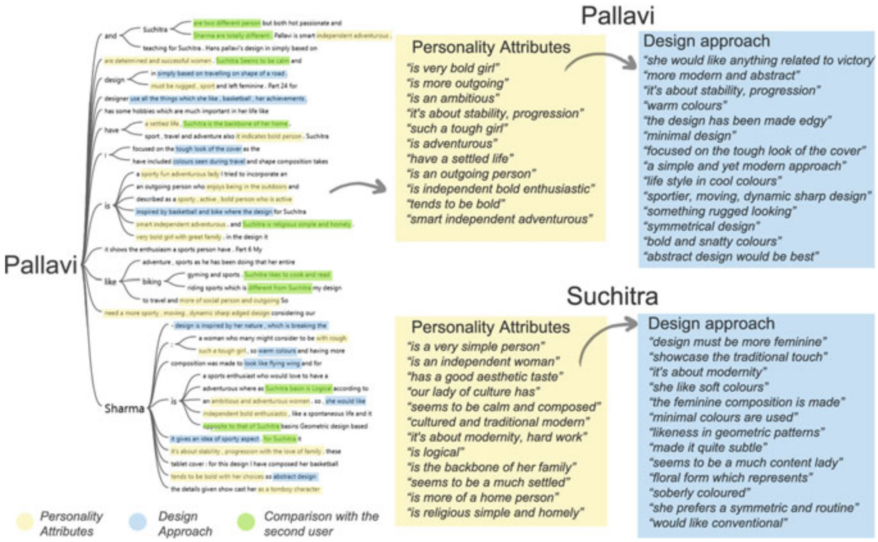

Fig. 14.3 Word tree diagram for Pallavi and coded segments (left), examples of personality attributes and design approach as explained by the participants

coded segments. Figure 14.3 (right) shows some examples of phrases that indicate personality attributes of the users, as reported by the participants and the design approach taken. The authors were interested in knowing the variety of attributes that were participants drew after reading the persona. Therefore, the attributes reported by the participants that were close to the words written in the persona description like "sporty" (for the word 'sport'), "traveler" (for 'traveling'), etc., were excluded.

As shown in Fig. 14.3, For Pallavi, personality attributes like "bold, "tough", "ambitious", "adventurous", "independent", "outgoing", "enthusiastic", etc., were reported by the participants. Analyzing the design approach taken by the participants to create graphics for Pallavi, words like "dynamic", "abstract", "rugged", "edgy", "modern", "sporty", "tough", etc., were frequently reported in the design description. Similarly, for Suchitra, the personality attributes reported by the participants included words like "simple", "calm and composed", "cultured", "traditional", "settled", "religious", "logical", etc. As reported by the participants, the design approach for a graphical composition for Suchitra included words like "feminine", "geometric", "traditional", "soft", "sober", "conventional", "subtle", "floral", etc. While most of the words used by the participants to describe the attributes and design approach were opposite for Pallavi and Suchitra. Some words like "independent", "modern", "settled" as an attribute were used for both the users. Similarly, words like "minimal", symmetrical" were used in describing the design approach for both the users. The observations and results are discussed further in the next section.

14.4 Discussions

Design industry has witnessed a rapid growth in the number of design and user-research tools and techniques in last few decades. These tools are helpful in making design process more swift yet rigorous. With the increase in number of design schools in India, a number of young designers are joining the design industry. It becomes necessary to understand how novice designers use these modern design tools in their design thinking process. It was observed during the research reported in this paper that the information given in persona does not necessarily create an objective impression of the target user rather there were tendencies in the novice designers to make assumptions about their users often using stereotypes from their own personal experiences. Study results indicate that novice designers when asked to work with a persona tend to focus more on 'direct representation of user information' in their design. Most of the design concepts produced were mere graphical illustrations of the words and phrases used in the persona. Results from the questionnaire collected after the design activity also indicated stereotyping effect. Qualitative analysis of design descriptions given by the designers showed observable instances of stereotyping effect. Designers were frequently describing many personality attributes that they thought the user must be having even though the basis of such confidence was not form the person description but rather form the prior personal experiences of meeting 'similar' persons. Many of these 'imaginary' and 'stereotyped' persona were found to be basis for their design decisions. The authors therefore argue here that it may not be sufficient to provide the persona to a designer, but the necessary exposure to user and training to use persona in an unbiased way will also be required. It is suggested here that of the designers who are involved in designing themselves do the required research to create the persona it may be a step toward removing this bias. Though the purpose of creating a persona is to provide aid to imagination of the designer's design thinking process for a given problem, the 'stereotyping' based on one's prior experience rather than the research information on the intended user group will create shortcomings in the solution. Therefore, this paper argues that if the designers are exposed to the user personally during user-research phase of the user-centered design process, it may take care of the personal biases. Further, appropriate training to the designer using the persona description can possibly aid the designer to take care of their personal biases leading to 'stereotyping'.

14.5 Limitations and Future Work

The paper talks about how stereotyping through persona can affect conceptual design solutions produced by novice designers. Both stereotyping and design thinking are very broad areas of research. The empirical study conducted to observe one's effect over the other is a very basic attempt as compared to the question that the authors are raising. The study lacks various explanations like how stereotyping occurs in human brain, what methods of user data presentation are more susceptible to stereotyping, how stereotyping affects the thinking process of a designer, etc. To investigate further in this area, deeper observations on how expert or experienced designers use persona information could be an area of research. Further, this study is limited to only graphical design problem. Therefore, a range of design problems studying the effect could be explored.

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Part II
Design for X (Safety, Manufacture & Assembly, Cost, Reliability, Robustness, Social Interaction, etc.)

Chapter 15
Multi-inspirational Design for Additively Manufacturable Products

Pritam P. Shetty, G. Krupakhar, and Jayachandra Bingi

Abstract The additively manufacturable products are emerging as a part of modern product revolution and innovation. This paper discusses the application of bio-inspired design in making the additively manufacturable spin coater as a case study. As a part of this, the method called multi-inspirational design for additive manufacturing (MiDAM) is proposed. The application of method is resulted in the additively manufacturable, low cost and affordable spin coater, with scope for tunable resonance vibration just by varying the dimensional and material parameters. The possibility for installing the dampers in the designed form contributes to better vibration isolation, still maintaining the aesthetic appearance. Further, the work shows the possibility of exploiting the bio-inspired design to support additive manufacturing of different products.

15.1 Introduction

The morphological and physiological evolution of life for billions of years gave itself advantage of survival in changing environmental and threat conditions. Hence, the study of biological life in nature can be a never-ending source of inspiration for design and engineering innovations. The literature [1] suggests three ways of introducing nature inspiration into modern product and technology development. First one is bio-inspiration which studies the functions and their working mechanisms and implementing them into product design. Product may just aesthetically resemble its biological counterpart or may only exhibit its features. Second is bio-mimicry, where structural, functional and morphological features of bio-systems are directly

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A. Chakrabarti et al. (eds.), *Design for Tomorrow–Volume 3*,
Smart Innovation, Systems and Technologies 223,
https://doi.org/10.1007/978-981-16-0084-5_15

copied for product development. Occasionally, in research writings, bio-inspiration and bio-mimicry are used in synonymous way when product combines functional traits from both techniques [2]. Third, bio-integration that integrates living biological systems with product, to achieve physical and functional purposes. Some of the commercial products with their form and operations inspired by biological systems are hook and loop fastener "Velcro" [3], hydrophobic coating "HydroFoe," robot dog "Spot mini," aerodynamic shape of Shinkansen, dry adhesive material "Sheargrip." It is observed that different works considered the single bio-system as an inspiration depending on their requirements.

On the other hand, additive manufacturing (AM) is becoming significant, especially fused deposition modeling (FDM) 3D printing, due to drastic reduction in cost and ease of availability of equipment. AM can give advantage over conventional manufacturing of products with respect to rapid prototyping, fabrication of complex geometry, efficiency, wastage reduction and product lead time [4, 5]. Moreover, most 3D printing materials, e.g., PLA, PETG and ABS can be recycled by re-extrusion method allowing development of sustainable products [4]. But, while product manufacturing is switching from conventional to additive manufacturing, the general problems are related to form, structure and functional inconsistencies. In this regard, bio-inspiration not only gives the advantage of variety of forms and structures for a particular product but also facilitates functional improvements. Complicated natural structures can easily be engineered by 3D printing which complements the bio-inspired design process [5]. Therefore, bio-inspiration shows the way for switching the manufacturing from conventional to additive. There is no successful framework defined to apply bio-inspired design for additively manufacturable product. Most of the proposed frameworks are used to make concept structures or virtual design, and none was applied to realize a complete product [6, 7].

Hence, *bio-inspired design assisted additive manufacturability (of different products) appears to be the potential topic of research in industry perspective.*

This research considers the spin coater, which is used to coat thin film layers, as our product case. Here, we propose and apply a simple and easy framework named as "multi-inspirational design for additive manufacturing (MiDAM)" to develop an additively manufacturable spin coater. The process flow of the framework is "defining, analyzing, comparing, linking and developing" which successfully bridge the correlation between bio-systems and our product of interest. At the same time, it considers the shape and material complexity for the effective 3D printing of parts. There are numerous homemade spin coaters developed by low cost strategies reported in the literature [8–12], though they are functional but none appears aesthetically pleasing and can be commercialized. Hence, we apply MiDAM to develop structurally appealing, functional and fully 3d printable body for spin coater.

15.2 Results and Discussion

15.2.1 Multi-inspirational Design for Additive Manufacturing (MiDAM)

MiDAM is executed in following steps to incorporate bio-inspiration into design of structure and additively manufacture it (Fig. 15.1):

- Important parts/sections of target equipment are identified. In case of spin coater, we identified following part as imperative for operation: body casing, spin drum,

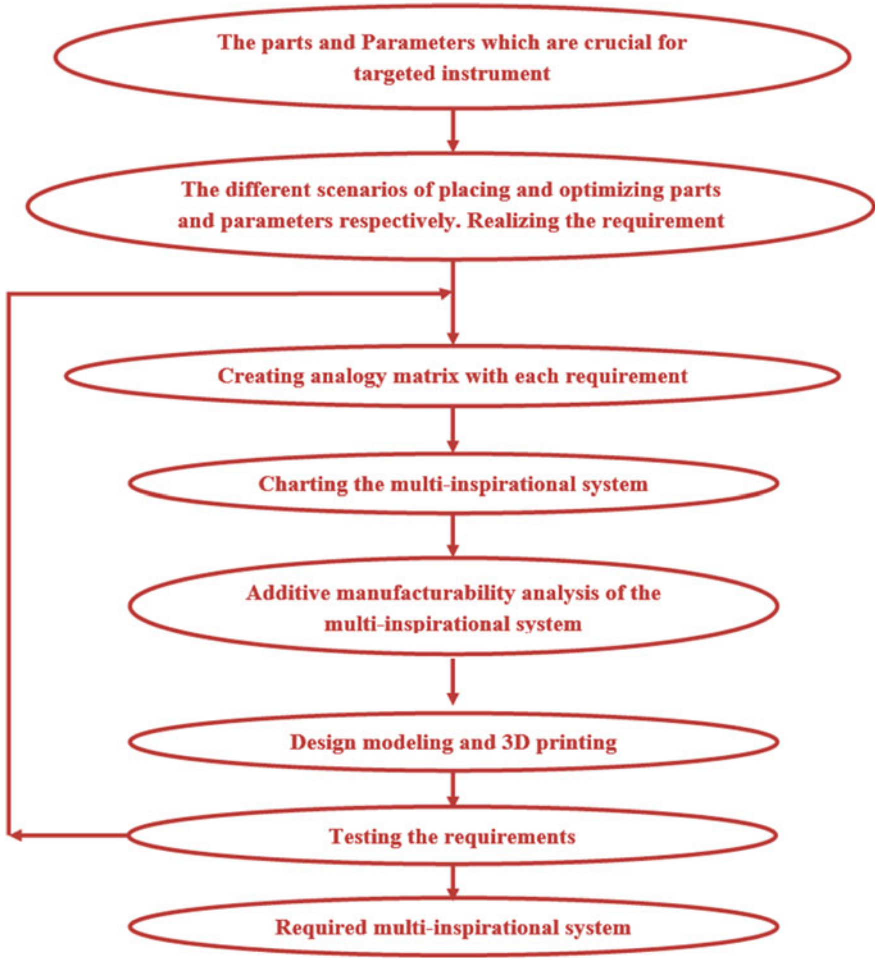

Fig. 15.1 Process flow for multi-inspirational design modeling

sample chuck, base alignment screw, lid with a hole, motor with supporting electronics and controls, vibration isolators.

- Different layouts for part or section arrangement with respect to their functions and suitability are determined. In the case of spin coater, the electronics of the device should be place in the least perturbing area; sample chuck and spin drum should be in concentric cylindrical conformation; body casing should symmetrically support the enclosure with spin drum, sample chuck, electronics and motor, etc., and lid should be placed on spin drum with solution dropping facility; these all sections should be fastened appropriately.

Requirements:

1. Proper alignment of sections
2. Vibration isolation
3. Strategic fastening points
4. Solution channelization
5. Expulsion of excess solution
6. Ease of detachment of spin drum for cleaning.

Hence, in additively manufacturable spin coater, one must have these mentioned sections, and the requirements should be fulfilled. Accordingly, we go for section/requirement-wise bio-inspiration as shown in Table 15.1.

- To design body casing, different animals whose body structure can be scaled and can resemble a multi-legged casing is researched. Tortoise and star fish were found to be eligible for this (Fig. 15.2). Finally, tortoise body was chosen based on ease of design and integration of final structure; the inspired casing will have four legs, and head of the tortoise can be represented as display and input unit.

Inspiration for lid was taken from nature by looking for structure with long neck or converging structural form. *Convolvulus* violet flower has deep groove at center, and mushroom has a long stem (Fig. 15.3). *Convolvulus* violet flower was chosen as inspiration for lid as the wide groove allows solution dispense at an angle and was visually appealing.

Table 15.1 Analogy matrix for MiDAM

Sections/requirements	Suitable analogy	
	1	2
Body casing	Tortoise	Starfish
Spin drum	–	–
Sample chuck/expulsion of excess solution	*Pandanus forsteri* leaf	*Phyllostachys aurea* leaf
Base alignment screw	–	–
Lid with hole/solution channelization	*Convolvulus* flower	Mushroom
Vibration isolator	Octopus suckers	Woodpecker skull bone

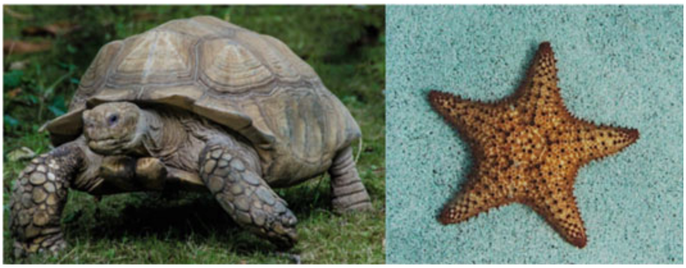

Fig. 15.2 Tortoise [13] at left and starfish [14] at right

Fig. 15.3 *Convolvulus* violet flower [15] at left and mushroom [16] right

Spin coater developed in this research needs vacuum less sample chuck. This chuck contains a recess at center to hold sample in place. It also needs a channel for excess solution to escape. Bio-inspiration for the same was found in two plants, i.e., *Pandanus forsteri* and *Phyllostachys aurea* (Fig. 15.4); these plants have some unique properties in its leaves to channelize rain water. In *Pandanus forsteri*, central groove in its leaf allows water to be directed to roots [17]. And *Phyllostachys aurea* has leaves with a combination of hydrophilic and hydrophobic surfaces to channelize water [18]. By taking inspiration from Pandanus forsteri, grooves were strategically incorporated into sample chuck design.

Horizontal alignment and vibration isolation of spin coater are very crucial for good quality film deposition. Vibration in spin coater is generated from the high-speed rotation of motor. Octopus feet suckers (Fig. 15.5a) are found to have good gripping strength but have no capability of vibration absorption, whereas woodpeckers have a special bone in skull at the region between brain and beak which is porous and spongy [19] (Fig. 15.5b). This soft porous nature of bone isolates vibration generated by woodpeckers' action of rigorous digging using beak, and its brain is protected.

Fig. 15.4 *Pandanus forsteri* (left) [17] and *Phyllostachys aurea* (right) [18]

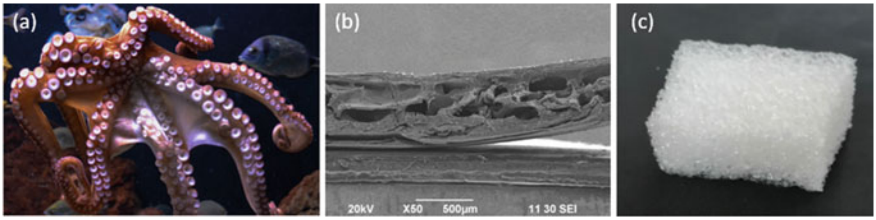

Fig. 15.5 **a** Octopus feet suckers [20], **b** wood pecker skull bone with porous spongy bone [19] and **c** packaging foam with similar porous structure

Here, porous nature of skull bone of woodpecker is taken as an inspiration for vibration control and packaging foam (Fig. 15.5c) was identified as cheapest and easily available material having porosity.

- All 3D components were modeled in Autodesk Fusion 360, and Ultimaker Cura was used as slicing software for generating GCODE for 3D printer. 3D printing of parts was carried out in Anycubic Kossel 3D printer (Liner plus) with build volume of 230 $\times$ 230 $\times$ 300 mm. Components were designed in a way that can be easily printed in most common 3D printers with build area greater than or equal to 200 $\times$ 200 mm. 3D printing was carried out using poly lactic acid (PLA) filament. The whole body of spin coater was divided into nine components, and only bio-inspired components are shown in Fig. 15.6, i.e., (a) leg, (b) lid, (c) vibration isolation shoe, (d) electronics enclosure, (e) spin drum, (f) display and control panel and vacuum less chuck, chuck holder, collar are not shown.

Unlike bio-mimicry where one has to exactly copy the structural design in nature based on size and morphology. Bio-inspired design gives flexibility to change the design and further enhance it based on aesthetic or functional needs. Before designing the model of the proposed product, designer has to consider its overall volume or

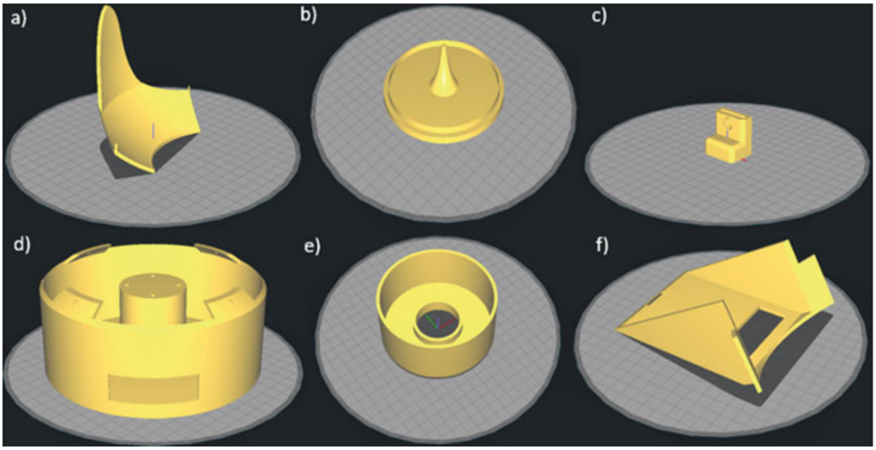

Fig. 15.6 Orientation of parts on 3D printer build plate to avoid more support structures and get good surface finish

size, which further depends on factors like need for portability, electronics encased within it and its functional aspects. In our work, we found that size of the electronics enclosure (Fig. 15.6d) would decide the final volume of the spin coater as it accommodates important electronic components like brushless DC motor, driver and control circuitry. Due to limited build area of 230 × 230 mm, dimensions of electronics enclosure were restricted to less than 200 × 200 mm.

Considering all these attributes, it was decided to design electronics enclosure with a toroidal space to hold circuitry, wiring and a post at the center to hold brushless direct current (BLDC) motor. Also size of the overall parts which are too big to 3D print can be designed symmetrically along with bio-inspired aspects and can be divided into small 3D printable parts based on symmetry. Here, the supporting leg of spin coater inspired by tortoise was found to be too big to be directly 3D printed; hence, it was 3D printed after dividing into four symmetric parts as shown in Fig. 15.6a. Later, instant glue is used to stick four parts together. Likewise, packaging foam was cut into cuboids shape of desired dimensions and glued to base of vibration isolation shoe (Fig. 15.6c). All the components are modeled for minimal to no need for support structure for 3D printing allowing good quality of print and minimal wastage of printing material. After 3D printing, some parts may require post-processing like sanding for smoothening surface and drilling for screw fastening. All these factors which was considered for additive manufacturing of parts for spin coater can be easily extended for any part design for products. Final assembled spin coater is as shown in Fig. 15.7.

- Testing of spin coater is done by evaluating two aspects, i.e., speed response for a given user input and vibration characteristics. User interface of the spin coater asks operator for two inputs, i.e., speed constant and spin time. Speed constant is a value ranging from 1050 to 1500; here, each value corresponds to constant

Fig. 15.7 Fully 3D printed spin coater at different views

RPM rotation of BLDC motor. Figure 15.8(b) shows good linearity of input speed constant with measured RPM of the BLDC motor allowing calibration for required RPM. As shown in Fig. 15.8a, even though there is a good linearity in spin speed up to 7000 RPM, it is restricted to 4000 RPM from user interface. Since above that speed, vibration was high for normal operation.

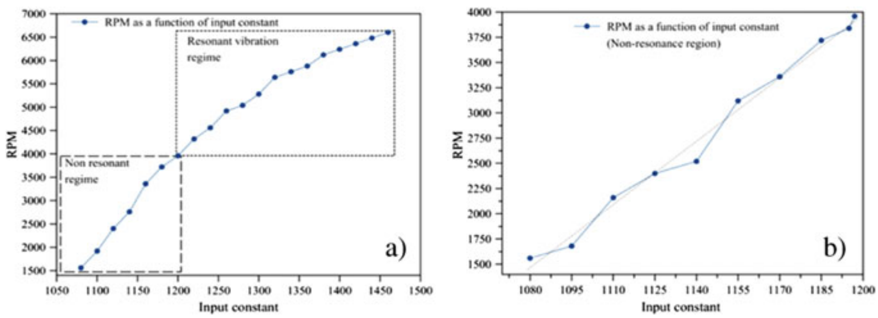

Fig. 15.8 **a** Plot of user input constant versus spin RPM showing resonant and non-resonant regime, **b** plot of user input constant versus spin RPM showing good linearity

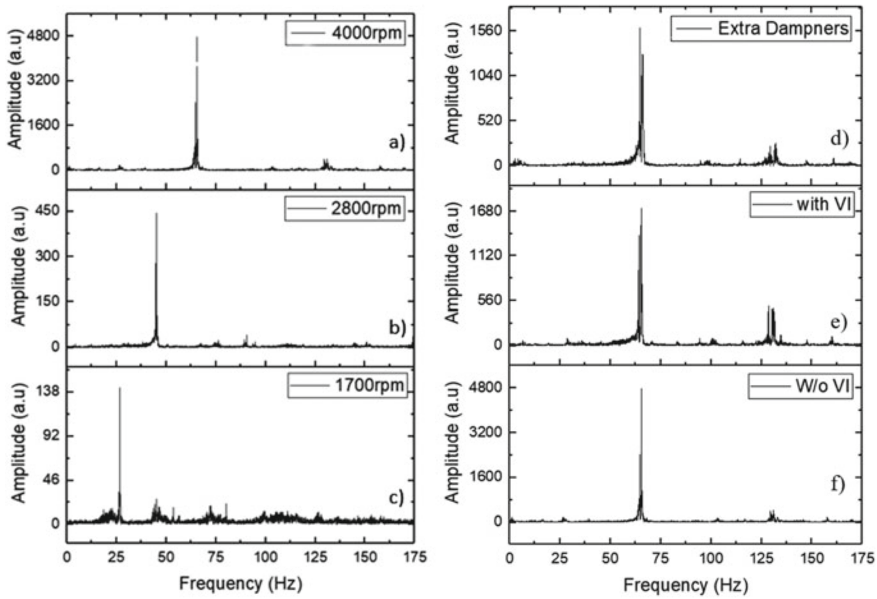

Fig. 15.9 **a**–**c** Frequency spectrum of spin coater by taking FFT of vibration amplitude in time domain for different spin RPM without vibration isolation shoe at 4000 RPM, 2800 RPM, 1700 RPM. **d**–**f** Vibration frequency spectrum of spin coater at 4000 RPM in different condition with extra dampers, vibration isolation (with VI) shoe and without vibration isolation (W/o VI) shoe

To capture the vibrational data of the spin coater during the operation, three-axis accelerometer sensor MPU-6050 coupled with microcontroller is used. This sensor was attached to the body of the spin coater. Fast Fourier transform was applied to the vibrational amplitude data to get the frequency spectrum of vibration. It is evident from Fig. 15.9a–c that magnitude of vibration is increasing with RPM of BLDC motor without vibration isolation. Additionally, frequency of vibration was found to increase with RPM of motor and resonance occurs near natural frequency of structure causing a spike in vibration amplitude at around 4000 RPM.

After attaching vibration isolation shoe, vibration amplitude at 65 Hz frequency was reduced by 64% at 4000 RPM (Fig. 15.9e). This demonstrated successful application of bio-inspired analogy of wood pecker for vibration suppression. To further check the possibility to reduce vibration, packaging foam was stuffed into the openings between legs and electronics enclosure. Again, vibration characteristics at 4000 RPM were studied. It was found that vibration amplitude (Fig. 15.9d) was further reduced by 2.4% indicating a scope for vibration reduction by incorporating design changes. Moreover, unlike other manufacturing techniques like injection molding and CNC milling where changes in prototype is difficult to incorporate and expensive, AM has advantage for manipulating design easily at CAD level. Designer can make the prototype again until desired characteristics of product are achieved while keeping cost of prototyping low.

15.3 Conclusion

In summary, the multi-inspirational design for additive manufacturing (MiDAM) framework is applied in spin coater as case study. This resulted in the spin coater which is additively manufacturable completely. The testing confirms the good working condition of the device with reduced vibration. In conclusion, this work opens the possibility for making different products additively manufacturable with the support of bio-inspired design.

Acknowledgements Authors would like to acknowledge help extended by Ms. Hemalatha V. for data acquisition.

This work was supported by the DST-SERB under Grant ECR/2017/001462; DST-RFBR under Grant INT/RUS/RFBR/P-262.

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Chapter 16
Scope of Improvement in Assembly-line of FMCG Industries through Ergonomic Design

Gurdeep Singh and Sougata Karmakar

Abstract In the industry 4.0 era, the assembly-line work forms the basis of various manufacturing industries, viz. the automotive, the electronic component manufacturing, and the Fast Moving Consumer Goods (FMCG). FMCG assembly-lines are distinct from the automotive and the electronic component manufacturing assembly-lines. These are high paced, and semi-automatic in nature and comprises short-cycled repetitive work. The researchers and engineers have taken several different approaches to improve the assembly-line related work in automotive and electronic component manufacturing industries, from a design and ergonomics perspective. However, very little is known about such design and ergonomic interventions pertaining to FMCG assembly-lines. This paper aims to find out to what extent the same/similar approaches associated with ergonomic design interventions applied in assembly-line work in diverse industrial sectors can be adopted/applied to the FMCG sector to improve productivity and OSH following the state-of-the-art literature review. Hence, the current paper assesses the need and determines the scope of 'Ergonomic Design Interventions' in assembly-line-related work in the FMCG sector. In this paper, authors have emphasized and advocated implementing ergonomic principles in assembly-line work of the FMCG sector in conjunction with productivity enhancement tools/techniques to ensure enhanced OSH and productivity.

16.1 Introduction

Fast Moving Consumer Goods (FMCGs) are generally the low-priced items referred to as consumer-packaged goods/groceries. These are used with a single or limited number of consumption occasions. The FMCG products comprise of three major product segments: food, beverage, and household. Groceries are an essential part of every person's day-to-day life and account for more than half of all consumers'

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A. Chakrabarti et al. (eds.), *Design for Tomorrow–Volume 3*,
Smart Innovation, Systems and Technologies 223,
https://doi.org/10.1007/978-981-16-0084-5_16

spending [1]. FMCG industries' production process typically involves a single-production stage followed by the packing of final products; thus alternatively, known as the 'make-and-pack' industry. Many highly paced assembly-lines commissioned and installed parallelly on a single-production floor are distinct features of FMCG manufacturing unit. On such shop-floors, there is the tendency toward more flow production, where products flow piece-by-piece from one station to the next [2–4]. Work-related MusculoSkeletal Disorders (WMSDs) are common occupational diseases among assembly workers worldwide due to repetitive motions or heavy workloads [5, 6]. The occupation of the assembly-line operator is associated with above-average ergonomic risks [7]. Several studies of assembly operators in different countries indeed confirm high prevalence rates of WMSDs [8, 9]. Essentially, the assembly-line forms the inevitable feature of industries like automotive, electronic component manufacturing, and FMCG. Contrary to the assembly-lines of other sectors, FMCG assembly-lines are generally high-paced, comprising short-cycle repetitive work and are parallelly arranged with workstations spread across both sides of the assembly line. Continuous improvement activities (Kaizens) are being carried out by engineers in such industries to remain competitive and achieve production/operation excellence [10]. Presently, most of the information about assembly-line related work is drawn from the automotive industries. Much of these researches focus on implementing lean principles in assembly-line activities, oriented toward production/operation excellence, and often ignore basic fundamental ergonomics principles [11]. Ignoring and neglecting ergonomic principles result in the non-realization of deriving the full benefits from these approaches, which could have been fetched if the ergonomic design principles would have been fully considered in accordance with other technical standards.

Unfortunately, there is a paucity of literature pertaining to ergonomic design interventions in the shop-floor of FMCG industries, explicitly operating in labor-intensive and semi-automatic production set-up, which are engaged in the production of high-volume and low-cost products. Such scenarios result in negatively impacting the Occupational Safety and Health (OSH) of FMCG industrial workers. The current paper aims to find out to what extent the same/similar approaches associated with ergonomic design interventions applied in assembly-line work in diverse industrial sectors can be adopted/applied to the FMCG sector following the state-of-the-art literature review. Hence, for the current review, the following research questions have been raised. (a) What types of approaches have been taken/considered by researchers/engineers to address the ergonomic issues in assembly-line related work in diverse industrial sectors? (b) Which of these approaches can be implemented in FMCG industries, explicitly working in labor-intensive and semi-automatic production set-up?

The intended research goal is especially interesting for industrial engineers, safety engineers, and factory management looking for ergonomic design-related planning to promote better OSH and productivity at their workplaces. This paper can serve as a single useful resource pointing out several different approaches that can be pursued by them, as the information regarding aforesaid topics is discreet and is not well documented or synthesized in a single resource.

16.2 Methodology

A systematic literature search was conducted using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) model. The online databases of Scopus, Web of Science, and various government reports were accessed to shortlist papers/reports using suitable search terminologies associated with different aspects of 'Ergonomics in assembly-line work.' The search was limited to articles in the English language published between the years 1990–2020. After searching online databases, all the collected papers/reports were uploaded into a database manager, and the duplicates were removed. The papers were further screened to include only those that fell within the three broad areas, namely the prevalence of WMSDs in assembly related work, ergonomics in assembly-line related work, and design interventions in assembly-line-related work. Finally, the 52 most relevant articles/reports addressing the current review topic were accessed online for citation purposes in different sections of the present article to cover different dimensions related to the article topic about 'Ergonomics in assembly-line work.'

16.3 Ergonomic Design Interventions in Assembly-line Work

16.3.1 Manufacturing Aspects and Production/Operation Excellence

In the context of Assembly-line related works, the researchers' most prominent work is related to issues concerning Assembly Line Balancing (ALB) [12]. Various approaches toward ALB have been implemented to simultaneously minimize both (cycle times and the ergonomic risks) associated with assembly-line workers. Paramount use of exoskeletons [13], rest allowance evaluations [14], multi-objective optimization algorithms [15], discrete event simulations [16], well-balanced work scheduling [17], etc., are among the various adopted methods for achieving success in ALB-related issues varying upon U-shaped, L-shaped, S-shaped, and I-shaped assembly-line flow. Such techniques are primarily focused on achieving production/operation excellence, and context-specific ergonomic improvements remain secondary and do not provide much-needed support to the workers engaged.

16.3.2 Lean-Manufacturing Principles and Work-standardization Approaches

In addition to the ALB approaches, researchers have also focused on implementing lean-manufacturing principles in assembly-line work systems. They debated its pros and cons among various assembly-line industrial work [18, 19]. Several researchers argued that implementing lean principles in manufacturing improves production efficiency by eliminating unnecessary steps, waste, and error and has been found beneficial for mass production. However, the other researchers argued that lean manufacturing might improve efficiency, but it resulted in other detrimental effects on the operators and workers from an intensification of the work. These researchers remain concerned that working conditions in lean settings lead to adverse employee outcomes [20, 21]. Another debate moves around the impact of the implementation of Total Quality Management (TQM), Just In Time (JIT), inventory control, continuous improvement (Kaizen and Six Sigma), and work standardization. All these are the managerial philosophy-specific guiding principles and goals for enhancing productivity through continuous improvement and waste elimination [22–24]. However, the lesser emphasis is given upon the redesign of assembly workplaces and the redesign of production/logistic processes to reduce inventory/lead-time using various methodical approaches connecting Value Stream Mapping (VSM) and Methods-Time-Measurement (MTM). All these measures would ensure excellence in production/operation in assembly-line work.

16.3.3 Operations, Packaging and Inventory Management

Another major focus area in assembly-line-related work focuses on other operational aspects related to packaging and inventory management issues. Scheduling of production processes in assembly-line-related works is a complex task as these are considered to be multiproduct-oriented industries and prone to frequent portfolio changes occurring with the change in season and consumer preferences, thus requiring higher flexibility [25]. Such works also focus upon research on Stock Keeping Units (SKU) to manage the large volume of packing material, work in progress, and finished goods lying on its production floor [26]. Lots of research in the assembly-line-related industrial sector are focused on packaging and new product development. Particularly, the packaging is a critical marketing tool and an integral part of the product of the FMCG industry; it plays a vital role in consumers' product choices and perceptions and results in increased sales and volumes. FMCG industries use packaging to gain competitive advantage, and it is thus considered as a tool to revitalize their mature products [27, 28]. However, the micro-analysis of the packaging activities like individual carton/case packaging being done manually remains ignored in such industries, and production efficiency is hampered. In the recent years, in the wake of newly introduced concept in manufacturing, Industry 4.0, the FMCG sector laid significant focus on its numerous technologies and associated paradigms, including Radio Frequency Identification (RFID), especially in packaging, Enterprise Resource Planning (ERP), and Internet of Things (IoT) in SKU management and logistics, and social product development [29, 30].

16.3.4 Supply Chain, Logistics and Distribution

Assembly-line-related production operations are notably dependent upon highly efficient supply chain, logistics, and distribution channels. In particular, FMCG products are dependent on highly efficient distribution channels; plenty of research is thus focused on supply chain and distribution-related areas. A thorough analysis of logistics component costs, the characteristics of the products being transported, and providing adequate training and development for people involved in distribution and logistics management are major focus areas of the research being carried on in this area. It helps in minimizing transportation costs while maintaining high service levels. The research focused on warehouse management is also carried out in parallel [31].

16.3.5 Identification and Evaluation of Ergonomic Stressors

Plenty of ergonomics research in assembly-line work focused on identifying and evaluating risk factors associated with prevailing ergonomic stressors in the industrial workplace. In most industries across the globe, among the assembly-line industrial workers, low back pain is the most common reason for days away from work [32]. In the majority of the industrial places dependent upon assembly-line work, repetitive manual labor is a risk factor associated with wrist and hand disorders, such as tendon-related disorders, Carpal Tunnel Syndrome (CTS), and cramping of the hand and forearm [33, 34]. Researchers have further reported that Work-related Upper Extremity (WRUE) symptoms can include pain, tenderness, swelling, numbness, and loss of function in the fingers, hands, forearms, shoulders, upper back, and neck [35]. Other researchers studied the risk associated with sedentary tasks and reported physical inactivity and sedentary behavior, both entail health risks. Physical inactivity, i.e., performing insufficient amounts of moderate-to-vigorous-intensity physical activity, leads to cardiovascular diseases, obesity, depression, type II diabetes, and sometimes cancer [36]. Assessing the risks associated with prolonged standing, researchers pointed out that Plantar Fasciitis is a relatively common foot-related problem in the manufacturing sector [37]. Such findings suggested several options for primary and secondary prevention strategies like shoe rotation and the use of shoe pad cushion to lower the risk of Plantar Fasciitis. Here, it is interesting to note that earlier researchers highlighted the prevalence of various ergonomic stressors and their ill effects on workers. To improve the exiting situations, they have given some recommendations only but have not provided any design interventions as solutions. There is a paucity of literature indicating design interventions as mitigation strategies to counter all such WMSDs issues prevailing on shop-floor across varied industrial sectors.

16.3.6 Occupational Safety and Health (OSH), Accidents/Injuries

Research on OSH issues and accidents/injuries has received less attention in all industrial sectors, especially in assembly-line activities, though these activities remain much prone to use sharp-edged tools, slippery floors, heavy manual load handling, and other horseplay activities. Context-specific OSH issues and hazard identification and elimination aspects related to assembly-line work need to be explored to improve the existing scenarios.

16.3.7 Design Interventions as Mitigating Strategies (Physical and Virtual)

Specifically, the design interventions to improve assembly-line-related work pertaining to workstation design, work accessories design, and furniture design are not readily available. Many other design interventions are witnessed in other manufacturing industries (non-assembly work), which positively affected the prevailing working conditions. Such studies indicated that with the appropriate type of ergonomics, there would be improvements in quality, productivity, working conditions, OSH, reduction of rejects, and overall profit [38, 39]. Several extensive workplace design interventions have been implemented in the USA's poultry division by OSH administration [40]. Some researchers proposed the shop-floor layouts as design intervention to increase productivity; however, these mainly focused on engineering concerns, and ergonomics of the design factors and work environment was least concerned in these interventions [41–43]. Few other researchers adopted another approach to improve the condition of the workplace from ergonomics and design perspectives. They implemented virtual ergonomic analysis using several Digital Human Modeling and Simulation (DHMS) techniques where digital representations of human were inserted into a simulation or virtual environment to facilitate the prediction and safety/performance [44]. Such research has been carried out primarily in the automotive sector using DHMS to improve vehicle design considering various anthropometric data and dimensions [45]. DHM was used in an industry engaged in heater manufacturing. It intended to design an ergonomic workstation and assembly-line for worker safety [46]. Similar software was used in the mattress production unit to improve the mattress production processes by evaluating the operators' visual and postural aspects and, based on that, implementing design ergonomic interventions [47]. However, the use of DHM technology in Industrially Developing Countries (IDCs) is not much prevalent, and scanty literature exists thereof. Within IDCs, Indian researchers successfully deployed context-specific design interventions to improve the working conditions of the Indian chemical conversion coating and injection-molded plastic manufacturing industries using DHM [48, 49]. Several researchers have also pointed out that assembly industries are under a lot of pressure in today's worldwide competition. There is a clear link between workstation design and worker discomfort within these industries [50, 51].

16.4 Research Gaps

Various ergonomics and design-related aspects focusing upon OSH, standardization of work activities, and design ergonomic interventions have been explored in automobile, and electronic component manufacturing industries that deal with less paced activities and high-cost and low-volume products. Many of such vital factors remain unexplored in the FMCG industrial workplaces, which relates to low-cost, high-volume products and highly repetitive short-cycle time work processes. Scanty research has been carried out in FMCG from a design and ergonomics perspective. FMCG research is concentrated on production/operation/management domains, and there is paucity of literature focusing on ergonomics issues in FMCG industries. Various unexplored factors related to assembly-line-related work in FMCG are summarized in the schematic diagram (Fig. 16.1) above and are further discussed in detail.

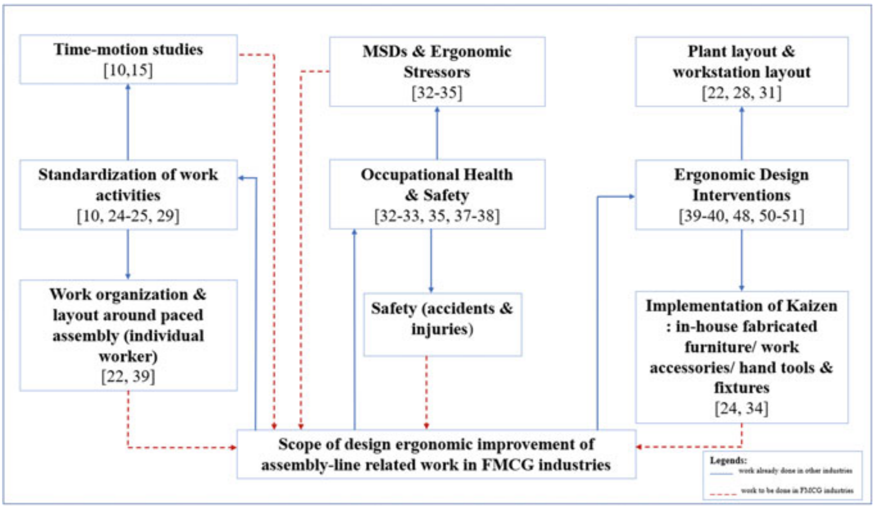

Fig. 16.1 Research gaps: Schematic diagram. *Source* Author

16.4.1 Occupational Health and Safety (OHS) and Ergonomic Issues

The schematic diagram indicates that many researchers have conducted research on investigating the prevalence of several ergonomic stressors and their associated risks in assembly-line related work. Still, little effort has been given to provide design ergonomic interventions as potential solutions to address those WMSDs related problems successfully. Specific ergonomic stressors related to FMCG assembly-line work, viz. prolonged standing, high repetition of upper extremities, long work hours, monotonous job work, man-machine pacing mismatch have rarely been addressed in FMCG industries. Considering an important industrial work-related issue, i.e., industrial accidents, injury rate, worker compensation, much information is not revealed by the industries. The information related to such matters is almost negligible in all sectors banking upon assembly-line-related work. The available literature on OSH issues majorly focuses on hazard identification, surface layer accident investigations, job satisfaction levels, and worker well-being-related aspects. Much deeper context-specific hazard identification/elimination, accident investigations/mitigation, and negative work-related consequences in the FMCG sector are unknown and mitigation strategies adopted to curtail those thus remain hidden.

16.4.2 Standardization of Work Activities

Further, it is interesting to note that the automotive sector's successful production strategies, like lean manufacturing, are being implemented into the FMCG sector without thorough investigations about its results and consequences when applied to FMCG work. Continuous improvement activities (Kaizen) are being implemented without considering ergonomic principles in FMCG assembly-line-related work, which negatively impact the workers engaged thereof. Several work-standardization approaches viz. Maynard's Operation Sequencing Technique (MOST), Method-Time- measurement (MTM) are being implemented in the automotive industry for work measurement and productivity enhancement. However, their relevance to FMCG work and their efficacy in FMCG work are not known. Overall Equipment Efficiency (OEE) is the single-limited approach being used in FMCG work to determine the production efficiency.

16.4.3 Context-specific Ergonomic Design Interventions and Kaizens

Available literature suggests 'Ergonomic Design Interventions' as a potential solution to mitigate adverse workplace-related situations. The researchers have suggested context-specific recommendations for shop-floor layouts and other workstation design interventions in varied industrial sectors. Such efforts from the FMCG sector remain missing or unreported. Among manufacturing industries, particularly assembly-line of heavy industries are already standardized and, in many cases, fully automated/semi-automated; thus, the information regarding workstation redesign, work accessories redesign are rarely available. Whatever design interventions have been proposed in those assembly-lines are not adaptable in the FMCG sector due to the nature of work in FMCG, which engages both skilled/non-skilled unisex labor and is particularly semi-automated. Ergonomic design interventions to improve OSH and productivity-related issues in part assembly-related work, viz. pump assembly have been reported too [52] that is context-specific work. Researchers/engineers can adopt such context-specific ergonomic design interventions addressing various issues of the workstation/work accessories and innovative tools in FMCG industries.

It is evident from the literature that design and ergonomics issues in the assembly line of the FMCG sector have remained unexplored. Plenty of scopes are there to identify FMCG areas where design ergonomic interventions can be applied for improvements. Researchers/engineers can identify context-specific areas in terms of work evaluation and design interventions in the FMCG industries' assembly line following the literature review. FMCG work's critical characteristics need to be further understood in-depth to select the most appropriate tools/techniques based on key attributes of identified FMCG work practices. Selected tools/techniques may be implemented to provide better design solutions in assembly-line-related work in FMCG industries. Moreover, the efficacy of such ergonomic design interventions may be evaluated to determine their success and impact.

16.5 Future Scope of Work in Assembly-line-Related Work

16.5.1 Implementing Kaizen with Thorough Ergonomic Considerations

Foremost, the researchers/engineers may thoroughly look upon the indispensable continuous improvement activities (Kaizens) related to inhouse-fabricated furniture (workbenches, chairs, and stools). It would help them design and fabricate those as per the working population's (engaged in such production units) distinct anthropometric needs with proper consideration of ergonomic principles. It will have a high impact and an immediate effect to curb the prevailing OSH and WMSD issues.

Research should be initiated to address anthropometric mismatch-related areas viz. assembly-line heights, workstation clearances from worker body, etc. Moreover, model assembly-lines may be commissioned based on the implications drawn from such studies and ergonomic evaluations.

16.5.2 Implementing Context-specific Work and Time Standardization Techniques for FMCG Assembly-line-Related Work

Contrary to the heavy industries' assembly-lines, the FMCG workers perform their tasks from both sides of the assembly line. Therefore, to capture the motion economy to enhance productivity, rigorous research needs to be conducted to find the best possible spatial arrangement (considering the workers' hand-dominance and the requirement of wok accessories) across such assembly-lines. Appropriate work-standardization assorted techniques considering ergonomic principles may be taken up by the researchers/engineers to optimize FMCG shop-floors' productivity. The efficacy of the implemented ergonomic interventions could be studied in terms of method study/motion study techniques on FMCG shop-floors. From the extrapolations of such studies, the best feasible man–machine ratio, pacing rate of assembly-lines, and adequate rest pauses may be determined to enhance productivity while ensuring OSH. Kaizen activities with proper ergonomic considerations must be executed in totality (holistic view) and not in a fragmented manner (considering each workstation as a distinct output driver) in the FMCG assembly line. All such activities must be done by taking all stakeholders (production, operation, maintenance, and safety divisions) into confidence.

16.5.3 Devising Context-specific Innovative Tools for FMCG-Related Work

Innovative tools should be designed and developed to aid the assembly-line-related work in FMCGs to ensure safety in such work practices to adhere/comply to ever-increasing strict labor laws and safety standards. Standard work practices and various work training methodologies and specialized safety-related training methodologies may further be explored to improve the OSH and promote workers' well-being. Rigorous research may be carried out to address various issues pertaining to health, hygiene, house-keeping, and slippery floor management to improve the shop-floor conditions prevailing in FMCG manufacturing units.

16.6 Conclusion

In this paper, authors have emphasized and advocated implementing ergonomic principles in assembly-line work in conjunction with productivity enhancement tools/techniques. This paper's approaches would help the shop-floor engineers/researchers design and fabricate the context-specific and highly capable model FMCG assembly-lines ensuring high product quality, production efficiency, and improved OHS.

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Chapter 17
Design for X: An Iterative Approach for Design Optimization in Pre-engineered and Pre-cast Construction

Arun Sekhar and J. Uma Maheswari

Abstract Inadequate planning and poor stake holder management are considered as root cause to delays and cost overruns in construction projects. Compartmentalized working of various stakeholders prevents smooth flow of information to achieve intended design–construction interface. The construction industry is gradually evolving to a manufacturing and product delivery process where design for manufacturability and assembly takes precedence. Design for a specific target value according to the utility has been an evolutionary process. The objective of the study is to look into the relevance and effectiveness of an iterative approach in design process to streamline the target values to optimize effort and resources in employing pre-engineered and pre-cast technology. The study also examines the various factors influencing the smooth interface from design to construction and critically examine the bottlenecks. Design for X (DfX) approach gives the stakeholders more rationale inputs for monitoring and decision making in a more controlled environment of manufactured construction. The study attempts to predict the future of manufacturability in construction where smooth assembly with automation is getting preference over conventional cast-in situ methodology. The bottom up approach of new policy initiatives and better communication between stakeholders promise more refined designs in the future where technology will be pushed to align with lean construction principles which will form part of deliverables.

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A. Chakrabarti et al. (eds.), *Design for Tomorrow–Volume 3*,
Smart Innovation, Systems and Technologies 223,
https://doi.org/10.1007/978-981-16-0084-5_17

17.1 Introduction

Design for excellence is not a novel concept in construction industry as targeting excellence is natural to achieve maximum utility from a product or a project. But its definition and scope kept on changing with every emerging technology. The mathematical and quantitative approach to design made the scientific community realize the importance of effective management of the execution process. The construction needed to be safe, ergonomic, reliable, and within planned schedule to provide value to the client [1–3]. A well-conceived design was inevitable to ensure accountability and safety [4]. Today, the construction projects are executed and monitored on the principles of well-researched management theories where each penny has to be accounted for [5–7]. Most of the modern-day marvels are more of management land marks rather than engineering ones. It was realized that every fancy design cannot be constructed without affecting the budget and hence constructability started gaining its prominence in design criteria. Almost 40% of the change orders or deviation orders are rooted in the design phase [8] and 30% cost escalation is attributed to poor communication during design phase [9]. This amply highlights the importance of reducing the change orders during execution phase and targeting constructability on the design table. Generating value for money is the new mantra in construction industry as specific targets like cost, time, constructability, assembly, manufacturability, procurement, and reusability dictates the ultimate value. This shift toward targeting specifics according to the client's requirement justifies the use of algebraic term 'X' which is used to denote an unknown quantity. But the real task is to substitute 'X' with the correct target or targets in right proportion. This right mix can be reached by an iterative approach as enumerated in the case study of pre-cast and pre-engineered construction which is an evolutionary product in the origin of technologies. The study looks into the iterative design process of pre-engineered and pre-cast construction to examine the targets which are evolved from conventional construction methods toward achieving excellence. Constructability translates to be the ability to construct something using appropriate technology within a specified budget and schedule producing the intended value. Value engineering has to be an integral part of constructability as its prime aim is to increase value than to reduce cost [10]. The design table is very much a place where the fate of the project lies and decides the value it will generate. In this paper, the constructability and value generation are critically analyzed in adopting an emerging technologies like pre-engineered and pre-cast construction to draw lessons in iterative design optimization using DfX concept along with procurement management challenges.

17.2 Genesis and Evolution for Pre-engineered Technology

Pre-engineered technology emerged as a cost-effective method to economically use steel in large span structures. Spans up to 90 m were achieved using this technology

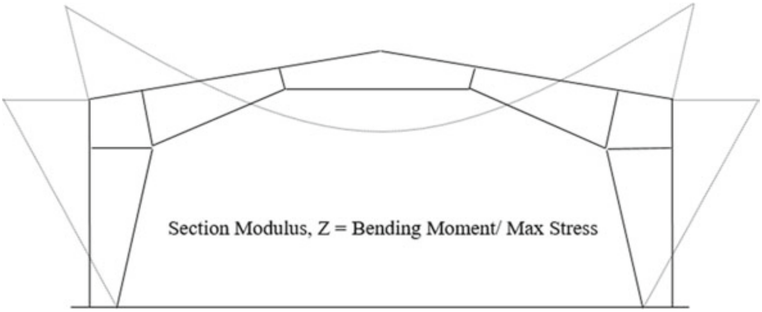

Fig. 17.1 Bending moment diagram super imposed on PEB frame

for aircraft hangars. Using RCC was out of question while planning these large spans as the beam depth would be too large making it uneconomical and unsafe. The urge to cut cost and reduce waste and thus produce more value was natural in early part of this century for the metal building industry to stay afloat in a competitive market. Steel was the answer to reduce self-weight of the structure and reduce construction time. But as the span increased, the depth of the section also increased. It occurred to the structural designers that the cross section of the steel frame can be matched with the bending moment profile to reduce dead weight and make the structure more economical. Figure 17.1 shows the pre-engineered building portal frame superimposed on its bending moment diagram to bring in the striking similarity in both profiles. The section requirement is directly proportional to the stress at that point.

17.2.1 The Iterative Design Approach

It can be seen that a pre-engineered building (PEB) frame is an attempt to follow the bending moment profile in most adverse loading conditions. This design for stress approach actually translates into design for cost as material is saved for a given span and floor area. Other considerations include structural safety, cost, and the maximum member size for transportation. Length of a column as per design is 12 m, but for the ease of transportation via road and for easy handling at site that might have to be restricted to 8 m, thus dividing the column into two members of 8 m and 4 m to make members of almost equal weight being tapered section. The connections need to be pre-designed, connection plate pre-welded, and bolt holes provided at the manufacturing yard. Else the column height has to be restricted to 8 m. These logistical considerations force the designer to have a relook again at the dimensions. The 8 m section should be available with the steel manufacturers and cost of assembly should fit into the procurement plan. This iterative design process continues till the loop is closed with a technically feasible, financially viable, and legally valid contract document is evolved. Figure 17.2 shows the iterative design process of a PEB foundation design process which are closely connected with column

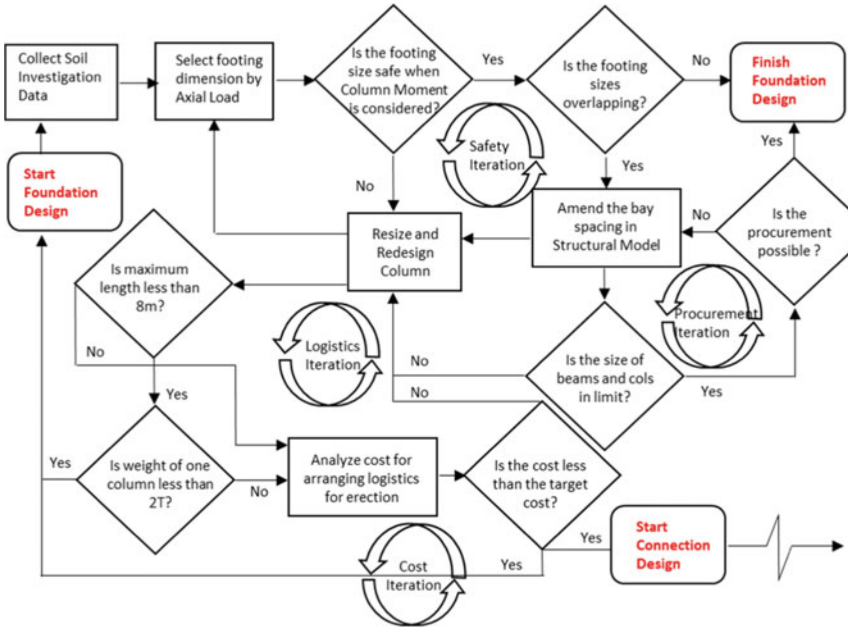

Fig. 17.2 Iterative design process of PEB

and connection design. The maximum member size is 8 m and weight is 2T for safe transportation and easy installation in the present case. Any dimension higher than this will attract an additional cost. It can be assimilated that the foundation design flows through iteration of safety, logistics, cost, and procurement to arrive at a constructible design. In pre-engineered and pre-cast construction, the building components are manufactured in a factory and transported to the site. The components are assembled at the site using appropriate tools and machinery. In this method, the designer's targets are different compared to a cast-in situ process. The components have to be with in the acceptable dimensional tolerance limit as there is little room for site corrections. Target value design gives the stakeholders more rationale inputs for monitoring and decision making. Target values have to be identified to incorporate in the design process which might vary for each stakeholder. The study aims to define values in a design process for optimization of resources. For this purpose, the concept of value needs to be addressed in a more objective way.

17.3 Value in Design

Value is a set of concerns with respect to cost and function. It has a futuristic component which is based on a various inputs and assumptions. It can be expressed as ratio of design function to cost. It is obvious that in order to increase value, the cost has

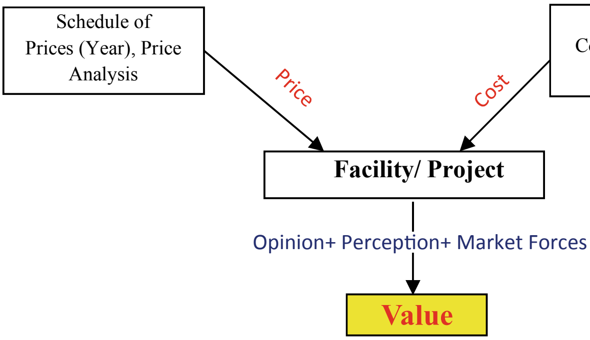

Fig. 17.3 Interaction of price, cost, and value

to be reduced or the design functions have to be increased. But while preparing a tender document, in the process of procurement, the price is the only readily available factor. A correlation between price, cost, and value need to be established to define the target values in design. The comparison illustrates that price is related to past tense, cost to present tense, and value in the future tense when we evaluate a facility or a project at planning. The price comes from the market and documented in the schedule of prices by various agencies and the cost is budget at completion of the project. The value is an opinion which goes back to market as set of benchmarks with respect to utility of the product or service. Figure 17.3 gives the value generation process in a typical construction project using price and cost. Price is a fixed factor compared to cost and value. In a project, it makes sense to plan cost cutting, but not price reduction. Price of materials is fixed with respect to time and location. Once the BOQ is prepared, the price factor has been considered. But the cost factor eludes the designer as that is depended on change orders, contingency and force majeure. Value is a promise in the future which is based on opinion, perception, and market forces. In order to optimize the value what should we aim for? Though a civil engineering project cannot be templated into a product manufacturing process, many lessons can be drawn from the evolution of assembly line manufacturing process which revolutionized the industrial production of construction materials.

17.4 Genesis of Pre-cast Technology and QFD

The pre-cast construction technology was emerged as a natural evolutionary process by improving on the lacunas of cast-in situ construction with reinforced cement concrete. The advancements in reinforced concrete technology and feasibility of slender sections made designers to take a bold step toward treating the concrete members like steel. Quality function deployment in construction industry is not often practiced due to its invisibility compared to other manufactured products. A direct translation of QFD concept from an automobile production unit may not suit a

Table 17.1 QFD of customer and designer

Customer	Designer
Should be earthquake proof	Monolithicity of connections
Smooth finish	Vibro compaction and smooth shuttering
Low maintenance cost	Easy access to MEP lines
No disputes	EPC contract
Affordability	Break even quantity
Fast delivery	Steam curing of RCC members
Quick assembly	Cranes part of inventory

building contractor. Customer's aspirations from a car varies greatly from a building or an apartment. Constructability is the synthesized end product after analyzing all QFD inputs. Table 17.1 illustrates the conflicting yet complementing requirements of users and designers while planning a pre-cast apartment building. It is pre requisite of any high rise building to be earth quake proof and in pre cast facility this translates to be monolithic beam column connection for the designer. It is quite natural for the customers to expect a smooth finish of exterior and interior. In pre-cast the designer has to ensure vibro compaction and smooth shuttering to save cost of plastering and ensure smooth finish at the same time. Customers are often smitten by the cost not by the value. At the same time, cost eludes the designers as they are indulged in price. These conflicting demands in constructability make it more challenging to set specific targets for planning the project. From construction activity, the entire process got converted to a manufacturing process to add value. In an evolutionary curve, we can see that steel overtook cement concrete as a preferred material for fast track construction. It is interesting to note that though the technology is not based on any new theory, the adoption happened by default, not by design. The reason is more value generation through manufacturing and assembly with relatively less effort. Pre-cast system is widely used now in many repetitive structures and claddings due to its versatility to act both as architectural and structural material.

17.4.1 Cost-Benefit Analysis and Breakeven Quantity

The actual value of pre-cast is often misunderstood as the direct cost of structural components will be high compared to the cast-in situ-framed system [11]. The components have to be manufactured in a pre-cast plant and transported to the site. Huge initial investment of casting plant and steam curing facility can be justified only with a minimum assured order of repetitive nature. This technology is ideally suited for housing sector as the layout is similar and slabs are spanning less than 5 m. The cost-benefit analysis in Fig. 17.4 shows a minimum number of 800 units have to be constructed to make the rate comparable to the conventional cast-in situ technology. This break even quantity is specific to a turnaround distance as the distance of plant

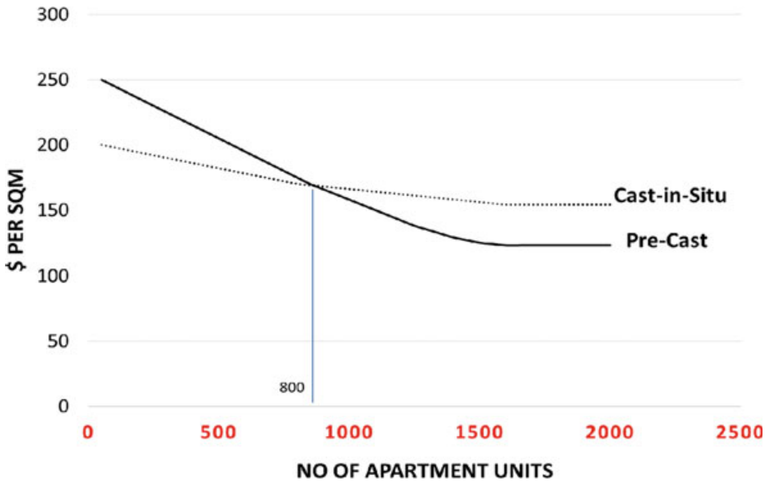

Fig. 17.4 Breakeven quantity of pre-cast facility

increases from the construction site, the cost changes. Figure 17.4 shows the data collected from Delhi, India.

17.4.2 The Design Targets (DfL, DfM, DfA, and DfP)

Having defined the relation between price, cost, and value, the design targets specific to the intended value can be assessed. These target values may be required in varied quantities as per the design optimization which should fit in the cost and time framework. In the case of pre-cast facility, location of a manufacturing plant can be selected as per the logistical requirement but if the components are not fit for assembly, there is no scope to perform any repair on site. Taking them back to the plant for changes will incur huge financial burden which may derail the whole financial plan. As time progresses, the influence of design aspects of logistics starts reducing and manufacturability increases. The iterative design process zoom in on to design for assembly as the prime target to achieve in the design process and constructability remains the strong foundation to achieve the final aim of producing a foolproof ready to construct drawing which is a legally valid document having implications on change orders and final cost. The pre-cast components have to be manufactured in a location which makes the turnaround time logistically feasible and economically viable. The location of the plant has to be decided based on the availability of the raw material and resources. The logistical challenges involve setting up the pre-cast plant, transportation of raw materials and transportation of manufactured components to the construction site. The dimension of vehicles for the above purpose will be governed

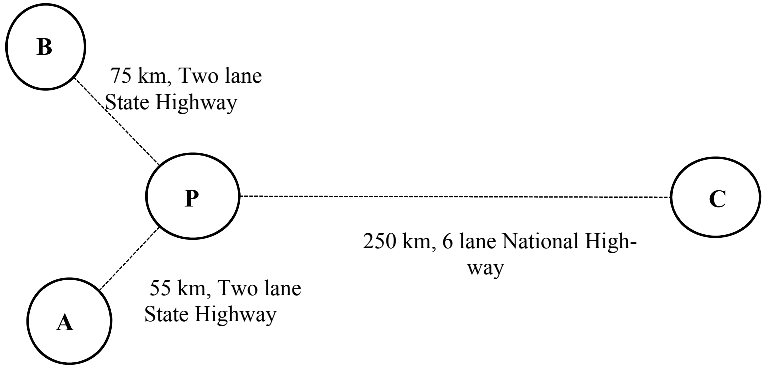

Fig. 17.5 Location of Plant P, with respect to sites A, B and C

by the size of the building components and their weight. The maximum height clearance permissible under the rail bridges and fly overs on the way plays an important role in this logistical planning. Once the location of manufacturing plant is fixed, rest of the parameters will be dependent on this aspect of logistical baseline. Figure 17.5 shows the map of three sites A, B, and C and the location of the pre-cast plant, P. The location of plant is so selected that the time to reach each site is almost same. The plant is sited based on the logistical feasibility which has a direct bearing on the overall cost and thereby being a value deciding factor. The components have to be pre-cast in the plant and assembled at the site. This assembly operation will be requiring cranes. That infers to the correct size and shape of components which will make the assembly easy. Assembly will govern manufacturability. The beams, columns, floors, and walls have to be cast in the casting yard. The dimensions of structural components have to be fixed and ready mix concrete is poured using automated systems. How can compaction be achieved? A normal vibrator cannot be used as it will consume more time and will result in non-uniform compaction. The casting bed has to act as a vibrator to save time and effort. This important criteria for casting bed design and the cost involved is a governing factor in manufacturability. The components have to be cured for required period to attain full strength and this for fasten the process, a steam curing facility has to be set up. All members should be hoistable using cranes as they will be moved several times once removed from casting bed. The location of these lifting hooks will have to be decided on the drawing table as they are part of structural analysis process. Assembly of various structural components at site has to be in perfect sequence to ensure a smooth execution. Unlike the cast-in situ method, the pre-cast members lack monolithic connection. The structural analysis is carried out based on certain rigidity of connection and these design assumptions have to match with the site conditions. In reality, the DfA is the most important factor in a pre-cast design process. If the connections are not strong enough, catastrophic failures might happen. After the structural analysis and design, a scaled model may be tested in a laboratory condition to ensure that the assumptions are correct. The cost for these tests has to be borne part of the Research and Development effort rather than in the estimates of the design at hand. These are part of the initial investments as it is practically impossible to carry a destructive shake table test every time. The results of the initial test can be interpolated or extrapolated in subsequent designs as the case may be. The aspect of assembly is so important that the structural design has to be carried out by taking these assembly into consideration. The design of floor slabs will illustrate this aspect in detail. Unlike a cast-in situ slab, the pre-cast slab has many functions to perform. It should have shear connectors to ensure connection between next slabs, it has to give a smooth floor finish and it should be easily hoistable by crane. A lattice girder in reinforcement steel is specifically manufactured for slabs to serve two purposes: to help in assembly as a lifting hook and to act as a shear key for connections. These functions are to be designed both for structural loading conditions and to facilitate construction.

17.5 Procurement Management, Monitoring, and Control

The processes involved in procurement management is limited to plan, conduct, and control as per PMBOK [12] and is a reaction to what is designed. But when we plan to adopt an assembly based technology, the procurement management cannot be independent of the design process. The design–build format suits procuring the pre-cast systems as the bid preparation is challenging when it comes to design and estimation. In an open competition to bid for a specific design, the purpose of providing equal opportunity and level playing field is not achieved. Moreover the DfA challenges will make the design favor a particular firm who has adopted a specific dimension for their projects in hand. Using design–build procurement format, the owner saves time and effort by executing only one contract with a design–builder, who takes responsibility for completing both the design and construction of the project [13]. The engineer, procure, and construct (EPC) model is often considered synonymous with design–build one in function as both shift the design and build responsibility and a bigger portion of risk to the contractor [14]. In EPC mode, the contractor is often entrusted with the desired output in the case of a production facility. In the design–build system, the designer, the builder and the consultant, all could be rolled into one due to uniqueness of technology and there may be very less control by the client over the project once the design has been finalized. But the designer has to ensure assembly, manufacturability and logistical feasibility by taking the client on board. Design for procurement (DfP) is also an important parameter in construction when it comes to innovative and emerging technologies. Every exotic design cannot be constructed and every technological feasibilities are not buildable on ground. There is a fine line between building a design and design something buildable. The design is tailor made for procurement to suit a design–build system so that the facility is built by the firm which designs it, thereby eliminating communication hiccups between a consultant and contractor. But is this killing fair competition and leading to monopoly of business? This question lingers on with all new innovations where very few people are experts initially. The fittest and adaptable will survive and probably the theory of evolution is applicable to construction industry too. The traditional monitoring and control process is designed to keep the budget always on track and effect minimum change orders. The stakeholders involved are reacting to the precedence diagram actual unravelling on site. So the monitoring process almost reduces to an assembly supervision as there are very less decisions to be taken. The scope is fixed in pre-cast no change order with respect to architectural or structural is feasible. This lack of flexibility is accounted for by numerous design iterations after repeated interactions with stakeholders.

17.6 Summary and Scope for Future Work

As the theory of evolution has proved, only the ergonomic design will be passed on and imbibed by the next generation. Economic viability with desired value will remain the sole criteria for the project's success in the modern world. Only constructible designs will be executed and a trade-off will be arrived between design and construction which could be an iterative process to reach at minimum financial burden, carbon foot print, and maximum value for money. The monitoring and control techniques like EVM will be helpful only when design–construction interface is hitch free with clearly defined target values. The study validates ample reasons to predict more impactful application of Lean principles with emerging material research for construction. Design and construction will remain complimentary activities with the constructability deciding the success and client satisfaction. The study predicts that constructability coupled with smooth assembly using minimum labor is essential for value addition. Emerging technology like modularity needs to be validated on the DfX iterative process before adopting in a large scale. The bottom up approach of new policy initiatives and better communication between stakeholders promise more refined designs in the future where technology will be pushed to achieve design optimization.

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Chapter 18
Space Design Intervention for Shivarapatna Craft

Md. Asic Hussain and Shivanshu Sagar

Abstract The craft of Shivarapatna is one of the finest stone craftsmanship and has been continuing for the past 2000 years. The craft is world-renowned and has been categorized in a prime category. The sculptures are primarily of gods and goddesses. Recently, they have seen a dip in their market share as well as pursuing the craft into the future. The study carries the underlying aspects of Shivarapatna craft to understand the lives of artisans, problems faced by the craft in the market, and future of the sustaining the craft. The research finds out the need of promoting the craft and creating a brand identity of the whole craft to get a bigger exposure to gain a new market and has a better market share. The study explores changing the mental model of the artisans toward the craft to keep pace with the market expectations while respecting their beliefs and practices. The craft needs to contemporize to be on par with other crafts but the emotional, cultural, and spiritual beliefs are to be taken care of while integrating contemporary design into their product range. The study proposes a concept of creating a brand identity of the craft for bigger exposure by designing a space of craft-based storytelling for craft visibility. The branding aspect is also seen as a way to slowly introduce the trends and market needs to the artisans to diversify the existing designs for adaptation.

18.1 Introduction

Craft is one of the prominent industries of India, next to agriculture [1]. The number of crafts present in India is immense, and the diversity among the crafts is a privilege that India proudly boasts of [2]. Each craft speaks about its region, culture, people, and lifestyle. Craft is very important to India due to its long heritage and the story it has built over due course of time. Crafts are the pride of people and the communities

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A. Chakrabarti et al. (eds.), *Design for Tomorrow–Volume 3*,
Smart Innovation, Systems and Technologies 223,
https://doi.org/10.1007/978-981-16-0084-5_18

involved [3]. It is also the source of income for the people. Crafts play a huge role in the Indian economy due to the high ratio of the value proposition from low capital investment and the potential of high foreign exchange [1]. These crafts skills are honed overages, passed from generation to generation, and have been treated as sacred and promoted as a unique identity. Crafts have been attracting tourist from all over the world due to its fine craftsmanship. Designs of Indian crafts are not only aesthetically beautiful but also are so unique that they have inspired designs across the world in different areas like fashion, product, home decor, and so on. The essence of the crafts in India lies in the place of its origin. Several factors like climate, language, terrain, and other geographical conditions shape the craft to get its unique identity. Similar crafts from different parts of India will still have significant strong elements to distinguish from each other. The popularity of the crafts is due to finesse craftsmanship, strong legacy, and the stories that are conveyed through their design. Designers are a big fan of these Indian designs as they take inspirations from the motifs, pattern, and texture which forms an integral part of their design collections. The fame of Indian crafts is one of the major reasons for tourism in India, creating India as one of the prominent global destinations.

18.2 Literature Review

Craft is unique to its geographical place and has been followed for ages. It is shaped by hand-honed with skills from years of experience. Not a single piece is the same within the same design, and the small irregularities are the most appealing aspect of the whole crafts [4]. The poor literacy level and less exposure to trends led to the high involvement of the middlemen that made a huge profit from them. It became so evident that middlemen became an integral part of the survival of the craft [5]. The craft industry lacks resources and data that can show them their weakness and potential upcoming threat. Lack of proper infrastructure has led to the unwillingness of the new generation to continue the craft [6]. Due to these factors like poor designs, low quality of materials, exploitations of the artisans, and the ineffective market penetration techniques are letting the urban markets overpower them [7].

Craft revival and craft innovation show a new path to the world to build togetherness among the citizens and also to create a unique identity in the world. The satisfaction from an occupation depends on how they see their work above monetary value [8]. Small batch production of the craft products gives room for flexibility and compatibility for promoting their unique skills, which can be enhanced by the effective collaboration between artisans and other creatives like artists and designers [9]. Cicheng is one of the examples of craft revival, where the heritage of craft is blended with tourism strategy. A commonplace for all the artisans to work allows collaboration and attracts designers and scholars to study the different crafts at the same place for new insights and build a good supply chain [10].

Crafts have a rich past and a huge legacy behind them. It goes beyond skilled manual labor because the craftsman focuses on the special connection between hand

and head. This is a dialogue between thinking and practicing that becomes concrete in learning by doing that is typical of the workshop situation in which apprentices learn from masters [4]. The amount of effort put by the artisans does not equate to the rewards they receive. The rewards include recognition, profits, growth of craft, and support for the development of infrastructure. The nature of the craft despite the low wages and profits is kept running by the craftsmen as long as they love doing their work due to several factors like obligations, legacy, devotion, and so on [11]. The love and affection for the craft products overcome the price and profits. The artisans are exploited by traders that are not involved in the crafting process but they act as a bridge between the artisan and the market. Many artisans kept the craft from dying just for the sake of love and emotional bonding they have with the craft [12]. The craft village has a lot of diverse products that can be easily marketed with a perfect combination of branding and marketing. The world has been riding high on the waves of the story behind every creation, and craft places are one of those places that have the immense capability of creating authentic stories that can build a strong emotional connection with the customers. According to consumer storytelling theory, the anthropomorphic identities associated with brands can build a strong relationship with the consumers. [13]. Myths and stories are often seen as a strong belief for consumers. They want to be a part of the belief as these directly target their emotions [14]. The common ground between a devoted artisan and the customers is the craft products. The authenticity of the product is well known but the buying tendencies for a craft product are based on how we convey the story. The story can be told in different powerful narratives depending on the behavior of the consumer to glue to it [15]. Consumer behavior involves the study not only of what people consume but where, how often, and under what conditions goods and services are consumed. An understanding of the consumer behavior of various market segments helps sellers to select the most effective product design, price, advertising appeals, and channels of distribution. Consumer behavior has been defined as behavior involved in planning, purchasing, and using economic goods and services [16].

To develop a place, the branding of the place can be very effective so that the visibility of the place increases. Branding and promotions are proven ways to draw the attention of people toward this place [17]. Surveys show that strong branding has changed the whole landscape of the place, and the deserted place turns into one of the busiest places. The strategic advantage of branding comes from creating value in the consumer's mind rather than the real value of the product [18]. Responsible and strategic design innovation that integrates the social, economic, ecological, and cultural aspects. According to statistical data, the turnover of natural stone products by export companies in Italy was highest in 2017 with 12,502 USD/ton. India is ranking in 11th position with 5104 USD/ton and has been predicted that it will overtake China (6901 USD/ton) in foreseeable future [19].

Government of Karnataka (GoK) plans a new strategy for 2015–20 which underlines improving friendliness administrations and measures, advancing innovative improvements, and revival of more seasoned vacation destinations to give an abnormal state of involvement to the guests. [20]. They chose to set up a craftsmanship and art town in the cash flow to demonstrate the way of life, workmanship, and part of Karnataka. The town goes about as a stage for the craftsman to demonstrate their specialties, works of art and create and get a hands-on association with travelers to sell items as well as increment their market. The challenges of artisans rangers from marketing capabilities like a different approach to different target segments, unorganized business plans and need to understanding to diversify their product ranges [21]. Kolar area of Karnataka has a few appealing spots with historical, cultural, and religious significances like Madivala, Chikkatirupati, Thoranahalli, Kadathuru, Shivarapatna, and Tekal. Stone sculptures of god and goddess of Shivarapatna are acclaimed everywhere throughout the world and traded to a few nations. There is an impressive increase of local and foreign tourists in Karnataka from 2011 to 2013, and the projected number of sightseers for the year 2014 is 40,200 which shows a considerable probability for the advancement of the tourism industry [22]. As indicated by work allotment report for general supervisor report, Karnataka State handiworks advancement Corporation Limited (KSHDC) proposed a work distribution which consistently direct and auspicious execute the tasks of state and local among those is Shivarapatna project which incorporates discount on lesser-known specialties, welfare plans for craftsmen, and different plans directly from the readiness of recommendations up to the accommodation of utilization declarations [23].

The Indian market does not recognize the true value of the craft rather opt for cheap mass-manufactured industrial products. The importance of craft has diminished as it used to be at the times of the kings [24]. The government treats this industry as a sunset industry which resulted in a lack of well-developed policies and programs. The marketing interventions by the government do not reach the majority of the artisans due to several reasons like demographics, awareness, and so on [25]. Crafts are now seen as a stigma of inferiority and backwardness and are also seen as decorative, peripheral, and elist. Globalization has affected the craft severely due to the demand for product, design, color, and style. The perception of local tourists and foreign ones is almost the same regarding crafts irrespective of the demographics they belong to [26]. The stone craft of Gaya, Bihar, and Art of China was experiencing a comparative sort of issue, where they do not have a particular spot for item show and are kept in irregular spots. Because of the non-appearance of a regular language, craftsmen and business visionaries confronted troubles in correspondence amid display as no presentation visit has been done as such far for them. So the government decided to promote the craft in the market with more contemporary design aspects that attract people in the country as well as in the international market [27]. International Trade Center (ITC), a joint organization of the WTO and UN, has begun the inclusive tourism program which gives the opening for work and market to the neighborhood individuals, where they can utilize their abilities to build up the required merchandise and ventures to fulfill the need of nearby purchasers that diminish the import of good and administrations [28].

Innovation and adaptability are the two skills most required of a craftsman to sustain his livelihood. To sustain, it is important to look for the utilization of resources and also pace up with the current market demand [29]. Instead of focusing on one holistic design, we should look for the multiple aspects of people's choice of preferences that lead to a strong and better outcome of the design intervention [30]. The difficulties looked by building up nations' handiwork showcase are now loaded up with the imported market, neighborhood item's quality, need assortment, and development which is unfit to draw consideration of voyagers. As per details, normal vacationer burns through $20–80 on handiwork buy in creating countries (inclusive the travel industry). To pull in vacationer, item structure, its quality should be improved, and items are not an impersonation of existing items. It ought to be both pleasant and keepsake so they can use at their home and less massive with the goal that it is anything but difficult to convey.

18.3 Research Gap

Our research found the craft is facing a huge challenge in terms of exposure as a premier craft and a lack of vision in upgrading artisan's designs to cope with the market demands. Despite having a rich history that dates back to 2000 years back and the product which is beautifully carved out of stone by the honed hands of the artisans, the craft is struggling to penetrate the market, unlike other crafts which have a significant market share. There is also a lack of awareness about the craft and so arises the huge need for promotion and branding of craft with an underlying need to have product diversification as per the trends to bring out a range of contemporary designs that matches with the current generation's lifestyle and their fashion.

18.4 Methodology and Methods

The whole research paper is based on secondary and primary research which initiated a concept to be designed as an experiment. As per secondary research, it was found that there is very little information about Shivarapatna craft, and there is a lack of awareness in people toward this craft. Our research is based on the exploratory method. To fill the gap, the following methodology is conducted:

1. The survey among the artisan
2. Interviews and observation of the artisans life (ethnography method)
3. Website and space layouts analysis
   (a) Development of interface and space layout (application and exhibition)
   (b) Promotion of craft (tourism and branding)
4. Developing the concept
5. Reviews from the customers.

The research analysis is based on the qualitative research we did in Shivarapatna. The quantitative data from the survey helped us to understand the nature of the craft, the current situation of the artisans, and gave us ideas on the areas to probe during the in-depth interviews and observations. The data collected were analyzed through thematic analysis to decide on the possible design interventions.

18.5 Sampling and Sample Size

We did a survey among the artisans of the village, where we did a convenience sampling of 20 craftsmen involved in the craft. The selection of the artisans was based on income, laborers employed, and who have been into the craft for more than 20 years. We mapped their key success factor that tells us about the competitive strength of a business which is based on the 4P's: convenient pricing (P1), product awareness (P2), innovation (P3), and customer service (P4) (Norman et al. 2009).

18.6 Questionnaire

The following questions were asked in the survey apart from the demographic questions.

(1) Craft practiced (Year). (2) Family members participating in the craft. (3) Work hours per week. (4) No. of the month involved in the craft activity. (5) Alternate source of income. (6) Month having a high demand for the craft. (7) Change in location or area of craft. (8) Planning your children to attend craft. (9) Monthly income. (10) Design you are working on. (11) Client product developed apart from traditional in the last 2 years. (12) New product is profitable. (13) Skill of artisan. (14) Parameter of product pricing. (15) Difficulty in marketing. (16) Delivery option.

18.7 Understanding the Underlying Needs

We did an in-depth study in Shivarapatna, where we observed the artisans about their attachment to the craft and practices. Ethnography was conducted by interviewing the artisans to gain their views and perspective related to the craft. The overarching question in our mind for conducting the interviews was to understand their problems in promoting the craft and how responsive are they in embracing changes. Government authorities present in the place like block development officer, government school principals, and doctors were also interviewed to understand their view of the place and any new policies that are taken by the government for uplifting the craft. We did a competitive analysis to understand the various craft related websites around the world and India. Current markets were mapped out to deeply understand all stakeholders involved in the craft directly or indirectly. The concept was developed through designing a space layout of a display area, and subsequently, an interface was developed to facilitate the space design.

18.8 Feedbacks

We asked various stakeholders to use the prototype (Website) and ask their opinion about the space design layout (CAD model) and get their feedback for further iteration to get a better result. Feedbacks were collected through interviews and observing their interaction with the mock-up of the digital medium.

18.9 Results and Discussion

The result of the survey showed a wide variation in the adaptability of the artisans in terms of exploring new designs and incorporating innovations. It also shows how the prices are getting fluctuated with time and the rise of competitions within the village. Further diving into their lives and observing them gave us insights like drifting in the minds of the artisans to move away from the craft and current generation of theirs are already in the process of changing occupation.

Observing artisans helped us to know that they are deeply rooted in their work life, and they take pride in their work, beliefs, and motifs. They take a firm stand on their current product designs which are stone carvings of gods and goddesses. Despite their inherited skills, they are constantly exploited by middlemen and merchant capitalists. We also got valuable insights into previous design interventions that were carried, out and how they were facing issues in different stages of implementation. We tried to understand the influence of their surroundings, history, and culture. The government is focusing more on the development of the craft promotion and artisan's life by taking measures like providing water facility and setting up of a government office in the place to facilitate the interaction of government with the artisans. They even build a place for accommodation for the tourists but it stopped due to superstitious beliefs while building it. Interacting with the customers on craft purchases in the craft exhibitions, many feel pride in owning any craft products as they acknowledge the quality and effort. When asked specifically about the Shivarapatna, many did not hear about it although they mentioned the nearby craft of Channapatna. Probing more, it was understood that they do not relate to the product of god's sculptures. Interestingly, they instead prefer small clay or metal god sculpture over the stone. The majority of customers knew about GoodEarth stores and also bought stone products like bath soap casing, etc. After the interactions, we concluded that the product segment was attracting only a small segment of customers due to the nature of the product while the products made of stone do appeal to people. The highly orthodox nature of the residents and artisans is to be respected before implementing any changes. Although the government is implementing schemes, they are narrowed to the lifestyle and facilitation, whereas there is a lack of design driving craft development. The styles are still old, and exposure gets limited. Even after government intervention, the commercial aspect and market share are still the same, and artisans are still facing the same issues. There is an imminent need to penetrate in their process and reinvent end product goals that make it simpler and make them more open to new ways.

18.10 User Experience of Digital Platform and Space Layout

The brainstorming and ideation process led us to several ideas that could align us toward our objectives like an e-Commerce platform, creating print media, and graphics. We mapped out the key focus areas and kept a hold over our element to not get diverse. To get the solution simple and effective, we focus our goals to design a space, where we can portray the rich heritage of the Shivarapatna that blend with the modern views of people. We want people to experience the hard work of the artisans being part of their life and appreciate their work which will give recognition to them. The integration of the recreational facility and conference site not only increases the time spent in the place but also creates a buzz of the destination, where the craft can complement the meetups. Events will be conducted which attract people and establish their presence in the state (Fig. 18.1).

The village of Shivarapatna is not as organized as the other craft villages are doing. The nature of the craft generates lots of dust and crater to only one product. Tourism is less likely due to the geographical positioning of the village, where the tourists have to take a long detour from the other prominent tourist places like kolar and Antara Gange. There is also no much attraction in terms of the crafting process that can appeal to the customers to be a part of the process. There is a need to create a space that can create an experience for the customers to come and visit them, where

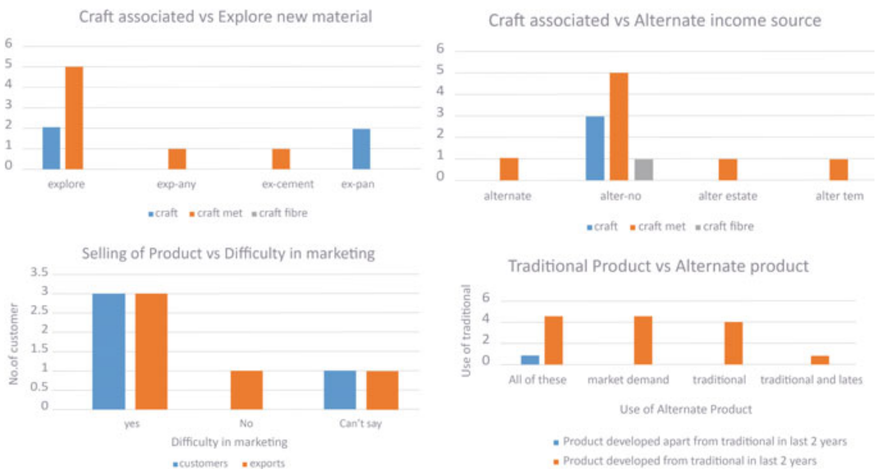

Fig. 18.1 Graph showing survey results conducting on different parameters

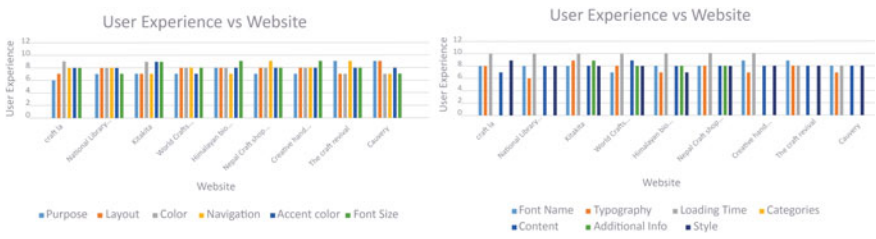

Fig. 18.2 Graph showing consumers' experience in navigation of different craft websites on a scale of 0–10 based on different parameters

artisans and the customers can both mutually benefit from each other. The idea behind the "Experience Space" is the lost connection between the art and craft of the Shivarapatna society with the urban settlers. With the change in lifestyle of people, choice selection regarding products is also changed like compatibility, aesthetics, transportation, and trends. Familiarizing the artisans with the expectations of the customers can help them include these different designs that can have better market penetration. Storytelling is the main objective to build emotional connections with the rich legacy the craft brings along with it. Loving a craft is about bonding with culture, tradition, and beliefs created over a long period which differentiates it from the mass-manufactured products. These myths and stories can create a powerful attachment with customers (Fig. 18.2).

"Experience Space" is designed based on the acclaimed ancient design layout, i.e., "The Golden Spiral". The product display arena takes the first spot in the trail of the golden spiral as we want them to have a view of the craft's finest product, followed by the rich history of the birth of the craft. Visitors are then led to the workshop area, where they can experience the life of the artisan and also know how they crave these sculptures to build an emotional connection with the product. There is a rapid increase in the market share of contemporary designed handmade products but still, it is difficult to change the mindset of artisans to accept these designs from the traditional design because of their beliefs and legacy. The innovation center in this experience space is such a place, where contemporary designs are displayed to let the visitors know the slow onset of product diversification, as well as let artisans, know how people respond to the design and slowly have these products along with the gods and goddesses' sculptures. It is a long-term goal, where the space design is just a baby step to connect all loose ends. The journey is full of experiences and artifacts that they never knew about. The innovation center also has info about other crafts that can be blended with the Shivarapatna craft. The whole arenas are very interactive so that they interact with different elements related to the craft and keep long-lasting memories. The amphitheater is placed in the heart of the layout, and the golden spiral trail gives you the overall look of the space. It has a conference hall and artisan meeting room, where one can personally meet them and get more about the beauty of the craft. Both cafeteria and park are places, where visitors can enjoy their local food and relax amidst nature (Fig. 18.3).

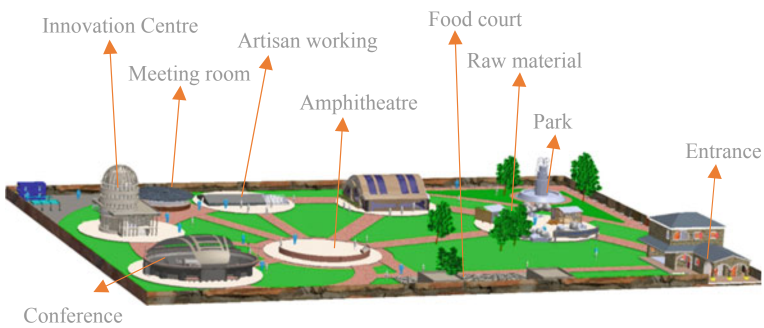

Fig. 18.3 Space layout design of Shivarapatna craft's experience space

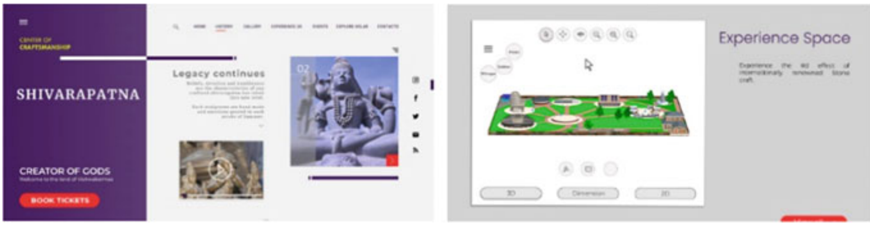

Fig. 18.4 Interface designed for providing information about the experience space

The proposed layout is planned on the NH-75 highway near the stretch of the Narasapur just before the beautiful range of Antara Gange starts, so that it creates curiosity among people to know the amazing story of Shivarapatna who pass through it. There is also a dedicated interface, based on the minimal design, to get easy access to all the information regarding craft (Fig. 18.4).

18.11 Reviews

Space design received positive feedback from the people. They liked the idea of craft being integrated with recreational space. The layout was different, and the placement of the places was appreciated. The innovation center was subtly blended with current designs with contemporary design. It had lots of open spaces that added to the open live culture which is on the trend. The artisan's point of view was encouraging as they like the concept of portraying their belief and legacy through their products. The block development officer was vocal about the space design layout, the website, and the connection of the physical space with the digital space. According to him, it allows customers to experience the whole craft as many of them were not aware of the rich history but used to buy their products for its rarity. The designers and other artists liked the concept as it gave them a common platform to work with artisans and customers and build a supply chain combining other crafts. Concerns came from artisans as their lack of tech-savviness to use the portal. The notable feedbacks were to use a conversational interface for voice usage, trend analysis based on the customer's feedback, and buying patterns. The patterns derived for forecasting and recommendation for design inputs were based on the market needs. Expecting interface to be designed based on human-centered artificial intelligence.

18.12 Conclusions

The craft of Shivarapatna is a very unique craft that has a lot of physical, mental, and emotional connection to the essence of its survival. The stone carving is itself a very big skill but the belief system among the people is very strong in the village and has to be respected. On the other hand, the current generation appreciates the minimal design-based products without a lot of emphasis on the religious aspect. The rise of handmade products is a great sign for a craft like Shivarapatna. Space layout design has been done before too, and few have gained recognition, while few have failed to create an impact. The intervention like the innovation center is a way to blend it in the artisans over a while. Stories and myths can be vital resources to attract in the craft's arsenal. This is again a proposed idea, where we are tweaking subtle experiences to bridge the consumers and the artisans and build a vision in terms of the scope and future of their revenue system.

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Chapter 19
Non-lethal Devices for Personal Safety

Tushar Amin, Tanmayee Puntambekar, and Aaksha Singh

Abstract

Introduction: Crime rates are escalating in India. Civilians are forced to live amidst criminal activities happening every day. Safety is taken for granted and people end up losing lives. These lives can be saved by using personal safety products. A good design can prevent loss of human life.

Need: Existing non-lethal weapons share a common flaw- they inflict serious injury and can be misused. The major flaw is that all existing products can be taken away and used by the attacker on the victim. There is a serious lack of accessibility to these products. Victims do not get enough deployment time.

Method: A study was conducted to find out problems in existing products. Data revealed that the maximum population feels threatened almost every day of their life. Existing literature was reviewed, and surveys were conducted to establish the need for new design solutions.

Purpose: Not every fight requires a lethal response. Therefore, non-lethal weapons should be owned by civilians for personal safety. The product will empower the victim. Self-sufficiency in personal safety will reduce both dependency on authorities and crime rates.

Conclusion: To reduce the fear of crime and its occurrence, non-lethal weapons and safety products can be redesigned. This will solve existing problems and provides safety to all and save lives.

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A. Chakrabarti et al. (eds.), *Design for Tomorrow–Volume 3*,
Smart Innovation, Systems and Technologies 223,
https://doi.org/10.1007/978-981-16-0084-5_19

19.1 Introduction

In India, increasing crime rate is a pressing problem. Recent cases like the brutal rape and murder of a doctor force us to realize the need for self-defense devices and personal safety. Previous researches have shown that the country is plagued with crime. Social and economic factors influence the increment/decrement of crime and the criminals committing it. The National Crime Record Bureau 2018 Report suggested that the lack of good governance has led to an unsafe environment [1]. In a densely populated country, it is impossible to protect everyone personally. Attack situations may not allow the time to inform the authorities or seek help. Therefore, the Constitution of India gives the right to self-defense to all citizens under Sect. 96-106 of Indian Penal Code. [2] Not everyone is skilled enough in self-defense. People panic in attack situations and end up getting attacked or losing lives. The best way to reduce crime is to make sure that it does not happen. This requires changing mindsets but it is not easy and takes time. Until that is achieved, the best way to reduce crime is to take charge of one's own safety [3]. With the use of non-lethal weapons, personal safety is possible. While there has been previous research on crime and non-lethal weapons, none of them focus specifically on the role of such products in reducing crime rates and saving lives of the people. Furthermore, as criminal activities have been on the rise in recent years it is important to build on the previous research work and explore new ways of solving the problem. The research deals with identifying the drivers of crime, understanding the role of non-lethal weapons and safety devices in reducing it and opening opportunities for design solutions.

19.2 Literature Review

Crime in India has been on the rise for a long time. Recent incidents of crime against women and children, street crimes, hate crimes, riots, and protests have made the society unsafe. Globally, India ranks 96th in list of absence of order and security. The growth in crime rate from 229.2 in 2014 to 233.6 in 2016 indicates an overall increase in crime. Specific categories of crime like crimes against women have seen a steep growth from 18% in 2010 to 55% in 2016. [4] According to the National Crime Records Bureau (NCRB), 378,277 cases of crimes against women were reported in 2018 which beat the number of cases from last year. [5]. The Constitution of India guarantees the fundamental right to life under Article 21 [6]. Since the independence the legislation has taken measures to reduce crime by doing necessary alterations in amendments and punishments. The Indian Penal Code (IPC) safeguards the right to self-defense. Section 96-106 of the IPC states that: "Nothing is an offence which is done in the exercise of the right of private defense" [7]. These exemptions give a lot of power and protection to the victim. However, the circumstantial nature of the attack situations makes it difficult to understand if the act of self-defense was justified or misused for selfish interests. Nevertheless, necessity knows no law [2].

Social and economic factors are the determinants of crime [4]. For designers to develop solutions, it is important to identify the factor that is responsible for the crime in a particular region. Studies have evaluated a relationship between crime and these components. Economic factors like GDP per capita, unemployment rate and demographic factors like urban population percentage have a relation with the increment/decrement of crime rate in India. Increment in GDP per capita and in urban population has a positive association with crime [8]. Economic growth and conviction rates have a direct relationship with IPC crime rates [9]. A person will commit crime only if the utility gained from it is greater than the utility gained in doing lawful acts [10]. Gender and crime have a strong relation. In India, districts with higher female–male ratio have lower murder rates [11].

The main reasons for crime in India are poverty, socioeconomic gap, urbanization, and lack of efficiency in the judicial system [4]. Some early theories have attempted to define the roots of criminality and explain criminal behavior in all genders [12]. Biological, psychological, and economic theories reveal personality traits responsible for criminal behavior [13]. In reviewing the literature on crime and criminals, it was observed that most researches have focused on criminals from weaker backgrounds. The fact that a criminal can belong to an affluent background has been missed. There is a contradiction among the researches regarding criminal traits and their identity. There is a lack of robust research on the usability of safety products by civilians and understanding user preferences. It will be addressed in this research for designing solutions that combat crime and save lives.

Parameters for a good crime scene include isolation, darkness, lack of proximity from police stations, etc. Criminals try their best to find a place that holds some aforesaid characteristics if not all. This reduces their chances of getting caught [14]. Most vulnerable places are the waiting areas of public transport during the night (bus stops, empty streets/roads, and auto/bus waiting areas). Other places are railway stations, poorly lit lanes, and abandoned buildings. Empty spaces are the perfect environment for committing a crime. A person has higher chances of being chosen as a victim in these areas [15].

In addition to a perfect crime environment, attackers choose their targets based on personal vendetta or ease of opportunity. In the latter case, attackers identify opportunity by evaluating risks and rewards. No attacker wants to get caught or injured and prefers minimum risks with maximum benefits. However, attackers who are mentally ill or under the influence of drugs are exceptions. Attackers use the element of surprise to their advantage. Awareness helps to take away this advantage from the attacker. People who are using headphones, talking/texting on the phone become easy targets [14]. Even after following all safety measures, one can still be attacked. If the attacker chooses to ignore the risks, then it becomes a matter of life and death [16]. Non-lethal weapons and safety devices are the only hope in such scenarios, especially when the victim is alone and cannot reach out for help. No attacker would want to attack an armed or a well-protected person. These products might not guarantee safety but will definitely make the person a bad target [14].

The best way to prevent crime is by creating education opportunities for all sections of the society, generating employment and promoting a secured environment [17]. These preventive measures will work if the entire society adopts them. To save lives at individual level, it is essential that people acknowledge the presence of crime and take responsibility for their safety by using non-lethal weapons.

The inception of non-lethal weapons goes back to more than a century. The British army started the use of weapons that used blunt force instead of penetration in the late 1800 s. For riot control, the army started using teak wood bullets. With the passage of time, this concept got iterated into rubber and plastic bullets. The idea of non-lethal weapons got adopted throughout the world due to its moral justification. Countries use non-lethal weapons for crowd control as these products avoid the unnecessary loss of life and suffering [18]. Non-lethal weapons have a debatable definition due to a lack of demarcation between what is lethal and what is not. Anything tangible ranging from a fork to a gun can produce lethal results if used in the right way. Therefore, the perception of the term "Non-lethal" is "less lethal." The United Nations Institute for Disarmament Research (UNIDIR) states: "Non-lethal weapons are specifically designed to incapacitate people or disable equipment, with minimal collateral damage to buildings and the environment; they should be discriminated and not cause unnecessary suffering; their effect should be temporary and reversible; and they should provide alternatives to, or raise the threshold for, use of lethal force" [19].

Existing non-lethal weapons have the following categories: Kinetic impact weapons: Weapons with striking function: batons (normal, expandable, and spiked) and projectile weapons like pellet guns (rubber and plastic bullets). Riot control agents: chemical irritants (tear gas, pepper spray, chili spray, laughing gas), dispensed liquids and foam. Available in hand held and pre-installed formats. Electric shock weapons: Projectile electric shock weapons—Tasers and close contact electroshock weapons—stun guns, stun shields, stun batons, stun belts, etc. Acoustic devices: SOS sound, ultrasonic sound devices, sound beam devices. Application-based: Location tracking, alerting (application and devices), siren alarm, camera recording for attacker proof and others [20].

19.3 Methodology

A rigorous research was conducted to achieve the following research goals:

1. Establish the need for personal safety equipment.
2. Understand the views of administrative authorities on the use of safety equipment by civilians.
3. Explore the perception and use of non-lethal weapons and safety devices by civilians.
4. Find out problems in the existing products and define user needs.

Triangulation method of research was adopted because both qualitative and quantitative data was required to achieve the aim. Quantitative data was required to draw patterns and make generalizations. Qualitative data was required to get realistic knowledge of behaviors and opinions of the target audience. Both online and offline surveys were conducted. The questions were targeted to a diverse audience of 180 people comprising civilians and administrative authorities. The questionnaire contained 20 questions that were aimed to understand the preferences and frustrations of civilians of the age of 13 years and above; and administrative authorities consisting of policemen and army officers of all age groups. Questions that were asked were multiple choice and rating questions on a 10-point scale. The following process was followed:

1. Primary resources mainly consisted of data from 2018 and 2019 reports of the National Crime Records Bureau, interviews taken at Gun Carriage Factory, Khamaria, and existing publications on the topic. This was done to gain existing statistical data that proved the increment in crime and clarified scenarios in individual crime categories (e.g., number of murder, rape cases, etc.).
2. Through secondary resources, theories of crime were studied and criminal psychology was understood. This helped in understanding crime scenarios, how and why attackers plan attacks and choose victims. The study was important for building a solution that will provide safety in maximum crime scenarios.
3. Sampling method of stratified sampling was chosen because partitioning the population into two major groups (civilians and administration officers), and sampling each group independently was advantageous for a detailed understanding. The samples within these two major groups were selected by simple random sampling and convenience sampling.
4. Through structured surveys police and army officers were interviewed. They were requested to consider both personal and official views. The aim of interviews was to understand their views on: increasing crime rate in India, legal aspects of using non-lethal weapons, effectiveness of non-lethal weapons and safety devices and the role of such devices in decreasing the crime rate.
5. After the need for personal safety products was established, civilians were interviewed through structured and unstructured surveys. The aim of these interviews was to find out: the age group and gender worst affected by crime, if people feel the need of owning personal safety products, how aware people are about existing products, their expectations and complaints from existing products, preferences of existing weapon, choice of approach (attack or defensive) during an attack situation, the confidence they would feel with a safety product and the intensity of fear of crime in their mind.
6. For additional understanding of the awareness of personal safety and opinions on it, offline semi-structured interviews were conducted with 10 participants. This was done to access the population who did not have Internet. Responses were recorded by note-taking and by audio-recording for those participants who gave their consent for it. This gave an in-depth understanding of the struggles

people face in addressing the issue and their beliefs, fears. All data was collected with the consent of the participants.

19.4 Result

The age group that is worst affected by crime is the age group of 18–30 years. Out of these people 65% were women. People of the aforesaid age group move out of their houses for opportunities of work or education and become victims of crime. During an attack situation, maximum people would call the authorities for protection and only 21% preferred defending themselves. 56% of people felt scared of using the existing products. People felt most anxious when walking alone at night (Fig. 19.1). Use of public transport and late working hours also revealed high anxiety rates. Majority of the people preferred carrying safety devices whenever they are alone (Fig. 19.2). High preference was also given to the options of carrying the device at night and while traveling. The most preferred choice in the type of device was distress alarms followed by impact weapons, tactical lights, and pepper sprays. In terms of accessibility, carrying the device on the wrist was the major choice of people. Maximum army and police officials believed that current non-lethal weapons can be misused (Fig. 19.3). However, most of them agreed that these devices have potential in bringing down crime rates if used for the right purpose (Fig. 19.4).

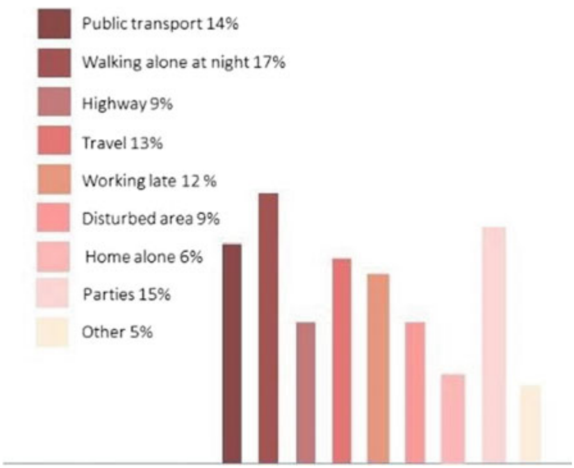

Fig. 19.1 Anxiety for personal safety

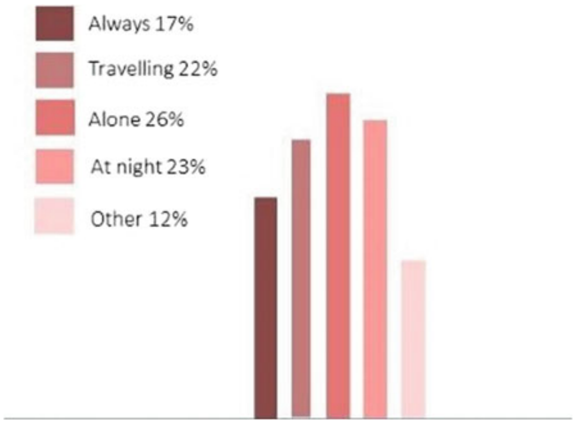

Fig. 19.2 Choice for carrying safety device

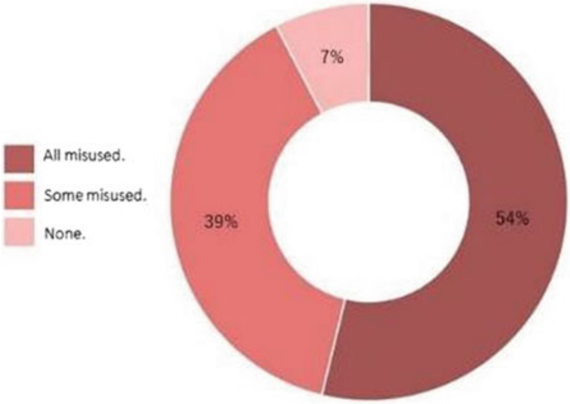

Fig. 19.3 Misuse of devices

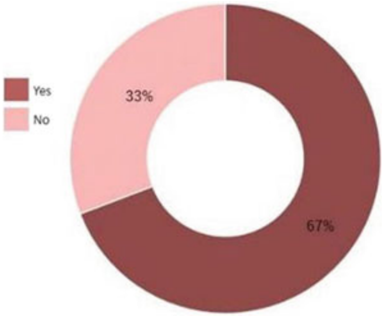

Fig. 19.4 Reduction of crime rate by safety devices

19.5 Analysis

Thematic analysis was done to analyze the data. The flexibility of this method allowed identification of common themes, ideas, and preferences. The research analysis points out the main problem with non-lethal weapons: lack of accessibility at the time of need and the chances of getting misused. Most devices like pepper sprays are handheld or stored in a purse. However if the attacker snatches away the purse or takes away the spray by overpowering the user, then the user becomes defenseless. This will worsen the situation because the attacker might use the spray on the victim. This is the case with all existing products. Due to this, people feel scared of using non-lethal weapons. Civilians feel the need for safety devices but do not own them. This shows that safety is taken for granted. There is a lack of awareness on such products and their market. People do not invest in personal safety products because they are unaware of their importance. Lack of revenue discourages investors from investing in this sector. This reduces production of safety goods. Poor quality of existing products discourages people from buying them. As a result, the popularity and demand for these products decrease. Additionally, even though authorities agree that there is a need for self-defense devices, they are not comfortable with the idea of existing non-lethal weapons being used by civilians. This is because of the lethal threat that all current products pose and might get misused.

19.6 Discussion

The results confirm that the use of non-lethal weapons and safety devices can decrease crime rates. The study suggests a scope of inverse relationship between crime rates and personal safety products. With an increase in the use of these products, the ease of committing the crime will be reduced. It can discourage criminals from committing crimes. The purpose is to avoid the attack from happening. In such a case, the ideal solution will be a set of two wearable self-defense devices. The first device can be defensive in nature with the function of deterring the attacker away. It will act like a first line of defense. It can be achieved by making the environment around the attacker uncomfortable which may force him to run away [14]. It may not help in winning a physical fight but it will give the user the time to escape the crime scene. In some cases, the attacker may be adamant in attacking a person. This scenario will require an offensive approach. A product that acts like a second line of defense and is offensive in nature can protect and empower the user. This product can be a wearable impact weapon. Both the designs can be wearable devices so that the problem of accessibility and misuse can be solved. The solution must guarantee that the devices cannot be snatched away from the user. A combination of a defensive and offensive non-lethal weapon can solve the problem of such devices being misused and provide users the confidence needed and safety. The study does not guarantee that safety products will stop every crime from happening. However, the use of such products can increase the chances of surviving an attack [16]. Self-defense products empower people to become self-sufficient and take charge of their own safety. Attack situations may not give enough time to inform the police. It may happen in an isolated place where there is no one to help. With the use of these devices the aforesaid scenarios can be improved. Self- defense devices may not stop crime from happening but they can give protection in case it happens.

This research provides a new insight into the factors affecting the rise and fall of crime in India. Lack of empathy is a major factor that plagues people with the incentive to commit crimes. In addition to the previous studies that focus on inequality in just monetary terms, this research brings forward the factor of moral inequality. In some cases, the attacker might not feel biologically, psychologically, or economically different from the rest of the society [13]. In the eyes of the criminal, he/she can be normal. Lack of empathy shown by society may intrigue them to commit crimes. Poor people are not born criminals but they can be forced into it by the rich. Nevertheless, whatever the factor may be, crime cannot be justified.

19.7 Conclusion

Loss of innocent lives by the hands of crime is a reality that can be changed. India does not have to be a country that is unsafe for its own citizens. Non-lethal weapons and safety devices can protect people who become victims of hatred and greed. This can be done by overcoming the existing problems of lack of accessibility and chances of being misused. A combination of defensive and offensive devices that are wearable can solve the problem. The research builds up on the existing literature and brings together relevant data and theories from diverse fields: law, social sciences, psychology, crime, defense, non-lethal weapons, and market of self-defense products. The research opens a window of opportunity for design and encourages to resolve the lack of safety in India. The problem areas identified in the research can be solved and innocent lives can be saved.

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Chapter 20
Design for Obsolescence Resilience

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Abstract Today, it is crucial, if not inevitable, for any company to make major or minor changes to the design of marketed products or systems in order to remain competitive. The accelerating pace of technological development fosters these changes, which can lead to the appearance of obsolete components, technologies, or system functions. It is now accepted that obsolescence occurs because of the difference between the life cycle of the components and the life cycle of the system that incorporates them. The resolution of the consequences due to obsolescence, whether proven or predicted, can have a significant impact on the architecture of the system. Indeed, due to couplings and dependencies, modeled in the system architecture, the consequences of obsolescence rarely remain confined. They can then spread gradually throughout the system. System architects and product designers must therefore be able to propose architectures that are resilient to obsolescence. In other words, they should be able to make design choices that, even when there is a risk of obsolescence, ensure continuity of functionality with the expected performance and within constraints. This work consists in proposing modeling of the system architecture using probabilistic graphs. These models offer the possibility to study various design configurations and to determine their consequences on the performance and functional requirements of the system. We propose simulations of different design scenarios in the presence of obsolescence. The objective is to qualify the resilience of the system under different design alternatives. A set of numerical experiments will be conducted to identify the most resilient design. This approach will be illustrated by a case study from a weather forecasting system. A discussion of the results and conclusions will conclude the paper.

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A. Chakrabarti et al. (eds.), *Design for Tomorrow–Volume 3*,
Smart Innovation, Systems and Technologies 223,
https://doi.org/10.1007/978-981-16-0084-5_20

20.1 Introduction

Customers are increasingly demanding, and competition in the industrial world is growing. For this reason, companies are accelerating the pace of engineering changes. They are changing the functions, components and even functionality of such a product to maintain its market position. This accelerated pace of change has therefore created another phenomenon, which is obsolescence. Indeed, new products are taking the place of old ones. This shortens product life cycles. If obsolescence affects a product, its turnover decreases rapidly. This may lead to losses for companies. To maintain products and systems with a long field life, obsolescence management strategies must be used. Obsolescence can affect any type of system and all elements of a system's architecture (component, function, or functionality). The risks arise particularly if obsolescence spreads throughout the system. So monitoring this propagation and knowing its path is important in the strategy of obsolescence management. Among the tools that study and calculate the probability of an event on architecture is the Bayesian networks and its software BayesiaLab.

20.2 Literature Review

20.2.1 Obsolescence

The Oxford English Dictionary [1] defines the noun "**obsolescence**" as "The state of being which occurs when an object, service or practice is no longer wanted even though it may still be in good working order." In other words, a product or system is obsolete when it no longer meets the functionality expected by customers. The obsolescence affects hardware and software. The principal reasons of the obsolescence are technology advancements [2] (new products appear instead the old ones), lack of support from vendors [2] (the organization is obliged to modify their product to obtain the necessary updates), merger and acquisition of a business [3] (The acquired organization may have to change its existing system, if it is not compatible with the other system used in the acquiring organization.) and incompatible product.

It is essential to mitigate the risk of obsolescence in order to minimize costs throughout the product lifecycle. There are several mitigation strategies. Sandborn [4] defines three types of obsolescence management: reactive, proactive, and strategic management.

- *Reactive obsolescence management*: This type of strategy is made for unexpected obsolescence events. We have to find a quick and immediate solution. Tomczykowski cites these solutions in [5] (Using excite stock, Life Time Buy (LTB), Redesign, Emulation, …).
- *Proactive obsolescence management*: In this case, the obsolescence has not yet been produced, but its possible date is foreseen. Among these forecasting

approaches, Soloman [6] proposed a method which contains seven steps. The essential idea of this method is the collection of data to determine the life cycle curve of such a product. Then by using the function provided by this curve, we estimate the date of obsolescence.

- *Strategic obsolescence management*: As its name indicates, these are long-term strategic approaches. It is a planning to reduce the risks of obsolescence by using different information (date of obsolescence, sales forecasts and logistic data). It excites two strategic approaches [7]: material risk indices (MRI) and design refresh.

20.2.2 Bayesian Network (BN)

Bayesian networks are part of the "Probabilistic Graphical Models" family. These models are developed to enrich the reasoning of systems whose operation is based on a set of uncertain rules. A BN is a technique for encoding a set of conditional independence propositions [8].

A BN is a directed graph with two properties: (i) qualitative property: the graph is oriented and acyclic, (ii) quantitative property: the probabilities of the parameters represented by the nodes are oriented such that they respect the Markovian condition that the conditional probability distribution of each parameter depends only on its parents. The existence of a link oriented from X to Z means that the state of Z depends on the state of X. In this construction, parameter/node X is the "parent" and parameter/node Z is the "child."

The Bayes rule (20.1) allows us to calculate the probability of occurrence of the child Z depending on the occurrence of parent X and vice versa.

$$P(X|Z) = \frac{P(X \wedge Z)}{P(Z)} = \frac{P(X, Z)}{P(Z)} = \frac{P(Z|X)P(X)}{P(Z)} \tag{20.1}$$

20.3 Obso-Mitigation Process

The three types of obsolescence management do not give a process to be followed in detail from the moment an obsolescence event occurs. In this section, we propose "Obso-Mitigation Process" in Fig. 20.1. This is a sequence that contains steps to follow in order to provide design solutions to a system affected or likely to be affected by obsolescence. The process is triggered by an obsolescence produced by one or more of the obsolescence causes developed in Sect. 20.2.1. It is necessary here to know the perimeter of this obsolescence, the subsystems concerned, the functions and the components.

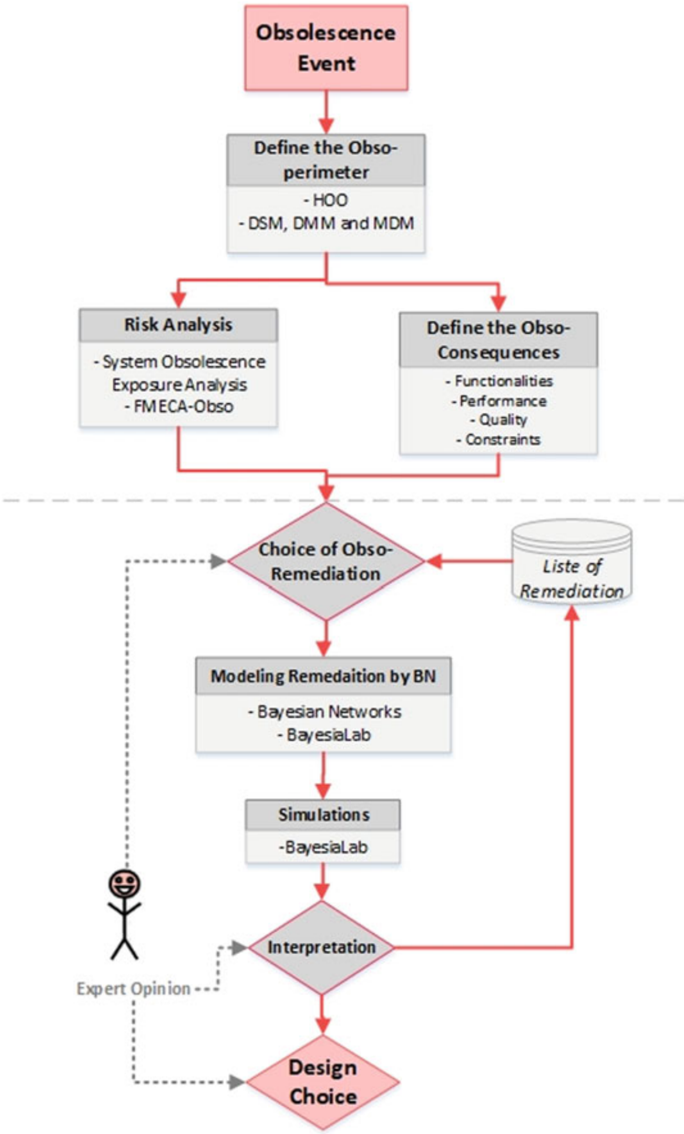


Fig. 20.1 Obso-mitigation process

20.3.1 *Obso-Perimeter*

The first step is to know the potential sources of obsolescence and the scope of its effect. We try to find out which elements of the system architecture may be sensitive to an obsolescence outcome. Soltan et al. [9] propose two types of sources of obsolescence. The first is external, which is generated either by the consumer, by the supplier or by the environment (supplier-driven, user-driven, and environment-initiated obsolescence). All three elements make up the external world of a system. The second type is internal, which is triggered by the system designer himself by proposing design improvements and corrections (designer-driven obsolescence).

For external source, Zolghadri et al. [10] propose the House Of Obsolescence tool, HOO which allows to link the three external sources of obsolescence by the components and functions of the system; see Fig. 20.7 in appendix. They propose three HOOs: Usage-Design House of Obsolescence for changes in customer requirements, Environment-Design House Of Obsolescence for environmental changes, and Supply-Design House of Obsolescence for Supplier-driven obsolescence issue.

In our work, we will focus on the Usage-Design House Of Obsolescence in the application case. The Fun-F sub-matrix detects the functions affected by changing requirements. For components, the PhyS-C sub-matrix is used; see Fig. 20.7 in appendix.

These tools are mainly based on design structure matrices (DSM) and domain mapping matrices (DMM) [11]. The relationships between Function and Function (F-F) and between Component and Component (C-C) are determined by two DSMs as they are square matrices. For the representation of dependencies between components and functions (C-F, who does what), a DMM can be used.

20.3.2 Risk Analysis and Identification of Obso-Consequences

The first step offers a set of functions and components that have different degrees of sensitivity to the risk of obsolescence. Therefore, a risk analysis must be put in place. Trabelsi et al. [12] develop a method to calculate the "degree of obsolescence" (DO). It is based on a mathematical model using the Weibull model [13]. The inputs of this model are "G" Gravity (measure the gravity of the obsolescence problem.), "O" occurrence (degree of obsolescence occurrence), and "D" detection (description of Obsolescence detectability).

They are determined by the Failure Modes, Effects and Criticality Analysis (FMECA) method. This tool is used in several domains in order to study the potential failure that may exist during the design of a system [14]. Trabelsi et al. [12] and Zolghadri et al. [10] adapt this tool to study the risk of obsolescence (FMECA-obso).

The DO is given by the following equation [12]:

$$\text{at}\, t = t_{\mathrm{o}}; \quad \mathrm{DO} = \int_{0}^{t_{\mathrm{o}}} \frac{k}{\lambda}\left(\frac{t}{\lambda}\right)^{k-1} \mathrm{e}^{-\left(\frac{t}{\lambda}\right)^{k}} \mathrm{d}t \tag{20.2}$$

where t_o corresponds to the date of observation and t, θ, k, and λ are strictly positive parameters and are determined basically from G, O, and D.

In addition to the risk analysis, it is necessary to know the possible consequences of obsolescence on the whole system and on the proper functioning of all system characteristics. For this purpose, Zolghadri et al. [10] propose four categories of possible consequences (obso-consequences): functionality, quality, performance, and constraint.

20.3.3 Choice of Obso-Remediation

Based on the degree of obsolescence and the potential consequences of obsolescence, we attempt to come up with a design solution. In the guide [15], there is a database of different types of possible design remediation; see Fig. 20.6 in appendix. It contains ten types of solution depending on the type of change created.

A brainstorming between system designers and experts should be carried out in order to choose the most appropriate types of solutions. This choice is based on the degree of obsolescence, and if it is necessary to change either the component or the function the most affected by obsolescence, or this element and the component that contains it, or the entire subsystem. The choice can be based on more than one solution if there is more than one highly sensitive element of obsolescence.

20.3.4 Modeling of Remediation by BN

To test the design choice and to make the decision to adapt it as a remediation of obsolescence, a probabilistic analysis must be done by Bayesian networks. For this, a Bayesian network of the initial system must be available before obsolescence occurs. A modification in this network is made in order to adapt it to this remediation scenario. So, if it is a question of adding functions or components, nodes are used and to show the new relationships between the new elements and the others, arcs are used. The purpose of this step is to check the coherence between all the components of the system and their proper functioning.

20.3.5 Simulations et Interpretations

This step concerns the simulation of the model containing the solution. In each simulation, the performance rates of the system components and functions are evaluated. When creating changes in the design, the design constraints mentioned in the specification must be maintained. The expert is consulted to interpret the results of the simulations. If the solution destroys the main functionality or affects the design requirements and constraints, another solution must be adapted; see Fig. 20.1. The same loop is then repeated: adapt the BN to the new solution, run the simulations, and interpret new ones until the right choice is made. This choice must keep the functionalities of the system and proposes an obsolescence resilient architecture (can resist to an obsolescence event and keep its main functionalities).

20.4 Case of Study

EOLE is a balloon probe system to provide meteorological data to users. It has two subsystems: an acquisition subsystem "in the air" and a ground processing subsystem.

Users of metrological data have proposed numerous recommendations in order to provide them with metrology bulletins with higher altitudes and to increase the capacity to carry the payload. In situations where scientific users want to have pictures in a higher altitude on different sides, the system must be able to transmit this payload in the air. So it is necessary to find a solution to meet these new requirements. In fact, the balloon technology used in the original design is a weather balloon 200 [16] which can reach a maximum altitude of 23,000 m and carry a load of only 200 g; cf. Fig. 20.2.

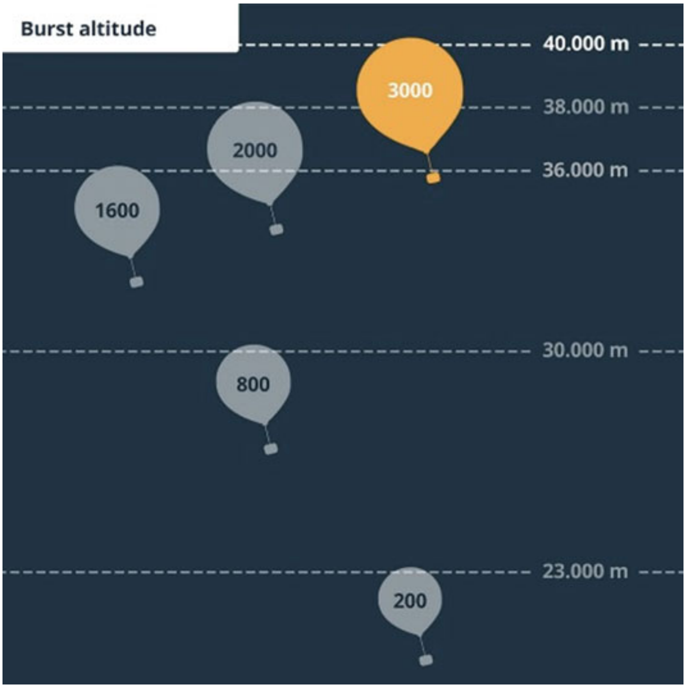


Fig. 20.2 Types of weather balloon technologies [16]

In order to find a suitable design choice that meets the new requirement and to mitigate this obsolescence, the obso-mitigation process will be applied.

20.4.1 Usage-Design HOO and Risk Analysis

The system contains two main functionalities. EOLE ensures the determination of the current metrological situation. This first functionality is provided by the in-flight partial. So, the balloon ensures the removal of a box that hosts pressure and temperature sensors. These data are transmitted by radio frequency to a ground station which performs the second functionality. Its mission is to treat the information received and elaborate it by software in order to forecast the weather. The data are then published to the scientific user with a management of his subscriptions to access these data.

We use the Usage-Design HOO because the source of obsolescence is the appearance of new customer requirements.

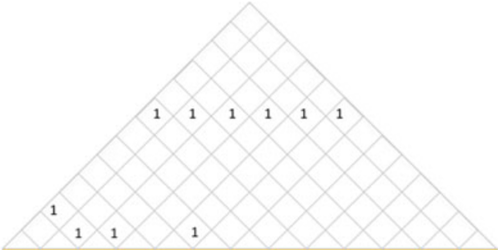
The obsolescence scenario mainly affects the first functionality (current weather). There are three functions that are affected by the obsolescence issue. The ability to lift the system has to be increased and its ability to carry a load too. There is a change in the intervals of weather data due to changing altitude limits. By using this tool, the functions and components touched by these changes are detected (identify the possible propagation perimeter).

According to HOO in Fig. 20.3, the following components with their functions are affected: temperature sensor, pressure sensor, and radio transmitter and receiver. Also, the weather balloon component is affected as well. The sensors and the radio are designed to operate normally at very high altitudes [16], but the balloon can reach a lower altitude than required by the customers. So, the obsolescence risk analysis will be done on this component.

In order to perform the risk analysis, the three inputs required to calculate the DO must be determined: gravity: $G = 6$ (important), occurrence: $O = 10$ (No doubt, real), and detection: $D = 1$ (easy to detect). The simulation of the DO formula gives a value of DO $= 63.2\%$.

20.4.2 Choice of Remediation

Based on the obsolescence perimeter and the risk associated with the critical component (Weather Balloon), a possible remediation to mitigate the risk of obsolescence is selected from the list in Fig. 20.6 in the appendix. This choice is based on the assessment of the system expert. For this case study, the choice is fixed on the type 7 of remediation: "choice of another component with other characteristics." The 3000 technology [16] is chosen, which offers temperatures up to the 40,000 m attitude and carries a payload of up to 1600 g; cf. Fig. 20.2.



		Acquire the temperature	Acquire the pressure	Transmission of metrological data	Elaborate on the current situation	Prepare publication	Manage subscriptions	Weather Balloon	Temperature Sensor	Pressure Sensor	Radio Emitter and Receiver	Data Processing Software	Publication Software	Subscription Management Software
Current Weather	Ensure the system flight	X	X	X	X			X	X	X	X			
	Acquire temperature and pressure	X	X						X	X				
	Carry a payload			X				X						

Fig. 20.3 Usage-design HOO of EOLE

To evaluate the effectiveness of the chosen solution and to verify the resilience of a system, the solution must be modeled and the functionality and performance of the system must be tested using Bayesian networks. In order to model the solution, the node representing the initial balloon must be changed to a node representing the new type. The DO is used to fill in the CPT for this node. An additional cost is associated due to the cost of purchasing the new balloon. The Bayesian network that includes the modeling of the solution is shown in Fig. 20.4. The components and functions of the flying part are modeled since the perimeter of obsolescence propagation is identified in this part of the system.

The simulation is run to see how the total system responds to these changes.

20.5 Interpretations and Future Scope

Figure 20.5 illustrates the performance rate of the functions in the subsystem (feasibility: its ability to provide the requested task). For the temperature and pressure sensing, functions have a feasibility rate of 97.63% and 98.75%, respectively. These values are discussed with an expert and deduced that are within the accepted tolerance ranges. For the final function of the in-flight part “transmission of meteorological data,” we have a rate of 96.66% which is satisfactory. It is noted that the application of this remediation resulted in an additional cost of 800 euros.

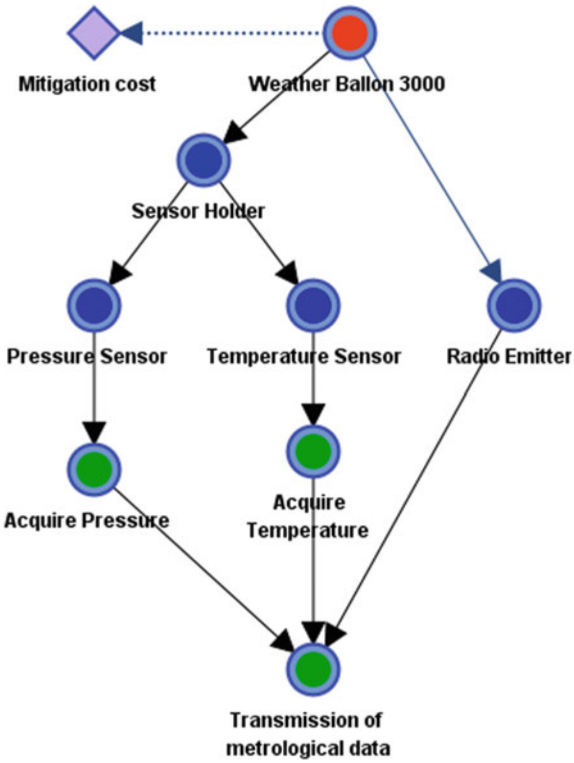


Fig. 20.4 BN of the subsystem in the air of EOLE

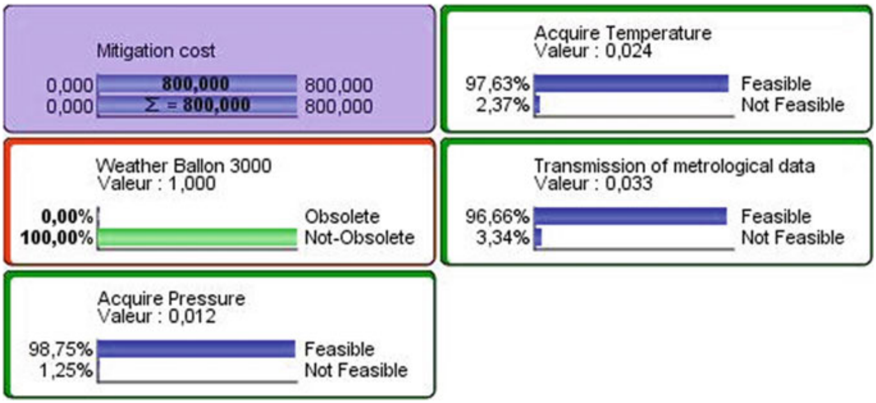


Fig. 20.5 BN's simulation

Making changes is paramount in product design, but the challenge lies in keeping the system in a state of equilibrium in the face of change. So, the question is how to maintain a system's resilience to the changes produced by an obsolescent issue. In order to design a resilient design, a process of obsolescence mitigation is illustrated in this work. It shows the steps to be followed from the occurrence of an obsolescence event to the implementation of remediation with a verification of this choice.

The "Obso-Mitigation Process" is based on a single occurrence of obsolescence, which is a limitation of our work. In the reality of the industrial world, we can be confronted with several issues of obsolescence. For example, a new regulation can lead to the simultaneous cessation of the use of several elements of a system's architecture. It can then be expected that several obsolescence remediations analyzed separately will not offer a multi-resilient architecture. This problem deserves to be studied, and we have made it one of our future research projects. Another part of future research is the study of system architecture to ensure resilience throughout all phases of the product life cycle.

Appendix

See Figs. 20.6 and 20.7.

	Resolution	*Definition*
1	No solution required	Existing stock will satisfy future demand.
2	Approved item	The issue is resolved by the use of items already approved on and still in production.
3	End-of-need buy	A sufficient quantity is purchased to sustain the product until its next technology refreshment or the discontinuance of the host assembly.
4	Repair	The issue is resolved by: Repair, Reclamation of items from marginal, out-of-service, or surplus materials, , ... to ensure continued support.
5	Extension of produc. or support	The supplier is incentivized to continue providing the obsolete items.
6	Simple substitute	The item is replaced with an existing item that meets all requirements without modification to either the item or its Next-Higher Assembly and requires only minimal qualification.
7	Complex substitute	A replacement item that has different specifications but requires no modification of the source product or the NHA, is researched and validated.
8	Dvp of a new item or source	A replacement product is developed that meets the requirements of the original product without affecting the NHA.
9	Redesign-NHA	The affected item's NHA must be modified. Only the NHA is affected, and the new design will not affect anything at a higher level.
10	Redesign–complex/ system replacement	A major assembly redesign affects assemblies beyond the obsolete item's NHA and may require that higher level assemblies, software, and interfaces be changed.

Fig. 20.6 List of obso-remediation [15]

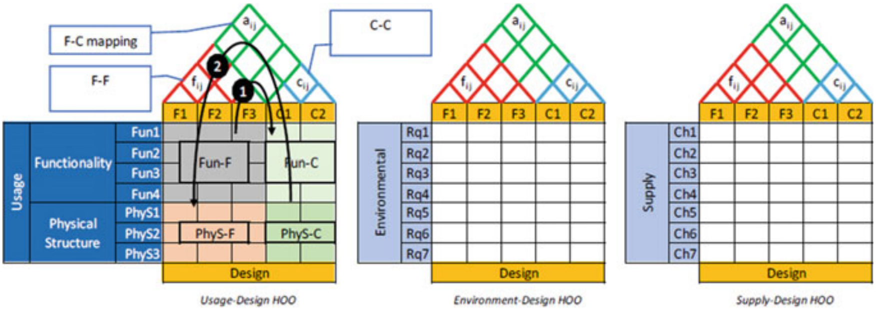


Fig. 20.7 Usage-design, environment-design, and supply-design houses of obsolescence [10]

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Chapter 21
Lightweighting in Electric Vehicles: Review of the Design Strategies Based on Patents and Publications

Anton Kumanan, Sudhir Varadarajan, and Karthic Narayanan

Abstract Lightweighting is one of the key focus areas in the automotive industry. It continues to be in focus even as the industry is shifting from internal combustion engines (ICE) to electric vehicles (EV). While the objective of lightweighting is similar in both ICE and EV, the differences in the product architecture of EV when compared to ICE affect the scope and approach for lightweighting in EV. In this paper, we attempt to tease out the lightweighting design strategies being adopted by automotive industry for EV. The key drivers and their relationships are identified through a study of recent patents and publications using a network perspective.

21.1 Introduction

There are strong indicators that EV is now on a path to replace ICE in the coming decade. The sale of EV has been increasing across the world since 2017. Adoption of EVs by consumers has increased in China, USA, and the European countries, with Nissan Leaf and Tesla Model 3 as the top selling EV in 2018 [1]. However, widespread EV adoption is affected by factors such as high cost and short range.

One of the strategies to improve range is lightweighting. However, lightweighting in EV is different compared to ICE due to the difference in product architecture. The change in the source of energy of EV has necessitated a change in its body structure. For instance, batteries in EV account for approximately 25% of the total weight of the vehicle, and it is in direct proportion to the range. Due to this, lightweight materials and designs are of interest starting from small range of 50 km range to

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A. Chakrabarti et al. (eds.), *Design for Tomorrow–Volume 3*,
Smart Innovation, Systems and Technologies 223,
https://doi.org/10.1007/978-981-16-0084-5_21

almost 400 km range. In high-end car with 400 km range vehicle, lightweighting is more critical compared to smaller range vehicle.

One of the key focus areas in lightweighting is material selection [2]. Literature shows that attempts have been made to look at lightweighting at a part level through use of materials like composites and aluminum (Al) or at the vehicle–system level using combination of different materials like advanced high strength steel (AHSS), magnesium (Mg) and carbon fiber composites (CFC) and different joining techniques. A second focus area in lightweighting is the design (structure and form). Literature shows that prominently used designs include sandwich, multi-materials, stacking, and bionic designs. Materials and design go hand in hand as a low-density material with poorly optimized design will not get the best lightweight for end application.

This paper reviews the underlying design strategies being adopted for EV (relationship between parts, materials, and designs) through a study of recent patents and publications. An attempt is made to use network analysis to extract more information from the relationship matrix. The study of patents and publications also reveals certain differences. In the next section, lightweighting in EV is discussed in detail.

21.2 Lightweighting in EV

One of the key objectives of lightweighting in EV is to improve range of vehicle. When compared to ICE, EV adds up approximately 200 kg which is mainly due to the e-powertrain and battery systems [3]. In ICE, the lightweighting is done in almost all the parts as a vehicle level, whereas in EV, the lightweighting is more concentrated on the chassis and the body region based on the packaging of the battery pack as other parts are similar to ICE. To reap the benefit of EV, the weight reduction must be compensated in other systems like the body, chassis, closures, and interiors without compromising on the functional requirements. Therefore, lightweighting in EV is far more challenging compared to ICE.

Lightweighting has led to significant increase in the use of lightweighting materials. For example, BMW i3 and Tesla Model S which are designed EV vehicles which although their battery capacity range are different, the energy consumption per kilometer (Wh/km) is a parameter to look for efficiency. Tesla Model S with a 60 KWh capacity battery with a weight of 2215 kg consumes energy of 200 Wh/km compared to BMW i3 which is a composites intense vehicle with 33 KWh capacity battery and a weight of 1440 kg consumes nearly half energy per kilometer. This example clearly shows even in case of EV how important is to shred the weight of the vehicle [4].

Toyota EQ, Ford Focus Electric, BMW Mini E, and Renault Fluence ZE where the conventional ICE has been adopted to electric version. Rather more benefits in performance and efficiency are achieved by naturally adopted models like BMW i3, Renault Zoe, Nissan Leaf, Model S [5]. This clearly shows that the architecture of EV is different compared to ICE.

The main difference between EV and ICE architecture is the engine, power transmission, chassis, exhaust and fuel storage. These components account for 50% of the weight of EV. Since the rest of the components are same as the ICE, the overall weight of EV always higher [6].

In ICE, lightweighting is mostly done on cast iron parts by replacing them with steel and aluminum and optimizing from manufacturing to parts performance. In EV, lightweighting mostly started at the base with steels and aluminum and now progressing toward magnesium and advanced composites. The main difference between the EV and ICE body design lies in the structural reinforcement of various parts around the battery. Much reinforcement needs to be added in pillars, frames, cross members, and energy absorbers in all applicable areas where crash is vulnerable [7]. This added reinforcement itself can lead to increase in weight added over the battery weight.

The goal of this work is to identify key direction where industry and academic research are heading and the methodologies used to attain the targeted lightweighting especially in EV. Lightweighting in EV requires a good understanding of the relationship between the parts–materials–design is important because some parts may work well with certain materials and structural designs. In this work, we focus on the pattern of relationships observed in recent patents and publications since 2017 (the time since when there has been a big jump in sales of EV). E-powertrain which includes the E-motor, battery pack, and the electronics part associated with that are not part of the scope.

21.3 Analysis of Recent Patents and Publications

The literature on lightweighting in EV is scarce. However, there have been an increased number of patents in this area. Therefore, an attempt has been made to study both patents and publications. Patents have been studied in the past to understand the relationship between EV suppliers and OEM's [8]. Detailed patent search was done using open patent search engine for patents for which the following keywords "*Electric Vehicle*", "*Lightweighting*", "*Industry*" were used. Similarly, journal publication search was done in public search engine with the following keywords "*Electric Vehicle*", "*Lightweighting*", "*Industry*".

The patents and publications were listed for "lightweighting" and an industry associated to that was mapped separately. Screening was done with the published date from 2017 to March 2020. The re-categorization of the data was done in following steps

- Industry wise the data was classification on lightweighting
- Automotive list taken from other industries
- EV lightweighting in automotive screened from other
- EV lightweighting—Parts and process were segregated to understand more on what type of parts and process in EV's is more looked at.

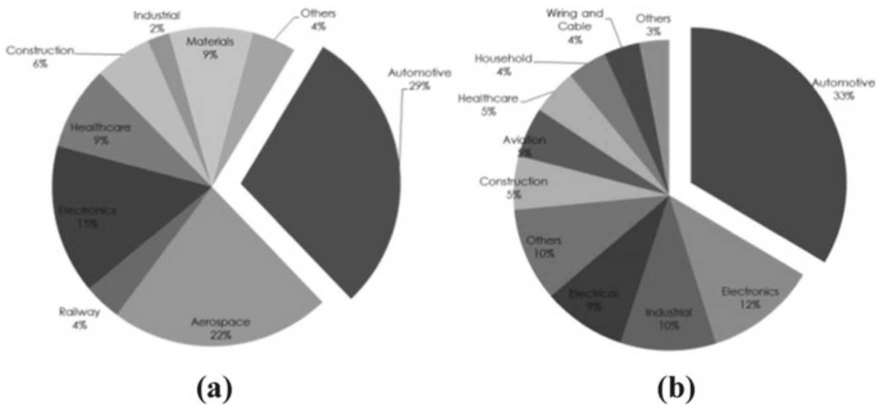

Fig. 21.1 Lightweighting in different industries, **a** Patents, **b** Publications

The above four steps were done for both patents and publications.

Categorizing industry wide and selecting automotive in which of those EV were looked into was screened. In the EV list, then, further classification was done based what has been discussed either the parts or process associated. Process could mean any process of making, testing, and designing parts of EV. Parts are mostly automotive parts used in EV and their description for lightweighting.

Out of 483 patents published since 2017, 31% of those were concentrated in automotive lightweighting. Similar trend was also observed in publications also where we were able to see 29% from the total of 365 articles. Figure 21.1a, b shows clearly that the automotive industry is keen in looking for lightweighting compared to others. There are also many other industry aerospace, electrical and electronics, healthcare, and construction in a decreasing order.

Since our aim was to look into lightweighting in especially EV, further deep dive in automotive literature was taken in both patents (162) and publications (131). Among the 162 patents related to lightweighting in automotive, it was found that majority (103) were focused on EV. On the other hand in 131 publications only few (33) were talking on EV. This can be attributed to the fact that apart from e-powertrain and battery components, most of the parts are same between ICE and an EV. Another important argument that can be made is that patents will be very specific to EV's for novelty. Selected articles were deep dived and listed according to their parts, material, and designs in the works which have also been modeled in network perspective. Further, the parts and process were again classified into materials and design-oriented approach. The detailed classification is shown in Fig. 21.2 where the automotive lightweighting is classified till design and materials.

There is a visible difference in the output of patents and publications as all of the patents are from industries and concentrated more from China. Publications on lightweighting in EV are very minimal as the publications are mostly from university and also most of the parts that were discussed in publications were common parts for EV and ICE. Both patents and publications gave different perspective of the

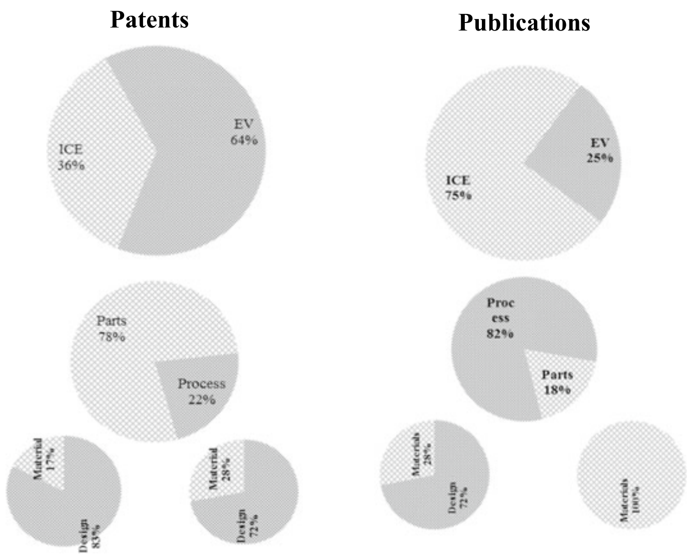

Fig. 21.2 Classification of references in patents and publications since 2017

analysis as patents were talking more on the parts whereas publications were more concentrated on the process associated with those parts. Further classification in both patents and publications indicates clearly lightweighting is more of design oriented compared to material oriented.

Total of 33 patents and 40 publications were shortlisted for next step of analysis. The summary of the parts, materials, and design was taken and a network model was constructed to identify patterns in the data. Kumke et al. have used similar network analysis to understand which of the design is suitable for a product. In that work, authors had tried to understand the design potentials for making a part with network analysis [9], which has clearly shown in the form of network analysis and the relationship with other parameters like cost, complexity in manufacturing, material, time and product value. Inspired by this work, an attempt was made to do networking on the data available from patents and publications. This is very important to understand the underlying relationship as this tool can be used to take material or design used in other industries like wind and aviation where also lightweighting is dominant. But, in this current work, we have restricted our understanding to only automotive EV parts with materials and design network perspective.

21.4 Network Perspective of Lightweighting in EV

Detailed analysis was done on selected 73 articles using software Gephi® which is a networking analysis tool. The parts were labeled against the materials and design involved in each article. In few article, a single part was discussed with single material involving multiple design concepts and vice versa was also present. For example, bumper beam was made with three different materials and three different designs in one of the literature which forms nine entries together. Similarly, total of 73 patents and publications led to 344 relationships. The data was incorporated into the software Gephi and one of the in-built algorithms which gave a result as shown in Fig. 21.3. This is the complete network of relation which is centered based on the parts in patents and publications.

The network chart clearly shows how different researchers in industry and academics have looked into lightweighting of EV for different parts. This approach totally gives a different perspective of looking at the literature review paper which usually is done in a table format with references. This networking perspective also helps to understand the key parts that are considered mostly for lightweighting in EV. Battery tray, body, bumper beam, hood, and door impact beam are the critical parts that has been worked on extensively for lightweighting in EV. Materials like steel, aluminum, and composites are extensively used and honeycomb, stacking, sandwich, different profiles designs are very prominent among designs. As stated earlier, this analysis is done for a time frame of past 3 years since 2017 due to which the least

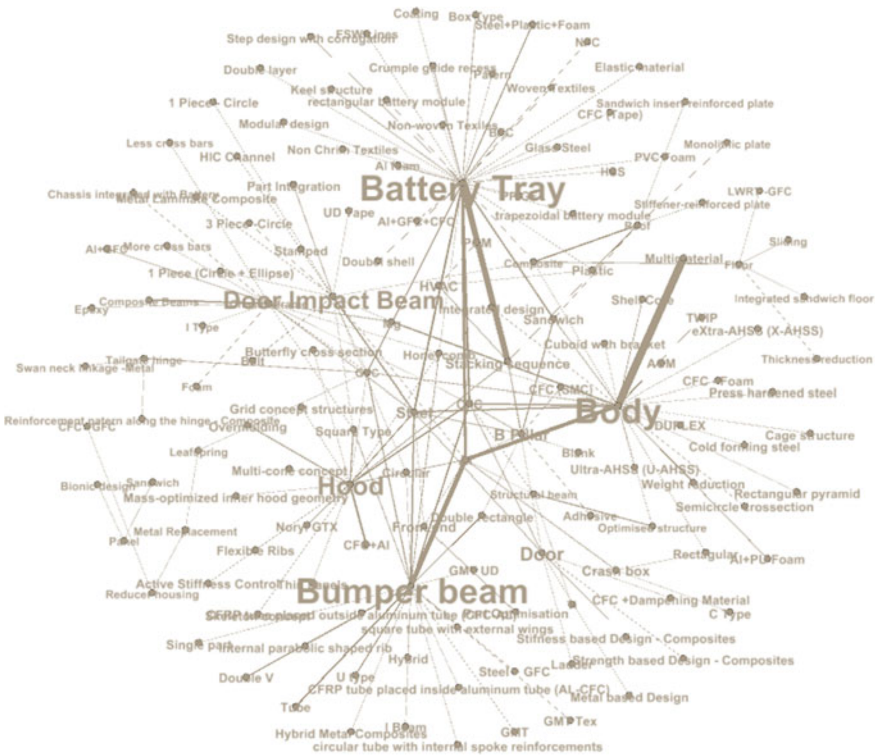

Fig. 21.3 Network perspective of literature survey

used materials and designs cannot be ignored as they may be the futurist approaches which are evolving or still not have much attention.

Further to that cross-pollination ideas can evolve from these approaches which will be a real success of this network perspective. Material and design used for on part can be taken to other part with lots of confidence. In this work, battery tray, steel, and honeycomb designs are the top denser nodes which are mostly used for lightweighting in EV. Alternative thinking can be put in front to understand what not has been done and why the same has not been done. This will help to understand the limitations and challenges to go ahead with that particular.

It also gives a holistic view of the clustered networks which obviously show the parts are more looked on. Similarly, one can see the clustering of material used also which will be connected to multiple parts. This work mainly talks about the part front, in which materials and design will be the subset of the part in the networks.

Parts: Battery tray which is holds the battery in EV is a standalone part specific to EV. Figure 21.4 shows the segregation of network in parts centric format where the design is on the left and material is on the right. The parts connectivity with materials and designs are plotted in chart shown in Fig. 21.5. The size of the bubbles shows the number of connectivity with that part and *X*- and *Y*-axis are the material and design connectivity, respectively. It is clearly evident that the structural members like the bumper beam, door impact beam, chassis, and hood are more oriented toward design concepts. Battery tray, body, and B-pillar are the parts which are having nearly equal connectivity with materials and designs. Battery tray is a new part for EV where the work with material and parts is common among researchers. The structural part which is mostly energy absorbers for the vehicle is design oriented. This clearly indicates that energy-absorbing parts are more design oriented than material and especially in EV, these is the parts improve crashworthiness.

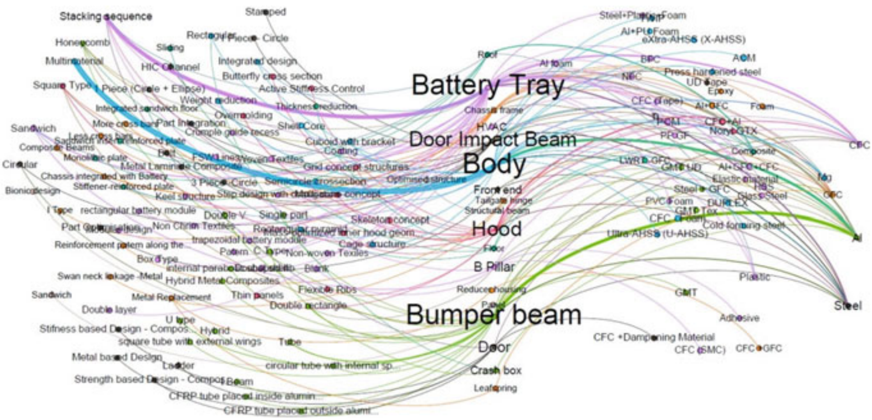

Fig. 21.4 Part centric—networking

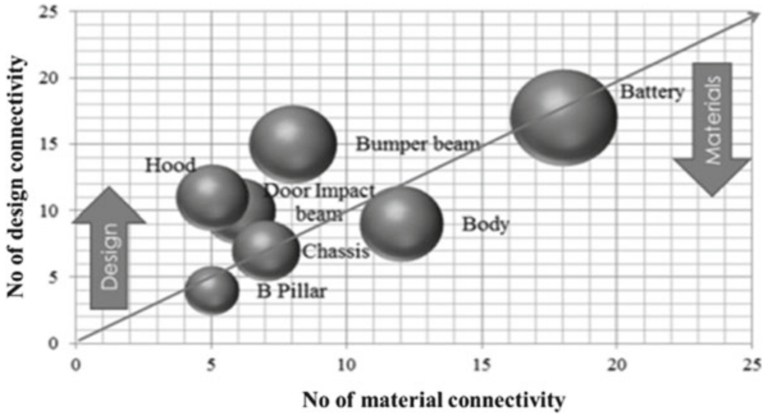

Fig. 21.5 Parts—materials and design

Materials: Steel which is the traditional and mostly used material in current vehicles has the higher connectivity with parts. Aluminum is the next more connected material with most of the parts due to lower density compared to steel. Composites (carbon fiber and glass fiber) are next key materials in lightweighting as it provides lot of design flexibility compared to metals. Magnesium is another material which is getting more traction in body and chassis mostly due to its lower density and good processability compared to aluminum.

Design: Design concepts mostly prevailing were honeycomb structures for reinforcement or extruded beams provided much better results in crash and safety perspective. Stacking and sandwich structure help to tweak the material properties based on the required level of absorption needed. Designs will have one or more materials joined together which will be fused as laminates by any joining techniques. Part integration is also one of the key design concept that people have used since ICE to reduce the number of parts and have a single part which avoids joining techniques. The purpose of design is going to gain traction design conversion to deployment in vehicle which is very important [5]. Similar work can be extrapolated to ICE and checked if the parts are similarly centered or there are some other parts which is in the center. This will give a clear picture of EV-specific parts and its importance in lightweighting which can be a future work.

Current work is based on part centric approach; there may be different results if we look it from materials and designs as the centers. In the left side of the design which includes both the structure and form of the parts list in which the impact of structure is more than the form. So form factor of the design may be underexploited. In case of battery lightweight in EV, more density could be found on the stacking sequence which is the structural form; however, there is also few form-dependent designs like trapezoidal battery model [10].

Interpretation of the network chart was done in detail by taking its PageRank and Eigen centrality. Eigen centrality is a measure of the highly influential node and

PageRank is the node having links with highly influential nodes. Since this was a part centric work, the parts were removed for this analysis and tried to understand only the materials and design which were more influential. Steel > Aluminum > CFC > GFC > Honeycomb was the order of high Eigen centrality and Steel > Aluminum > CFC > GFC > Stacking sequence of PageRank. The material used has the same influence in both Eigen centrality and PageRank but the design concept had a change. Although honeycomb design was the most highly influential node, but stacking sequence was more connected with other highly influential nodes. So the interpretation of network analysis gives us a different angle to be looked upon which will provoke new underlying understanding of relationships. Same is clearly shown in Fig. 21.5 where the honeycomb is connected with only structural beams, whereas the stacking sequence is almost used in all the parts.

The future work is to study the design elements of the battery system such as battery cells, crash structure, BMS unit, cooling unit, and wiring harness to identify the opportunity for lightweighting. Preliminary analysis of battery cells which contribute to majority of weight of battery pack indicates that form of the cell has an important role to play in lightweighting. For example, different forms like cylindrical, prismatic, and pouch type [11] have different packing efficiency, heat dissipation [12], and contribution to weight.

21.5 Conclusion

The current analysis of recent patents and publications has been done to understand whether there is any significant importance given to lightweighting in EV similar to ICE. This analysis of recent patents and publications since 2017 clearly shows that lightweighting is still considered significant in EV. The key contribution is the literature study modeled to check if there are any underlying relations between the part, material, and design in all permutation and combinations. The center of lightweighting in EV considered within the scope of this work is mostly on the battery tray and its surrounding parts that protect the battery. The research could be in the direction of battery tray and the reinforcements required for further research and attaining lightweighting based on materials and design, as they will significantly increase the range of EV vehicles. In case of battery pack, there is also more increased effort taken to probe the form factor of the design to achieve lightweighting.

The complete work has been based on the patents and publications from open source with a set of keywords. However, there is no guarantee that it provides completeness of search which is a limitation in this work. The inference made out of this work is subjected to this limited data.

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Chapter 22
Rule of Mixtures Model to Determine Tensile Strength of 3D-Printed Kevlar-Reinforced Nylon: Thermal Gravimetric Analysis of Kevlar Filaments

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Abstract Incorporation of high strength composite materials into additive manufacturing by fused deposition modeling (FDM) has opened the doors to new lightweight, robust, and efficient structures. However, our knowledge of the behavior of these structures under various loading conditions is still not completely understood. Further, with the large number of fiber and matrix options to choose from, the number of possible combinations of composites is quickly increasing. This is making experimental testing of every possible combination prohibitive due to its large time and cost investment. The issue gets more complicated when structures with complicated geometries need to be analyzed. This calls for designing a model that can use the data from simple experiments to accurately predict the behavior of structures under various loading conditions. This work highlights an experimental procedure to determine the elastic modulus and tensile strength of Kevlar fiber-reinforced nylon (KFRN) samples produced with FDM. The thermal gravimetric analysis (TGA) was employed to quantify the volume fraction of fiber and matrix in the filament. Samples with varying fiber reinforcement layer configurations were manufactured based on standards. Tensile tests were performed to determine the elastic modulus and tensile strength of the samples. A rule of mixtures model was used to estimate the load borne by each layer configuration. The results demonstrate that the relation between volume fraction and load-bearing capacity follows the rule of mixtures. This work provides a straightforward method to determine the tensile strength and elastic modulus of KFRN parts produced by FDM. The approach may decrease development time by simplifying the design process.

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A. Chakrabarti et al. (eds.), *Design for Tomorrow–Volume 3*,
Smart Innovation, Systems and Technologies 223,
https://doi.org/10.1007/978-981-16-0084-5_22

22.1 Introduction

Additive manufacturing by FDM has advanced to a popular method for building prototypes and manufacturing of small production batches. New developments in this technology allowed for the inclusion of continuous fiber reinforcement in FDM [1]. Some of the fibers available for reinforcement are carbon fiber, Kevlar, and glass fiber [2]. These advances extended the application of FDM with stronger and lighter parts. However, the mechanical behavior of the parts is a function of the quantity and location of the fiber reinforcement [3]. Therefore, it is fundamental to understand and quantify the mechanical properties of these materials [4].

Some authors have characterized mechanical properties such as the tensile strength and elastic modulus of these composites. Dong et al. [5] investigated the tensile strength and elastic modulus of KFRN. The study looked at volume fraction, fiber orientation, and position of the fibers. Naranjo-Lozada et al. [3] studied the properties of carbon fiber-reinforced parts produced by additive manufacturing. The factors included in the study were geometric parameters, infill density, and infill patterns. The study suggested that the rule of mixtures could be used to estimate the properties of 3D-printed composites. Melenka et al. [6] and Al Abadi et al. [7] used the average stiffness method to predict the mechanical properties of AM parts reinforced with fibers. Deng et al. [8] presented a method to predict the tensile strength and elastic modulus of carbon fiber-reinforced FDM parts using the rule of mixtures. The study also accurately quantified the volume fraction (VF) of carbon fiber in the filament using scanning electron microscopy. With the VF of the filament, it is possible to easily estimate the fiber quantity and mechanical properties based on the number of passes of filament. However, the procedure is cumbersome and labor-intensive. Hence, the need for a method of precisely predicting the VF, tensile strength, and elastic modulus is needed.

In this work, the use of the rule of mixtures to predict properties of KFRN is investigated. An approach to determine the VF of Kevlar in the filament [9] using TGA is described. The elastic modulus and tensile strength of KFRN are studied.

22.2 Methods

22.2.1 Samples Preparation

The samples used in this article follow the ASTM D3039-17 [10] standard guidelines. The dimensions and construction of the samples are shown in Fig. 22.1. Three configurations were devised with varying number of layers of Kevlar and Roof/Floor. All configurations have longitudinal uniaxial fibers in the same direction as the load, layer height of 0.1 mm, and 100% infill. More information about the layer configuration is shown in Sect. 22.2.2. The slicing and programming were prepared in the proprietary software Eiger. Next, five samples of each configuration were printed

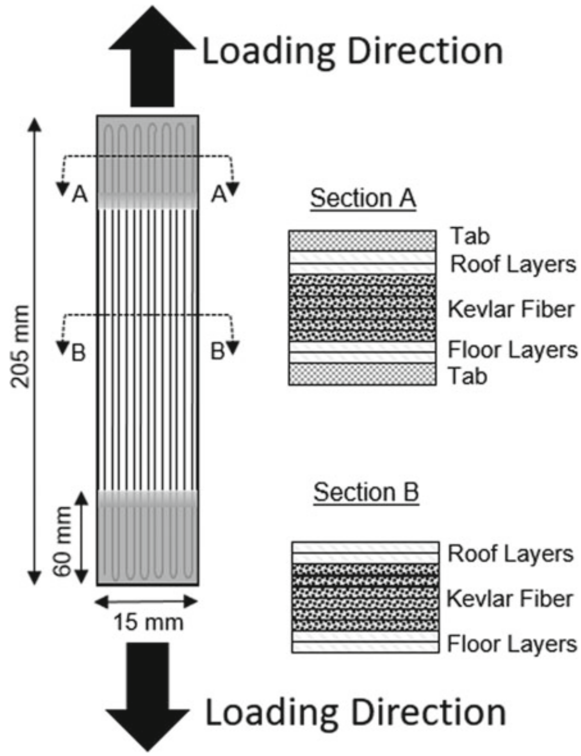

Fig. 22.1 Portrayal of the composition of the KFRN samples. Adapted from [8]

in a Markforged Mark X machine. Garolite G-10 tabs were attached to the gripping section of the samples using an epoxy gel. These tabs are shown in Sect. A of Fig. 22.1.

22.2.2 Determining the Volume Fraction of Kevlar Filament

Samples of pure nylon and KFRN filaments were prepared for the thermal gravimetric analysis (TGA). The test was conducted using thermogravimetric analyzer (TGA) and differential scanning calorimeter (DSC)—TA Instruments, model DSC SDT Q600. The parameters used in the TGA test for both samples are described in Table 22.1.

The next step was to transform the TGA results from mass fraction to volume fraction using data from the density. The density of both materials was measured with a pycnometer. Finally, the volume fraction of Kevlar, V_K in the filament is calculated using Eq. 22.1.

Table 22.1 Parameters and settings used in the TGA test of pure nylon and KFRN

Parameter	Pure nylon	KFRN
	Values	
Sampling interval	0.5 s/pt	0.5 s/pt
Starting temperature	25 °C	25 °C
Temperature ramp rate	10 °C/min	10 °C/min
Initial sample weight	16.235 mg	10.7302 mg
Final sample weight	0.1125 mg	1.9205 mg
Final temperature	600 °C	700 °C
Purge gas	Nitrogen	Nitrogen
Purge gas rate	100 ml/min	100 ml/min

$$V_K = \frac{\left(\frac{M_K}{\rho_K}\right)}{\left(\frac{M_N}{\rho_N}\right) + \left(\frac{M_K}{\rho_K}\right)} \tag{22.1}$$

M_K is the mass fraction of Kevlar in the KFRN, ρ_K is the density of Kevlar, M_N is the mass fraction of nylon, and ρ_N is the density of the Nylon. Similarly, the volume fraction of Nylon, V_N, is computed by Eq. 22.2.

$$V_N = \frac{\left(\frac{M_N}{\rho_N}\right)}{\left(\frac{M_N}{\rho_N}\right) + \left(\frac{M_K}{\rho_K}\right)} \tag{22.2}$$

Finally, the volume fraction is converted to area fraction using Eq. 22.3. This is done assuming that there is a uniform distribution of KFRN in the sample.

$$A_K = \frac{V_K A_{KF} N_P N_L}{A_{sample}} \tag{22.3}$$

In Eq. 22.3, A_K is area fraction of Kevlar in the sample, A_{KF} is the cross-sectional area of Kevlar, N_P is the number of passes of filament in one layer, N_L is the number of layers, and A_{sample} is the cross-sectional area of the sample. The diameter of KFRN filament was reported by Markforged as 0.34 mm. The samples in this research had N_P equal to 13.

Table 22.2 contains information on the three configurations and the respective area and area fractions. The configurations, originated in [8], were selected to represent samples with low, medium, and high volume fraction. The standard deviation is shown in parenthesis. The configuration with larger fiber content, 16 KFRN layers, has approximately 22.7% Kevlar. In contrast, the samples with 2 KRFN layers have 2.9%.

Table 22.2 Sample configuration and respective area fraction and area

Configuration	Nylon layers	KFRN layers	Wall layers	Average area (mm^2)	Average area fraction of KFRN (%)
9-2-9	18	2	4	31.961 (0.309)	2.891 (0.009)
5-10-5	10	10	4	33.155 (0.447)	14.08 (0.197)
2-16-2	4	16	4	33.062 (0.824)	22.72 (0.547)

22.2.3 Tensile Tests

The tensile tests were conducted using a United SSTM-20kN universal testing machine with the United EZ-2-2 extensometer mounted to acquire data from the elastic regions. The uniform displacement rate was set to 0.1 in./min. Each sample was tested three times for Young's modulus. The data was acquired using United software. After testing for the elastic modulus, the system was configured for tensile strength. The extensometer was removed and the displacement rate was set to 0.05 in/min. The displacement was maintained until the fracture of the samples. Figure 22.2a–c, b, show the experimental setup described here and the samples post-failure, respectively.

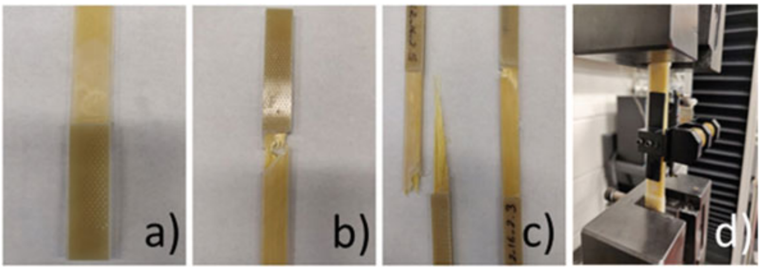

Fig. 22.2 **a** Post-failure 9-2-9 configuration; **b** post-failure 5-10-5 configuration; **c** post-failure 2-16-2 configuration; and **d** experimental setup

22.3 Results and Discussion

22.3.1 Volume Fraction

The volume fraction obtained by the experiments is described here. The results for a pure nylon sample are shown in Fig. 22.3. In Fig. 22.3, the variation of weight with temperature is demonstrated by the blue curve. The derivative of the blue curve is represented by the red curve. The derivative aids in identifying the inflection points. A slight weight decrease is observed at 150 °C. This decrease appears to be resultant of moisture present on the sample. At 380 °C, it is observed a sharp decomposition rate that extends until 480 °C. After that, the data indicates that the entire mass has decomposed. In this sample, the point of 450 °C corresponds to the temperature at which the maximum rate of decomposition occurred. The results of this experiment are in agreement with the work of Kang et al. [11].

Similarly, the TGA results for the KFRN are demonstrated in Fig. 22.4. The red curve now has two inflection points. The first inflection point, at 450 °C, corresponds to the nylon; the second inflection point, at 580 °C, corresponds to the Kevlar. Brown and Ennis [12] present a similar result of TGA for Kevlar with maximum decomposition rate at 590 °C. After the nylon is completely decomposed, starting at around 480 °C, approximately, 39% of weight remains. This value indicates the mass fraction of Kevlar in the filament. Also, around 19% of mass remains at the end of the temperature scan. This mass corresponds to the fibers present in Kevlar (Fig. 22.4).

The density of nylon and Kevlar filament, ρ_N and ρ_K is found as 1.083 and 1.205 g/cm^3, respectively. These values are within range of those provided by the

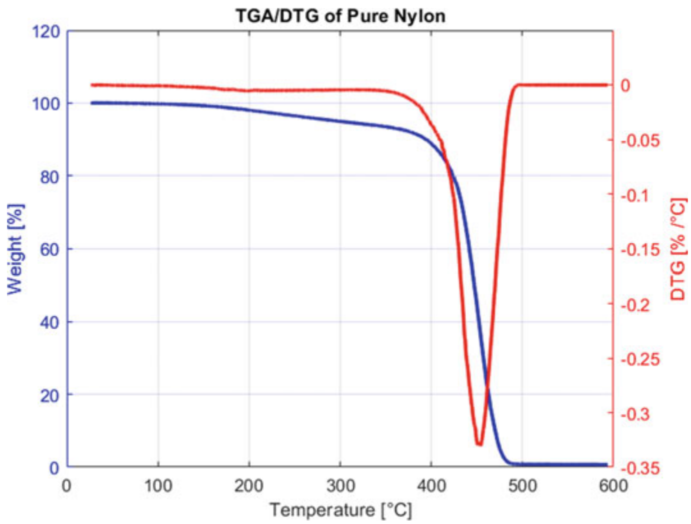

Fig. 22.3 TGA test of pure nylon

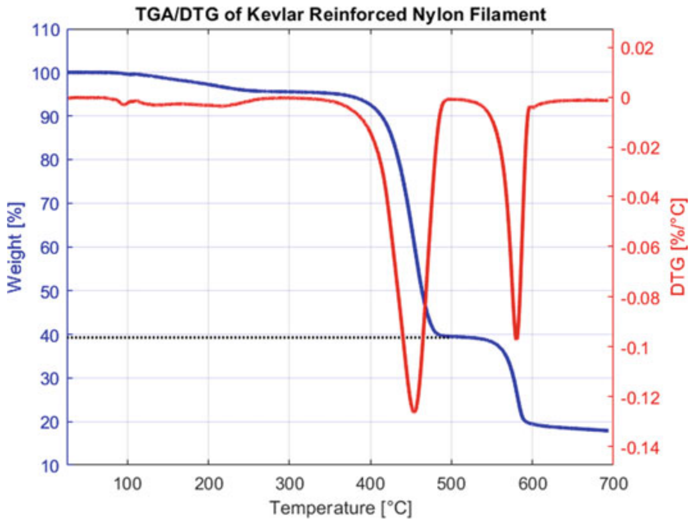

Fig. 22.4 TGA test of KFRN

manufacturer. The volume fraction of Kevlar in the KFRN filament, V_K, was found as 0.327. Finally, the nylon volume fraction V_K found was 0.673. Another method of computing the volume fraction in the fiber-reinforced filaments is demonstrated in [8]. The approach utilized in this article is simpler and faster than [8].

22.3.2 *Tensile Test*

The results of the tensile test are described in Table 22.3. Elastic modulus and tensile strength of different configurations of KFRN. As the number of layers of Kevlar increase, the elastic modulus also increase. For example, Young's modulus of configuration 2-16-2 is 260 times larger than configuration 9-2-9. The coefficient of variation was around 4% in the 2-16-2 configuration. The tensile strength follows the same rationale as the samples with larger fiber content have higher strength.

Table 22.3 Elastic modulus and tensile strength of different configurations of KFRN samples

Configuration	Average elastic modulus E_{sample} [MPa]	Average tensile strength at break σ_{sample} [MPa]
9-2-9	78.987 (2.325)	79.880 (18.25)
5-10-5	14,454.472 (3.806)	291.562 (17.825)
2-16-2	21,067.463 (3.9146)	419.782 (42.495)

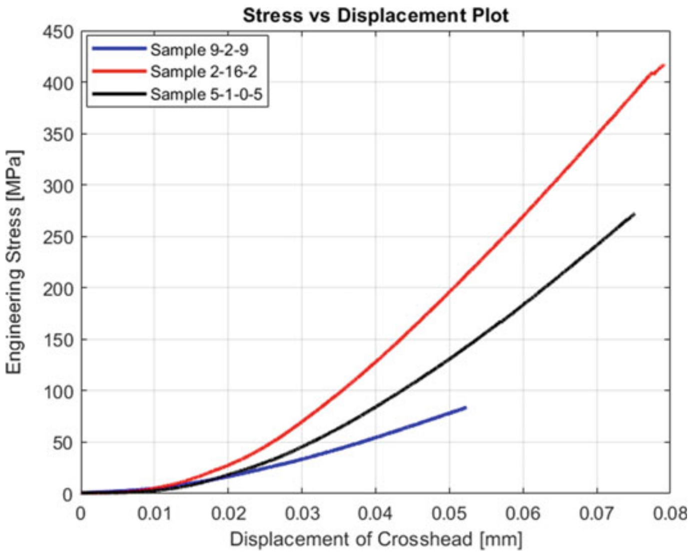

Fig. 22.5 Tensile strength of KFRN—samples stress versus displacement

Figure 22.5 demonstrates the tensile curve for the KRFN samples. According to Mittelman and Roman [13], Kevlar has a viscoelastic behavior. Therefore, its tensile curve and properties can vary with the displacement rate.

Figure 22.6 presents the different samples elastic modulus versus Kevlar volume fraction. The linear trend shows behavior that follows the rule of mixtures as in [8] and is used to find the parameters for the rule of mixtures in Eq. 22.4. Since the samples are uniform and uniaxially distributed KFRN, the volume ratio is substituted by area fraction. From the linear fit, by extrapolating A_{K} to 100%, we can find an E_{K} of 91.79 GPa and E_{N} of 1.002 GPa. These values of E_{K} and E_{N} are within the range given by the respective manufacturers.

$$E_{\text{sample}} = E_{\mathrm{N}}(1 - A_{\mathrm{K}}) + E_{\mathrm{K}} A_{\mathrm{K}} \tag{22.4}$$

A similar result was obtained for the tensile strength. Figure 22.7 shows the linear fit for the tensile strength of the three configurations. σ'_{N} is 35.211 MPa and σ_{K} was 1773 MPa.

$$\sigma_{\text{sample}} = \sigma'_{\mathrm{N}}(1 - A_{\mathrm{K}}) + \sigma_{\mathrm{K}} A_{\mathrm{K}} \tag{22.5}$$

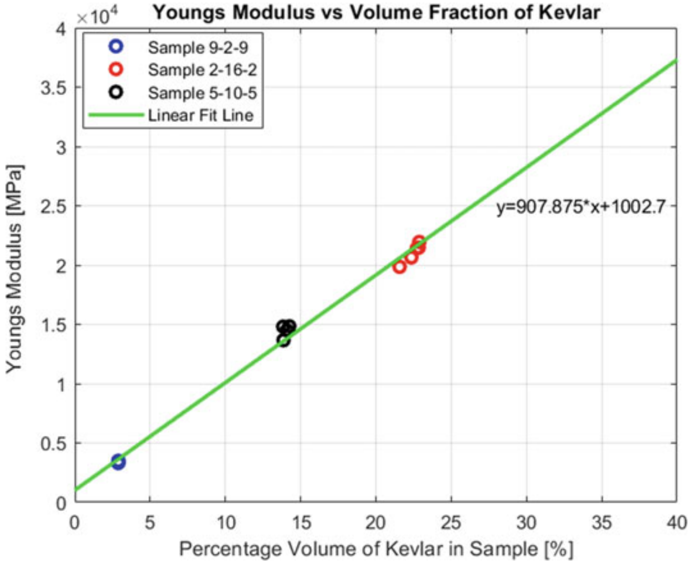

Fig. 22.6 Linear fit for elastic modulus versus volume fraction of Kevlar fiber

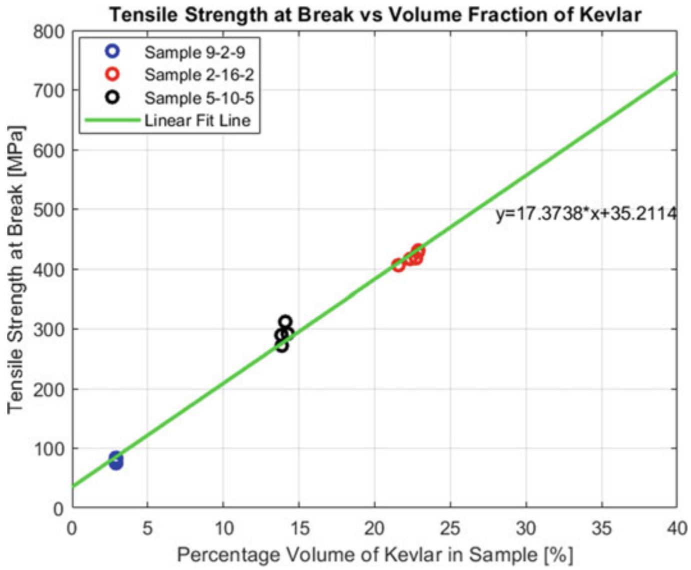

Fig. 22.7 Linear fit for tensile strength versus volume fraction of Kevlar fiber

22.4 Conclusion

This article described an investigation of the use of the rule of mixtures to determine the elastic modulus and tensile strength of KFRN. TGA tests were conducted to determine the Volume fraction of Kevlar in the samples. Tensile tests were conducted in samples with 3 different configurations of fiber content. The use of the rule of mixtures demonstrated to correctly predict the tensile strength and elastic modulus of uniaxial KFRN produced by FDM.

With the approach developed in this paper, designers can easily quantify the tensile strength and elastic modulus of uniaxial KFRN. Thus, reducing the number of experiments needed to characterize the material and development time. The model was tested with fiber concentration of 22.7%. Further testing is needed to verify predictions with fiber concentration higher than 22.7%. Although only three configurations were tested, previous work by Deng et al. [8] already demonstrated the use of rule of mixtures in fiber-reinforced FDM. In that research, 13 configurations were tested. Future work may test additional configurations to further understand the use of rule of mixtures. Additionally, further research includes modification in the tab material and strain rate in high fiber content samples. The additive manufacturing and fiber reinforcement produce behavior that is not isotropic. Thus, future investigation of properties in other directions is suggested.

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Chapter 23
A Framework for Improving Rural Microgrid Sustainability Through Integrated Socio-technical Considerations

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Abstract With the advancement of the engineering science there are increased capabilities for engineering models that consider the complex relationships among multidisciplinary phenomena. Cyber-physical systems are a technology that can be implemented in model-based design. An example of these systems can be found in smart microgrids that are now being installed in rural villages. The inability to regulate microgrid power often leads to power losses. Moreover, these losses have a deleterious effect on the quality of life, and hence, the progress that rural electrification aims to promote. In this paper, we present a computational framework for integrating quality of life and power management to promote sustainability in this cyber-physical system. Using the framework, we elucidate quantifiable relationships that exist between these domains in the context of sustainable rural electrification. In the context of power management, we achieve the same by balancing supply and demand. User demand is examined and related to quality of life. This is realized by identifying the roles of powered devices in daily life. Our main contribution in this paper is a framework to incorporate quality of life in power management for a rural microgrid. The foundational mathematical construct for decision support in the framework is the compromise decision support problem (cDSP). The cDSP is a mathematical construct used to formulate decision support problems. The cDSP is executed for different scenarios and the solution space is explored to identify satisficing solutions. In this paper, we demonstrate the utility of the framework and design constructs presented using a rural microgrid design problem. Our focus in this problem is to balance energy loads and battery storage. The key functionalities of the framework tested are the flexibility and adaptability, both of which are crucial in

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A. Chakrabarti et al. (eds.), *Design for Tomorrow–Volume 3*,
Smart Innovation, Systems and Technologies 223,
https://doi.org/10.1007/978-981-16-0084-5_23

creating sustainable solutions. We are interested in understanding the quality of life through a system dynamics perspective, exploring multi-resource dependent allocation problems, and developing models to enhance the framework established in the current paper.

23.1 Frame of Reference

The introduction of technology can facilitate social development in impoverished communities. For example, microgrid systems are effective in providing access to electricity in areas where grid connection is not feasible. Electrification can provide easier access in fulfilling basic needs [1–3]. Positive impacts on education, health, agriculture, and other aspects of life through electrification improve quality of life [1–3]. Yet, challenges with insufficient energy supply can stall social progress. In rural communities, renewable energy sources are used for power production. The intermittency of the generation impacts the available energy. Therefore, power management is critical for sustaining the electricity demands and social well-being. Many factors contribute to social well-being.

Maslow's hierarchy of needs and Max-Neef's fundamental human needs are two common methods of defining needs [4, 5]. Maslow's hierarchy defines levels of needs from basic to complex using a hierarchy [4]. This hierarchy is no longer appropriate. For example, there may be cases where education is accessible, but clean water is not. Max-Neef defines fundamental human needs without a hierarchy [5]. These fundamental needs include subsistence, protection, affection, understanding, participation, leisure, creation, identity, and freedom. The parameters that contribute to fulfilling basic needs are needed in understanding quality of life. Social development indicators have been defined to rank countries based on well-being, quality of life, and progress. Some of these indices include the Human Development Index, Social Progress Index, Eurostat QOL, World Happiness Report, and Bhutan's Gross National Happiness Index [6–10]. While the ranking provides some information overall, the indicators themselves may provide more sufficient context for the status of well-being. These parameters can be utilized in establishing design and operation requirements for technical systems. Additionally, the ranking for a country may be different compared to a community within that country. The parameters used in these indices may also be applied on the community level. There is a need to integrate considerations to well-being in decisions regarding technical systems in rural communities.

Socio-technical design refers to including considerations to parameters impacting social dynamics. In [11–14], principles for socio-technical design are discussed. Understanding the setting, culture, and context are highlighted. Akinyele and Rayudu [15] studies the challenges in solar power systems in developing regions and the need to include a social analysis of energy demand. The social dimension is applied in forming design requirements, progress, and energy demand. Yet, there is still a need to integrate non-technical information in the analysis. Additionally, there is a need to address quality of life. We are focused on the relationships between access to electricity and community well-being. In this paper, a framework for connecting quality of life and power management to support decision making is proposed. The details of the framework are discussed in the next section. The foundational mathematical construct used in this framework is the compromise decision support problem (cDSP). Using the cDSP, we formulate a multi-goal power management problem taking into consideration the quality of life of people in rural villages and further explore the solution space to identify "satisficing solutions." The exploration of solution space is carried out by addressing the cDSP for different design scenarios and further visualizing the exploring the solutions generated using ternary plots. The paper is organized as follows. In Sect. 23.2, we discuss the details of the framework and the problem formulation using the cDSP. In Sect. 23.3, we discuss the results based on the exploration of solution space and the operational implications of the solutions identified. We close the paper with our remarks in Sect. 23.4.

23.2 Framework

The framework relating quality of life and power management is discussed in this section. The framework is based on the decision-based design perspective and intended to support human decision making. In this perspective, we believe that design is a decision-making process. The fundamental role of a human designer is to make decisions using the information available. The framework is visually represented in Fig. 23.1. Block A includes the identification characteristics of the community. Some of these characteristics can be direct design or operation requirements. Other characteristics need further interpretation or modeling to develop the requirements. Block B1 includes supportive modeling for the development of system

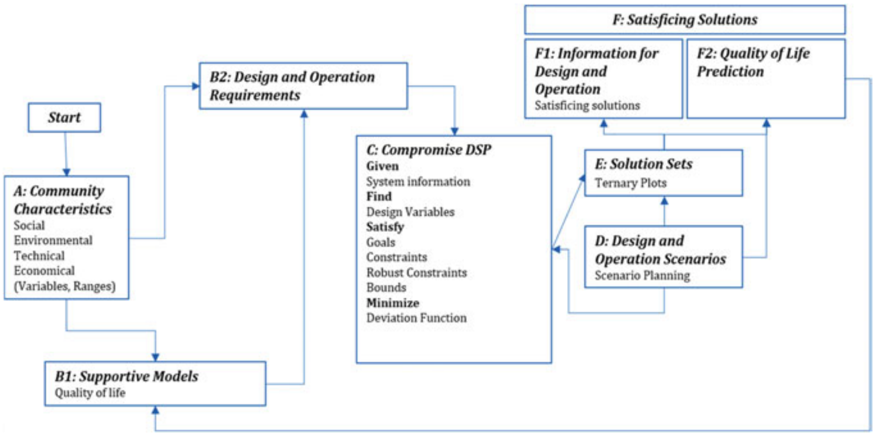

Fig. 23.1 Framework overview

requirements. A quality of life analysis is presented as one of these models in [16]. Understanding the factors that impact well-being supports socio-technical requirements. The parameters used in the social development indices contribute to this understanding. The design requirements are established from the characteristics and modeling, represented in Block B2. This information is used in the development of the inputs for the cDSP, Block C. The design or operation scenarios of Block D are also inputs to the cDSP, Block C. The solution space is created by exercising the cDSP for different scenarios. This is represented in the framework by Block E. Decision makers can then select solutions and provide feedback, as in Block F. In this paper, Blocks B-C are our primary focus. The requirements, as the inputs for the cDSP, are related to quality of life in this paper. This framework is demonstrated in the next section through a test problem.

23.2.1 Blocks B1 and B2

The characteristics of a community define what is needed of the technical system. However, organizing the information and supportive models may be required to transform the qualitative characteristics into design or operational requirements. The supportive models are represented in Block B1 and the development and organization of the requirements are represented in Block B2. The established requirements serve as inputs to the cDSP. We examine socio-technical considerations through quality of life. In this analysis, we relate quality of life aspects to electrical loads. Understanding this relationship, it allows us to use the cDSP to develop a set of solutions that balance the energy supply and demand with the perspective of improving quality of life.

23.2.2 Blocks C-E

The cDSP is a hybrid between mathematical programming and goal programming. The cDSP is used to formulate multi-goal decision support problems and explore satisficing solutions [17]. Using the cDSP construct, we formulate a set of goals to be met for system operation. These goals are based on given information for the system to find the variables that satisfy the system requirements. The problem is bounded by the constraints of the system. The cDSP is formulated by identifying system variables, constraints, and goals. Through the use of the cDSP a set of solutions is determined that satisfices the requirements. These solutions are not optimal, but satisficing. The variables are found by satisfying the goals, constraints, and bounds. Using the cDSP, the deviations for the target values for each of the goals of the system are minimized. The specifics of this process are available in [17].

In this paper, the solutions from the cDSP correspond to energy load allocations based on the production and consumption. These solutions are derived by exercising the cDSP for different scenarios. The demand is represented by specific energy loads in the cDSP. In the cDSP, the goal for each load is to meet the target value. These requirements are formed with the intention of maximizing the positive societal impact, or minimizing the practices impeded by limited access to electricity. The goals are derived from the quality of life information. The end requirements are formatted as goals in the cDSP, as in Eq. 23.1.

$$\frac{P_i t_{it}}{PT_{it}} + d_i^- - d_i^+ = 1 \tag{23.1}$$

where P is the power, i is the number of loads, and t is the time period. In Eq. 23.1, the numerator of the first term is the design variable, and the denominator is the target value of the design variable. The deviation variables, d_i^+ and d_i^-, represent the distance between the actual and target values of the variable. Equation 23.1 is applied to each load and each time period.

The variables in this problem are the energy for each load, and the amount of energy supplied for the battery storage. The difference between the target and design values is the deviation variable. Minimizing the sum of the deviation variables is the overall objective function in this problem as in Eq. 23.2. Two deviation variables exist; for underachievement of the goal, or overachievement of the goal [17]. If one exists, the other should be a value of zero. The variables and deviation variables are described as listed.

Variables

P_{it}: Power demand for the load.

S_{it}: Energy storage.

Deviation Variables

d_i^- : Underachievement.

d_i^+: Overachievement

$$D = \sum_{i=1}^{n} W_i * (d_i^- + d_i^+); \sum_{i=1}^{n} W_i = 1 \tag{23.2}$$

In Eq. 23.2, W refers to the weight applied to the deviation variable. The cDSP is exercised for different design scenarios. This is achieved with different weighting combinations of each variable to create a solution space.

Energy dispatched for the loads cannot exceed the amount produced. The energy demand or anticipated demand is necessary in formulating the target values for each of the goals. The system specifications are represented using the constraints and bounds of the problem. The relationships between the demand, generation, and storage are defined in constraint Eq. 23.3. The conflicts between the goals are also related using this equation.

$$S_{t+1} = S_t + P_g t_{gt} - P_1 t_{1t} - P_2 t_{2t} - P_3 t_{3t} \cdots - P_n t_{nt} \tag{23.3}$$

In Eq. 23.3, S_t is the current energy in storage, $P_g t_{gt}$ is the energy generated, and the remaining terms, $P_{1:n} t_{1:n}$, represent the energy demanded by each load. The constraint equation represents the relationship between the supply, and the energy demanded. The list below describes the boundaries for each variable.

Boundaries

$Pt_i \geq 0$: The energy demand is assumed to be greater or equal to 0.
$S \geq 0$: The system storage is assumed to be greater or equal to 0.
$S \leq SystemCapacity$: The storage cannot exceed the capacity of the battery.
$d_i \geq 0$: The deviation variables must be greater or equal to 0.
$d_i^- * d_i^+ = 0$: The deviation variable must multiply to 0 such that one variable has a value of 0.

A solution space is developed from exercising the cDSP. The solutions for different scenarios are depicted using ternary plots. These plots allow for visually representing the solution space for design scenarios. The design scenarios correspond to weighting combinations of the goals for each exercise through the cDSP. Decision makers select appropriate solutions for the scenario. Additionally, decision makers can revise requirements to restrict or expand the solution space.

This framework is applied to a test problem to demonstrate how the solution space can be expanded by modifying the input requirements. The application is balancing the energy supply and demand for a rural microgrid. This is discussed in the following section.

23.3 Results and Discussion

In this section, test problems are used to demonstrate the framework. The data used in this paper is provided by SunMoksha. In this paper, electrical loads are related to quality of life parameters. The electrical loads examined are for powering water pumps, powering streetlights, and powering household devices. The corresponding parameters related to quality of life are water, safety, education, and leisure. These are selected based on information from the World Bank [18] and SunMoksha [19]. In the framework, these connections are established as represented in Blocks B1 and B2. The energy supply and demand are balanced through the perspective of quality of life.

We assume two light bulbs, one television, one fan, and one mobile charger per household are used for six hours per day in the evening, for 80 houses. For the entire community, three water pumps would be used for six hours per day, during the day, and streetlights would be powered for 12 h in the evening. The available energy of the system is estimated to be 40 kWh/day. This is based on solar insolation and solar panel data. To simplify the calculations, the fluctuations in production and consumption are not considered.

Two test problems are presented to demonstrate the functionality and flexibility of the proposed framework. For each example, a set of solutions is determined. In the first test problem, the inputs for the target values of the loads are:

Test Problem 1

- 45.0 kWh/day for powering water pumps
- 2.0 kWh/day for powering streetlights
- 70.0 kWh/day for powering the household loads.
  The target values are reduced to expand the solution space for the second test problem. The target values are:

Test Problem 2

- 23.0 kWh/day for powering water pumps
- 1.0 kWh/day for powering streetlights
- 35.0 kWh/day for powering household devices.

The total energy demand for both scenarios exceeds the energy available. The target values for the second test problem are intentionally half of those of the first test problem to demonstrate the expansion of the solution space. Moreover, power management is needed to ensure the loads critical to social well-being are satisfied. This is achieved by connecting components of quality of life to the energy demands.

23.3.1 Exploration of the Solution Space

The cDSP is exercised for 16 different design scenarios, see Table 23.1. The 16 design scenarios are considered by assigning different weight preferences to the goals considered in the problem. We use judgment to select the design scenarios so that an effective representation of the design space is obtained using the ternary plot for visualization and solution space exploration. Scenarios 1–3 are for a situation where our goal is to achieve the target on a single goal, i.e., meet water load requirements (L1), meet safety load requirements (L2), meet household load requirements (L3), respectively, as closely as possible. For example, our preference in scenario 2 is to achieve only the safety load requirements. In scenarios 4–6, we give equal preference to two goals and the third goal is not assigned any preference. For example, our preference in scenario 4 is to equally meet both water and safety load requirements. In scenario 7, we give equal preference to all the three goals. In scenarios 8–10, all the goals are assigned preferences with two of them being the same preference. In scenarios 11–13, we assign preferences to all the goals with all being different weights. In scenarios 14–16, we give greater preference to one goal, a lesser preference to the second goal and a zero preference to the third goal. We carry out the exploration of solution space by exercising the cDSP for these different design scenarios and plotting the solutions in a ternary space. The weights assigned are represented by the axes of the ternary plots and the interior region represents the achieved values of

Table 23.1 Design scenarios and weights assigned for goals

DS	Weight on L1	Weight on L2	Weight on L3
1	1	0	0
2	0	1	0
3	0	0	1
4	0.5	0.5	0
5	0.5	0	0.5
6	0	0.5	0.5
7	0.33	0.34	0.33
8	0.6	0.2	0.2
9	0.2	0.6	0.2
10	0.2	0.2	0.6
11	0.5	0.35	0.15
12	0.15	0.5	0.35
13	0.35	0.15	0.5
14	0.7	0	0.3
15	0.3	0.7	0
16	0	0.3	0.7

the specific goal. Using the ternary plots, regions that satisfy the goal requirements are identified. Such regions identified for the three goals are then superposed in one ternary plot to identify satisficing solutions that meets all the three goals.

The results of the cDSP for the test problem are represented using the superimposed ternary plot in Fig. 23.2. Each solution from the cDSP provides a quantitative value for the energy allocation to each load. The solution space for each of the loads is plotted together to reveal the combined solution space. The operation scenarios correspond to weighting combinations for each of the variables. Decision makers can select the most appropriate solution based on the requirements and the operation scenario.

The energy demand is balanced with the perspective of quality of life. Considering the quality of life supports socio-technical solutions. If the solution space is not adequate or appropriate, the decision maker can adjust the inputs to the cDSP. The requirements can be changed to restrict or expand the solutions space. A second test problem is presented to demonstrate this. In test problem 2, the solution space is expanded. This is achieved by reducing the target values for each of the goals. The target values for test problem 2 are assumed to be half of that of test problem 1. The combined ternary plot for test problem 2 is represented in Fig. 23.3.

The solution space in Fig. 23.2 is used to create the expanded solution space that is shown in Fig. 23.3. This is achieved by reducing the target values for each of the loads. As requirements change, other solutions within the space can be selected. Thus, operation procedures can be constructed appropriately to support the quality of life.

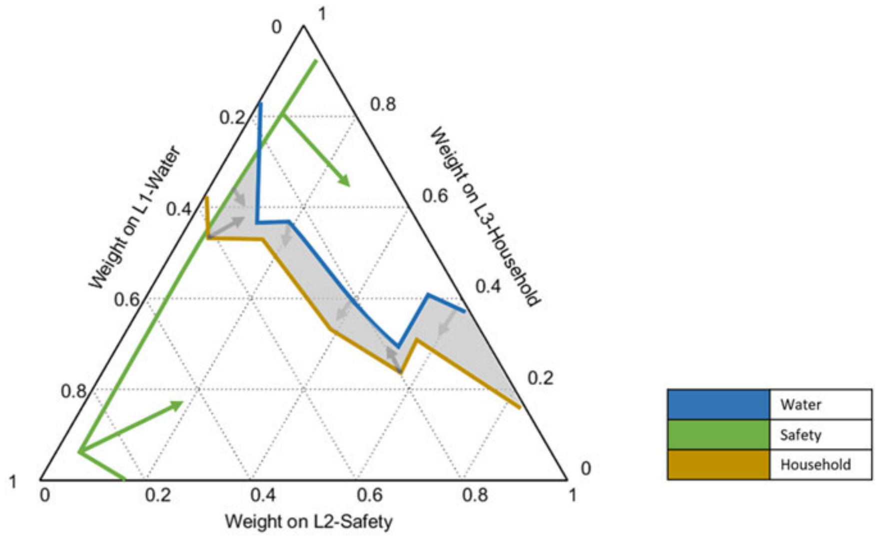

Fig. 23.2 Test problem 1 ternary plot

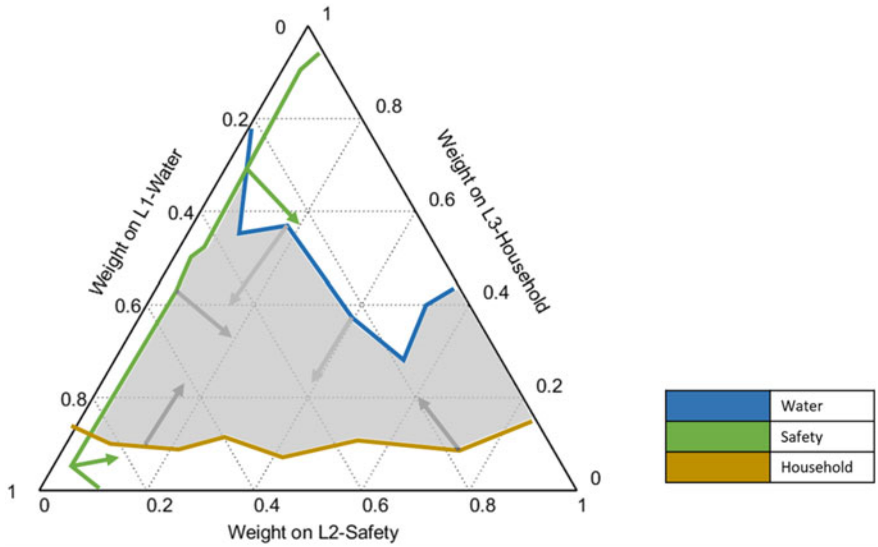

Fig. 23.3 Test problem 2 ternary plot

23.3.2 *Operational Implications*

The solutions developed from the cDSP provide a set of operation options. The solutions correspond to different prioritizations of the loads. Accordingly, decision makers select the most appropriate solution for the required prioritization. This is achieved by using the socio-technical requirements developed in Blocks B1 and B2 of the framework. As conditions change the required prioritization, other solutions within the set can be chosen. If those solutions are not fitting for the conditions, the inputs to the cDSP can be changed.

In the presented test problems, three loads are balanced. The solutions align with the prioritization required for the community. For example, when water and safety parameters are high priority, the available energy is allocated to pumping water and powering streetlights. Using the results of the cDSP, 38.0 kWh/day would be allocated to the water load and 2.0 kWh/day would be allocated to the safety load for test problem 1. Similarly, in test problem 2, 23.0 kWh/day and 1.0 kWh/day would be allocated to the water and safety loads, respectively. As the demand is expected to fluctuate, different solutions can be beneficial in deploying effective operational strategies.

The outcomes of this analysis provide insight for decision makers. Examining power management through quality of life supports decision making for bettering living conditions. The solutions correspond to the socio-technical requirements established in Blocks B1 and B2. In addition to operation, the results provide information for design decisions. If the available energy is consistently insufficient, or the power management solutions are not appropriate for the conditions, changes to the system may be required. This allows decision makers to understand what is needed of the system to satisfy the demand. Connecting quality of life to power management allows us to develop solutions anchored in social development.

23.4 Closing Remarks

In this paper, we present a framework for connecting quality of life with power management to support decision making. Developing sustainable solutions require considerations between the social and technical domains. Using the framework, a decision maker can select the solutions most appropriate for a set of conditions. The solutions are developed using the cDSP, and the foundational mathematical is constructed for this framework. In the test problems, solutions that prioritize the water and safety loads are selected. If the solutions within the set are unacceptable, the input requirements can be modified. The flexibility of the framework allows for adapting the solution space as dynamic changes within a community occur over time. More work is needed in determining the impact of the solution selections. For example, if two of the loads are of high priority, should any energy be allocated to the third load? The relationships between the qualitative aspects of the social dynamics and the quantitative aspects of the technical system are assumed in this framework. Thus, there is a need to expand the framework to mathematically include these relationships. The future work will be focused on the integration of qualitative and quantitative information. Furthermore, we are interested in collaborations to better our understanding of social dynamics.

Acknowledgements We acknowledge Dr. Janet K. Allen, Dr. Kirsten Campbell, Lin Guo, Dr. Farrokh Mistree, and Abhishek Yadav for their guidance and expertise throughout this research. We also thank the National Science Foundation for their support through the Graduate Research Fellowship. This material is based upon work supported by the National Science Foundation Graduate Research Fellowship under Grant No. 2019244055. Any opinion, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

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Chapter 24
Mapping Design Values Across Time for a Single Product Category (Two Wheelers) Using Harley Davidson Advertisements

Deepshikha Dash and Sugandh Malhotra

Abstract In the field of mobility, Harley Davidson is an iconic brand that has a loyal fan following. Hence, it is beneficial to observe the design values that the company has been propagating over time. To do this, the authors conducted a manual text analysis of 150 American Harley Davidson advertisements, which were evenly distributed across five decades beginning from 1920. The result of this analysis showed that irrespective of social, cultural, political, economic, or technological changes, ten design values were repeatedly observed in the advertisements, namely aspirations, style, performance, convenience, affordability, comfort, durability, safety, conservation, and security. In addition to this, the authors also documented the changing propensities of the design values across time and the ways in which they were achieved.

24.1 Background

24.1.1 Introduction

Advertisements are one of the most important cultural artifacts produced by a society. They provide key insights into design values. For the purpose of this paper, 'design values' may be defined as the factors of consideration in a designed intervention, that are of value to human beings. To understand how these design values change over time for a single product category, 150 American Harley Davidson magazine advertisements were studied across a period of 50 years, beginning from 1920.

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A. Chakrabarti et al. (eds.), *Design for Tomorrow–Volume 3*,
Smart Innovation, Systems and Technologies 223,
https://doi.org/10.1007/978-981-16-0084-5_24

24.1.2 Relevance of Advertisements for Designers

Advertisements have often been critiqued as being fallacious or attempting to sell products, systems, and services that are unnecessary or harmful, to benefit the seller.

These arguments may be valid. However, such criticism can also act as an obstacle in understanding the role of advertisements in our society. Indeed, advertisements have been created with the intent to sell things, but to achieve this, they must also create structures of meaning. 'Advertisements must take into account not only the inherent qualities and attributes of the products they are trying to sell, but also the way in which they can make those properties mean something to us' [1]. Hence, advertisements have to translate designed interventions that belong to the world of 'things' into a form that means something to human beings. For example, if a car could travel 50 miles per gallon, then it may be translated into affordability or imply that the user is a certain kind of person, for example, a smart saver. The numeric connotation of 'mpg' is simply a factual attribute. However, advertisements must translate these facts into 'humanly symbolic 'exchange value'' [1]. It is this 'humanly symbolic' value that is explored in this paper in the form of 'design value.'

Traditionally, designers first identify design values and then use them to create designed interventions. This process reverses in the case of advertisements, which take designed interventions and use 'humanly symbolic' values to sell them. However, in doing so, they provide a key insight into what sellers think humans value, thus becoming important sources of information with respect to exploring design values that were of relevance in the past.

24.1.3 Novel Approach Adopted by the Authors

According to traditional design approaches, designers are heavily dependent on user and context-based methods such as ethnography, contextual analysis, and user interviews to gain insights on design values. However, these values would be relevant only if there is no change in the user or the context, which might suffice for the near future but not the far future. This fundamental shortcoming has been identified by the authors in their previously published work where they suggest observing factors of change rather than factors of immediate influence [2, 3]. To observe factors of change, the authors have explored magazine advertisements as the medium of study. Though magazine advertisements have been extensively studied before, it was found that no existing research attempted to identify patterns in design values projected by Harley Davidson over time.

Another study relevant to this paper is the development of the Design Futures (DeF) framework [3]. It was formulated through the historical study of modern design movements, a variety of successful products from the past century, and award-winning contemporary products. The framework identified 19 factors that were consistently observed through time and categorized them under three headings, namely technology, environment, and human. Specifically, the ones related to human were joy of using, styling, comfort, convenience, safety and hygiene, affordability, social advancement, and cultural advancement.

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24.2 Methodology

24.2.1 Data Collection

Harley Davidson is an American motorcycle company that was founded in 1903. By the 1920s, it managed to get the largest two-wheeler manufacturer title. During the Great Depression that began in 1929 only two major American Motorcycle companies were able to survive, of which Harley was one of them. Since then, the company has managed to endure intense global competition, two world wars, and numerous technological disruptions. Today it is known as one of the world's most iconic two-wheeler brands and is widely acknowledged for its loyal fan following [4]. The historical artifacts chosen to be studied were old American, Harley Davidson, magazine advertisements. These advertisements were seen as mediums of communication that contained content curated for Harley Davidson to communicate the design values of its products. A repository of 150 advertisements was created that spanned across 50 years beginning from 1920. Each decade was represented by 30 magazines. These magazines were uniformly distributed across the years. Also, it was ensured that the samples belonged to a variety of publications ranging from technical to family genres.

24.2.2 Data Sorting

The authors chose to follow a manual documentation process to capture the context sensitivity reflected by the text occurrences, which would otherwise be overlooked by typical content mapping and digital text mining software. Though this may be seen as a limitation with respect to errors due to human interpretations, it has also helped add richness to the study. During documentation, each complete meaning was acknowledged as an occurrence. Every occurrence expressed a single complete idea which could be in the form of a word or a phrase. The information projected by the magazines was then divided into two hierarchies. The first comprised of '*design values*' while the second comprised of ways to achieve 'design values,' known as '*design value considerations.*'

24.3 Observations

24.3.1 Design Values Across Time

Based on the manual text mining process, 10 unique mobility-related design values were found to be relevant across the time studied. These values were aspirations, style, performance, convenience, affordability, comfort, durability, safety, conservation, and security. See Fig. 24.1. Decadewise, it may be observed that the top

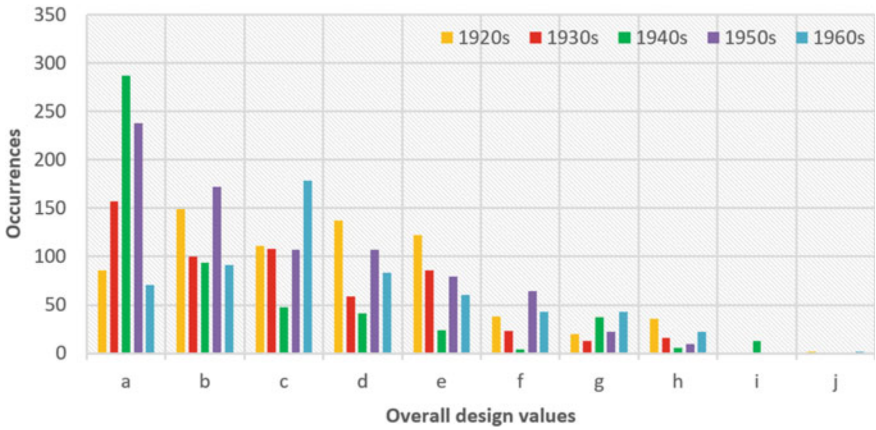

Fig. 24.1 Total occurrences of design values across five decades. Key for design values: **a** aspirations, **b** style, **c** performance, **d** convenience, **e** affordability, **f** comfort, **g** durability, **h** safety, **i** conservation, **j** security

projected values in 1920s were style, convenience, and affordability while in 1930s, they were aspirations, performance, and style. In the 1940s, aspirations and style were prominently observed along with the entry of a new design value, conservation. In the 1950s, aspiration, style, performance, and convenience were predominantly observed while in the 1960s, performance, style, and convenience dominated along with the reentry of security which doubled from its last observed occurrence in the 1920s. However, compared to all design values, conservation and security seem to have the least presence. Hence, only the first eight design values have been elaborated in this paper.

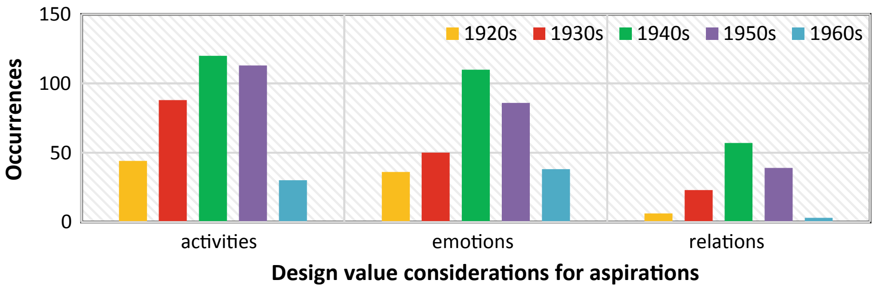

Fig. 24.2 Total occurrences of design value considerations for aspirations across five decades

24.3.2 Design Value Considerations for Aspirations

Aspiration (*n*) may be defined as 'a strong desire to achieve an end' [5]. The advertisements were observed to propagate three types of design value considerations for aspirations, namely activities, emotions, and relations. See Fig. 24.2.

Aspirations peaked during the 1940s. The war had stirred many emotions and the Harley oscillated as an object for a 'dream getaway' to an object 'in the fore front of action.' During World War II, soldiers desired the carefree life and hence, the advertisements reminded them of life before the war. Postwar, many engaged in meetups and as the Harley had been used as a war vehicle, the clubs became common grounds for many veterans to develop new relationships. The Harley also saw a spurt of sports events in which many loyal fans would participate. This created a new search for challenges and risk taking, thus stirring emotions of joy, thrill, and excitement. The activities related to the product also gradually changed to incorporate 'play' along with 'work' such as 'vacations' and 'weekend getaways.'

24.3.3 Design Value Considerations for Style

Style (*n*) maybe defined as 'a kind or sort, esp. in regard to appearance and form' [5]. The advertisements were observed to propagate five types of design value considerations for style, namely personalization, aesthetics, personality, associations, and demography. See Fig. 24.3.

From as early as the 1920s, the Harley began to be associated with the 'police' and 'crime fighting.' In the 1930s, associations were made to the latest scientific advancements such as 'rockets' and in 1940s they were to 'defense' and 'victory.' Finally, in the 1950s, they were associated with the good old 'outdoors.' All these associations created a distinct personality for the product that soon became identified as 'the protector' with a bold, strong, and sturdy frame. Till the 1950s, there were little variations in the models. However, post-1950s, Harley Davidson emphasized

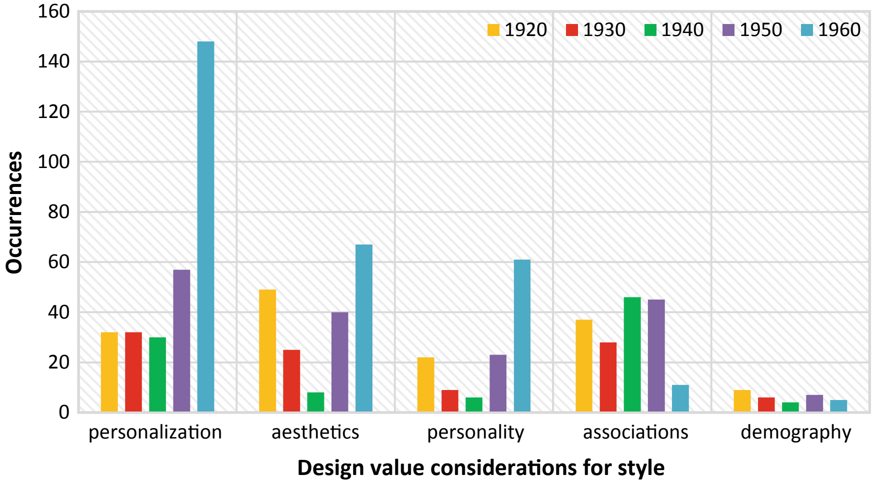

Fig. 24.3 Total occurrences of design value considerations for style across five decades

on choice and personalization with minimum demographic variety. During this time period, the primary focus of the Harley was male users.

24.3.4 Design Value Considerations for Performance

Performance (n) may be defined as 'achievement under test conditions or the capabilities of a machine' [5]. The advertisements were observed to propagate five types of design value considerations for performance, namely power, speed, acceleration, quality, and reliability. See Fig. 24.4. Performance has greatly increased over the

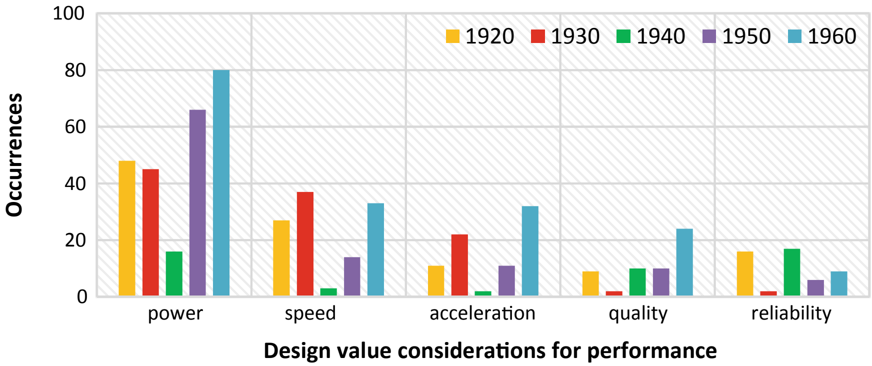

Fig. 24.4 Total occurrences of design value considerations for performance across five decades

years due to new technology. The occurrence of 'reliability' related words became more dominant in the 1940s where references to its successful use in defense activities were mentioned. However, this reduced in the later years as the company established its market position.

24.3.5 Design Value Considerations for Convenience

Convenience (*n*) may be defined as, 'the quality of being convenient, freedom from difficulty or trouble, an advantage, a useful thing, esp. an installation or piece of equipment' [5]. Here, convenient (*adj*) may be defined as 'serving one's comfort or interest, available at a suitable time or place, easily accessible, well situated for some purpose' [5]. The advertisements were observed to propagate fifteen types of design value considerations for convenience, namely (*A*) time saving, (*B*) terrain versatility, (*C*) easy maintenance, (*D*) easy use, (*E*) easy access, (*F*) storage facility, (*G*) easy visibility from the outside, (*H*) easy visibility from the inside, (*I*) effort saving, (*J*) environmental protection, (*K*) traffic advantage, (*L*) easy parking, (*M*) easy delivery, (*N*) manageable weight, (*O*) easy learnability. See Fig. 24.5.

In the 1920s, movement between city and the countryside increased due to industrialization, two wheelers were the speediest form of transport available. The company even introduced a sidecar attachment to carry guests. As many places still did not have roads, the ability of two wheelers to be versatile enough to go through a variety of terrains and spaces made them very popular. Unfortunately, the 1940s were greatly impacted by the war, Harley stopped civilian motorcycles and began manufacturing for the defense.

Visibility became an exciting aspect as one could see more when driving on a motorcycle, resulting in a richer immersive riding experience. Sightseeing and adventure outings were also encouraged. Hence, two wheelers soon became the best vehicle to discover and see 'America' with. Also, visibility from outside acted as a great opportunity for the brand to create accessories. It also helped the police and defense command attention and easily communicate while being mounted on the

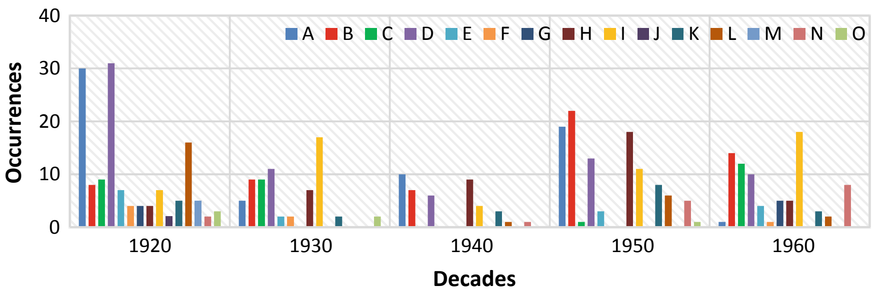

Fig. 24.5 Total occurrences of design value considerations for convenience across five decades

motorcycle. Speed and terrain versatility further added to the Harley becoming a symbol of national security.

By the 1950s, two wheelers were more developed and had been tested in different extreme conditions in the war. This helped the advertisements to use the Harley's success in rough terrains as their value proposition. Also, as traffic increased, the Harley was seen as a convenient way to avoid traffic jams and parking issues.

24.3.6 Design Value Considerations for Affordability

Affordability (*n*) may be defined as 'ability to be afforded, inexpensive,' 'the cost or price of something' [6] where afford (*v*) may be defined as to 'have enough money, means, time, be able to spare, be in a position to do something (esp. without risk of adverse consequences)' [5]. The advertisements were observed to propagate six types of design value considerations for affordability, namely initial cost, running cost, upkeep cost, resale cost, insurance cost, and garaging cost. See Fig. 24.6.

Affordability was an important aspect in the early years as the two wheelers provided the cheapest form of transportation. The company also offered easy payment plans to help make the two wheeler more affordable. However, in the later years the Harley was able to create a niche that went beyond affordability. After initial cost, running cost was the most mentioned in the advertisements. Interestingly, garaging cost appeared in the 1920s but then vanished. A new type of cost in the form of insurance began to surface during the 1950s and 60s.

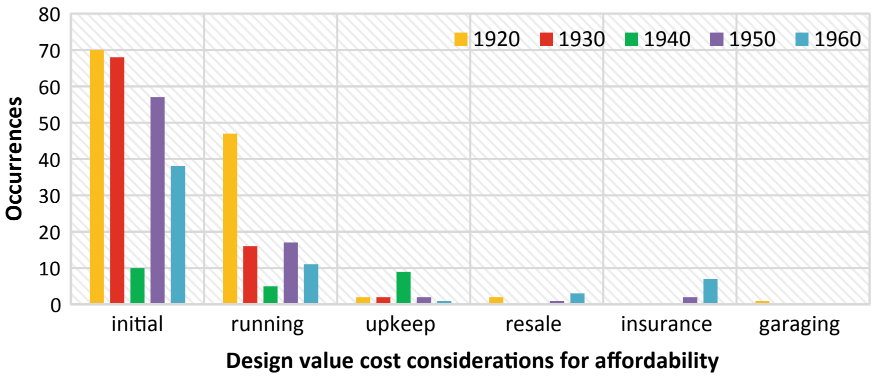

Fig. 24.6 Total occurrences of design value cost considerations for affordability across five decades

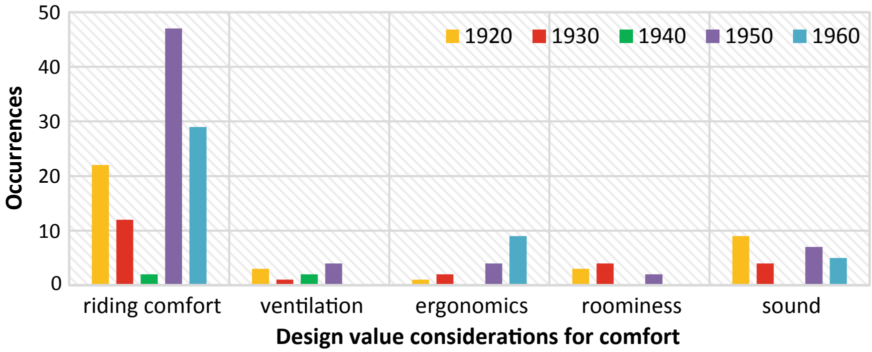

Fig. 24.7 Total occurrences of design value considerations for comfort across five decades

24.3.7 Design Value Considerations for Comfort

Comfort (*n*) may be defined as 'a state of physical wellbeing, things that make life easy or pleasant' [5], while comfortable (*adj*) may be defined as 'free from stress or tension' [7]. The advertisements were observed to propagate five types of design value considerations for comfort, namely ergonomics, ventilation, riding comfort, roominess, and sound. Riding comfort remained the most prominent consideration and was expressed through two aspects—balance and smoothness. This consideration became even more highlighted in the 1950s due to the availability of superior technology.

Ventilation and roominess were related to access of fresh air and space to stretch and move. Roominess was also expressed as a factor when the Harley offered a sidecar during the 1920s and 1930s. Interestingly, though the Harley is today associated with being the 'noisy' motorcycle, advertisements in the initial years used words like 'wonderfully quiet' and 'silent,' by 1950, words like 'soft purr' and 'purring' began to be used. Meanwhile, ergonomics peaked in the 1960s and was mainly expressed through saddle form and handlebar grip (Fig. 24.7).

24.3.8 Design Value Considerations for Durability

Durability (*n*) may be defined as 'The ability to withstand wear, pressure or damage' [8] or implying durable. Here durable (*adj*) may be defined as 'capable of lasting, hard wearing,' where 'durare' means endure and 'durus' means hard [5]. In synonyms of durability one can find 'longevity, permanence and ability to last' [8]. The advertisements were observed to propagate three types of design value considerations for durability, namely longevity, endurance, and strength. Durability has steadily increased over the years with endurance playing an important role in the 1940s. For a complete picture of durability, it should be read along with 'associations'

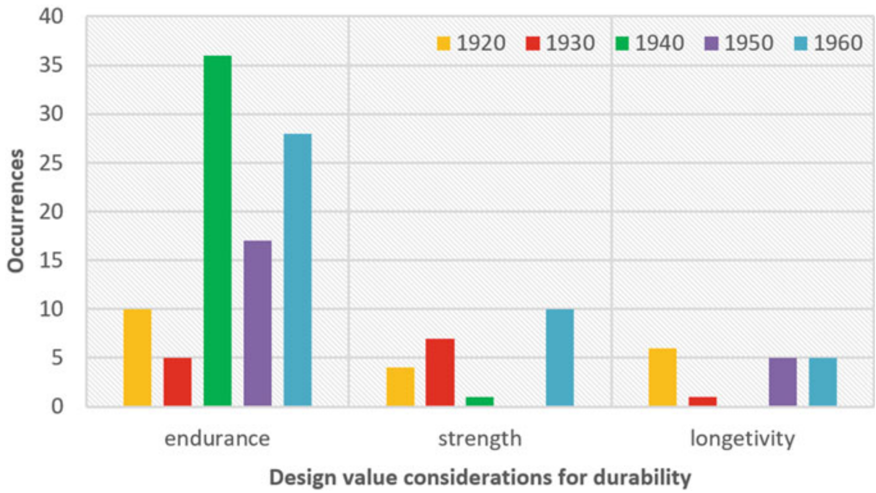

Fig. 24.8 Total occurrences of design value considerations for durability across five decades

under 'style' and 'terrain versatility' under 'convenience.' Durability was greatly expressed through the Harley's association with the defense and police departments. It was also acknowledged as a winner at sports events that required endurance and strength. Mentions of climbing steep hills and difficult off-road tracks were often made (Fig. 24.8).

24.3.9 Design Value Considerations for Safety

Safety (*n*) may be defined as 'the condition of being safe, freedom from danger or risks' where safe (*adj*) is defined as 'reliable, certain; that can be reckoned on' [5]. The advertisements were observed to propagate three types of design value considerations for safety, namely control, user protection, and object protection. Though the initial years reflected overall safety, later it was mainly expressed through the ability to have greater control over the product. For example, superior breaks. The gradual reduction of focus on user or object protection may be attributed to the development of safety products like helmets, body guards, and wind shields (Fig. 24.9).

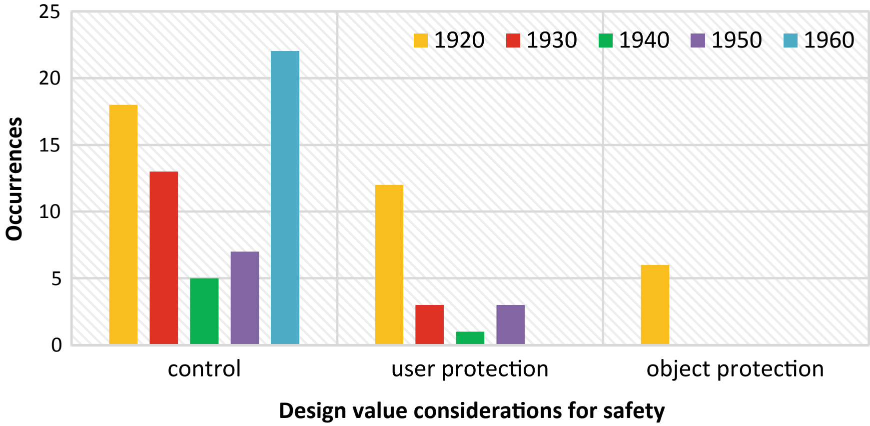

Fig. 24.9 Total occurrences of design value considerations for safety across five decades

24.4 Discussion

24.4.1 Design Values Through Time

The years between 1920 and 1970 demonstrated a crucial period for Harley Davidson two wheelers. There was growth in industry, the Great Depression, world wars, nation rebuilding, and technological and scientific advancements. Hence, it was a dynamic and ideal period to explore how drastically diverse the changes in design values could become with time. However, the study demonstrated that the same set of design values were observed throughout the 50 years. Except in the 1940s when conservation of resources was introduced due to the world wars. Also, though security vanished post-1920s, it came back in the 1960s. This encourages one to believe that though new design values may be added, existing ones would most likely remain, making them relevant even in the future. This hypothesis is further strengthened when one compares this study's findings to the (DeF) framework research outcomes.

24.4.2 The Relevance of Design Value Considerations and Their Occurrences

Design values are often abstract. Hence, the observation of how they are achieved in the form of design value considerations greatly helps to quantify them. For example, how do you compare the comfort of two vehicles? The design value considerations help provide means by which the comfort of two vehicles can be compared. Additionally, documenting their occurrences adds another layer of learning. Through the analysis of occurrences, we gain a deeper understanding of how design values are interconnected, what external factors influence them, and how their meaning might change based on which design value considerations are given more emphasis.

24.4.3 Future Scope

The intention of this study was to observe design values over time rather than observe design values of immediate influence. However, its relevance to future contexts can be further validated by the study of current design values. Another interesting direction for future research is to compare this study's results with other two wheeler products to explore factors of variation.

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Chapter 25
What Can Designers Learn from Failed Solutions in BOP Contexts?

Pankaj Upadhyay and Ravi Mokashi Punekar

Abstract The topic of design and development of solutions for the base of the pyramid (BOP) and similar contexts has garnered significant attention in recent literature. This topic is multidisciplinary with dimensions of business, product design, supply chain, sustainability and social development. Many contributions in each of these dimensions use a case study-based approach for developing theories, guidelines and heuristics. Arguably, despite explicit mention, most selected cases in these studies are included in the analysis because they are successful. Unfortunately, this may create an inadvertent sampling bias in the body of knowledge generated. Furthermore, this may be unavoidable since failed case examples, barring a few, are never reported in academic or non-academic literature. In this paper, we attempt to partially fill this lacuna by collecting and analysing six case examples that are considered and reported as failed. To do this, first, we conduct a systematic search in academic and non-academic sources to find examples of unsuccessful solutions for marginal context. Selected cases from the list are analysed to understand why they are reported as failures. We study these cases based on a framework derived from a review of recent relevant literature. Specifically, we highlight the recommended guidelines which we found in our research, which the case examples followed or did not follow. Given the results, we propose some changes to the design process when designing solutions for the base of the pyramid and similar marginal context. Additionally, we discuss the implication of the study for the general mindset, which the designer must inculcate to design for the BOP effectively. The paper concludes with a discussion on the scope for future research and limitations of the presented work.

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A. Chakrabarti et al. (eds.), *Design for Tomorrow–Volume 3*,
Smart Innovation, Systems and Technologies 223,
https://doi.org/10.1007/978-981-16-0084-5_25

25.1 Introduction

We have a typical' design process. There are two specific ways in which there is a difference. Firstly, the designer's approach in solving the design problem for the marginal contexts is different than what they would use for resource-abundant contexts [1]. Secondly, it is because of the in-depth contextual knowledge required during the design process and the inherent constraints on executing the solution in the context [2]. The current notion is to account for these constraints when designing solutions and employ systems thinking approach and broadening the scope of the design solution and the process [3].

A significant part of what we understand about the design process for the BOP is an accumulation of the work in varied domains. The BOP context and how to approach it have been studied from the perspective of product design [3] business or strategic design [4], sustainable development [5], and supply chain management [6], among others. We can find that a significant number of these studies use a case study-based approach due to the methodology's appropriateness to the topic at hand. In a typical case study-based research, cases are selected based on their impact of the phenomenon. It just so happens that most of the case examples which end up getting chosen for studies are the ones that have been able to break through the barriers and constraints laid down by the context [7]. These cases do tend to provide the most valuable insights which the researchers are searching. Unfortunately, unless a design solution has significantly failed to achieve the expectations they had laid down, *and* the media widely report it, it may not become the subject of academic scrutiny. We believe the term 'Failed case' needs a more deliberate definition in this paper's context and in the field of design for the BOP. We will attempt to provide our definitions of 'Failed case' in the next sections.

There probably are many more failed cases than successful ones among all the designs done for the BOP. This notion is strengthened by the fact that a large number of reports in the domain suggest that execution of the design process in such context is different and possibly even harder than the typical design process [8]. However, we cannot disregard the fact that a lot could be learned from every failed example. In this paper, we attempt to take a few steps in this direction. We first define what could be called failed cases and try to find some case examples which fit the description. Then, we will analyse the relevant literature for identifying the key suggestions for designing for the BOP and similar marginal contexts. Using this as a framework, we will examine the selected cases, present the information we find and highlight the information we could not find. In conclusion, we discuss the outcomes, its implication on the design process and the designer's overall approach for such projects.

25.2 Research Questions and Objectives

This research aims to collect some failed solutions for BOP and identify some learning for the design practice. Our aim followed the research question to understand how failed cases deviate from the prescribed guidelines for the design for BOP. An underlying hypothesis was that failed solutions do not meet many of the suggested design guidelines for the BOP. Although we present only a qualitative analysis with a small sample of cases, this analysis can strengthen the overall value of these guidelines.

In this research, we define failed case examples as the solutions whose 'core idea' has been discontinued from further development by the initiating agency since it did not meet one or more of the primary needs after it was developed. 'Core idea' is defined as the embodied tangible artefact whose primary function leads to fulfilling the primary need or solving a problem. With this, our objectives were, firstly, to collect failed case examples from academic and non-academic literature, secondly, to develop a framework for their analysis and thirdly, to analyse the cases and uncover some insights to inform design practice.

25.3 Methodology

To find failed case examples, we first search the Scopus database for articles, where the keywords 'failed' and 'solutions' and 'base of the pyramid' appear together in the title, abstract or keywords. The search was broadened by using other terms that were similar to these key terms. We reviewed the abstracts of around 300 articles and eliminated those that were not related to the topic or did not mention any cases in the abstract field. We did not consider reports related to failed social innovations and policy interventions since we are primarily concerned with the design of products and artefacts. We found 17 relevant articles, where specific cases were discussed in the abstracts. There are very few articles that delved into analysing failed case examples from the perspective of design for the BOP.

Furthermore, we searched in an online database of solutions provided by 'engineeringforchange.org'. The website lists product and solution which are aimed towards one of the sustainable development goals. A significant number of products listed are directly related to a base of the pyramid context. We collected a list of solutions that the database had marked as 'discontinued'. Many such discontinued products were replaced by a better version or were still distributed under a different name. Such cases were not considered and were eliminated from our list. Additionally, we removed solutions, where reliable published literature (academic or non-academic) was not found. To further enrich our list of cases, we conducted a web search using a combination of relevant keywords.

Finally, one of the most indispensable sources was to ask people. The first author asked the alumni group of his design school, colleagues and a few experts in the field and to suggest some case examples that they knew (and thought) had failed. Many of the suggested cases had already been collected, which indicated that saturation was occurring. From all the searches, a total of six cases could fit our criteria and were analysed further.

25.4 Framework for Evaluating the Cases

To formulate a framework for evaluating the selected cases, we reviewed recent literature on design for emerging contexts. Several authors have written about the design process for the context [3, 9]. A common notion is that there is a significant difference from the typical design, development, business and dissemination process when it comes to the emerging and marginal context [1, 10, 11]. Authors also agree that the design process needs a broadened scope [12], a co-design approach [3] and a deep understanding of the context and the users [13]. Additionally, several authors have tried to inform the design process by collecting and proposing guidelines from relevant literature [13, 14]. The most recent and comprehensive review to inform the design process for emerging contexts was given by Jagtap [13].

Jagtap proposes ten guidelines to inform the design practice for marginal contexts [13]. Due to this literature's recency and the breadth of the review, we use these ten guidelines to formulate a framework for our analysis. Specifically, after a thorough examination of the ten guidelines, we formulated the 14 questions for which we tried to seek an answer from each of the selected case examples. These questions are presented in Table 25.1.

Apart from these questions, we record the 'Core Idea', the basic need to be fulfilled and the indicated reason for failure. Based on the answer to these questions, we can see the guidelines, where each of the failed case examples performed inadequately. Furthermore, it may be possible to gauge at a remedy to these failings, which may directly inform the design process.

25.5 Results

Following is the list of case examples that we discovered through our search and their analysis based on the framework (Table 25.2).

Our search found many other examples that had been deemed failed by multiple sources but could not be included in the list due to our inclusion criteria and definition of failure. For instance, Vestergaard's Lifestraw®, a water filtering product, is considered a failure by some [42, 43] due to its prohibitively high cost. Still, the technology has been diversified into several products since its introduction. The idea has not been abandoned, and thus, the product cannot be considered a failure as per our definition. Additionally, we also found case examples that some reports deemed

Table 25.1 Framework for evaluating the case examples

Title	Question
Q1 Holistic understanding	Is there evidence of holistic knowledge of marginalised communities and the context?
Q2 User's daily life	Is there evidence of a deep understanding of the daily life of the user?
Q3 Co-Design	Is there evidence that a co-design process was used at key stages of the design process? (key stages are, understand needs, concept generation, concept selection)
Q4 Adaptation	Is there evidence that the solution (or its parts) was contextualised or adapted to suit the scenarios in which it was deployed?
Q5 Leverage social strength	Is there evidence that the solution leveraged local socio-cultural strengths of the communities, where and when it was deployed?
Q6 Used existing infrastructure	Is there evidence that the solution used the strength of existing infrastructure, products or resources in the context?
Q7 Training programmes	Is there evidence that the solution provided training programmes to the actors in the context for implementing, using, or maintaining the solution?
Q8 Income opportunities	Is there evidence that the solution provided income generation opportunities for increased income from current means directly or indirectly?
Q9 Appropriate awareness	Is there evidence that the solution employed means of creating awareness that was contextually appropriate and suitable to the literacy level in the context?
Q10 Services	Is there evidence of contextually appropriate services or support was provided for post-use and end of life scenarios?
Q11 Reliability	Is there evidence that the solution is designed to be robust, reliable and resilient to the extreme environment or usage pattern?
Q12 End of Life	Is the solution designed to be easy to repair upgrade, adapted or modified?
Q13 Collaboration	Is there evidence of collaboration and partnerships in various stages of the lifecycle of the solution?
Q14 Desirability	Is there evidence that the solution considered aspects of aesthetics, usability, ergonomics and other such factors of desirability?

failed, but could not be regarded as failed since they did not fit our definition or did not have enough information available.

Similarly, we found several examples of discontinued products in the engineering for change database (www.engineeringforchange.org), where the underlying technology was taken further to develop other products for the same contexts or the product was upgraded. From a total of 29 case examples of discontinued products

Table 25.2 Failed case examples and their analysis based on framework developed

Case name and details	Analysis of the case
Case 1—Tata Nano: Nano was termed as the 'world cheapest car' and was designed and developed in India by Tata Automobiles. The product failed to meet customer expectations, and reports suggest that production may halt in 2020 [15]. The core idea was to create an affordable car for people whose primary family transport is a two wheeler [16]. Reports indicate that the product failed due to on road performance, production problems due to political issues, lack of manufacturing capacity at initial stages, marketing and product positioning problems [17, 18]. Based on existing literature and reports[16, 17, 19], we make the following assessment with our framework	***Q1 Holistic understanding***: Somewhat. The development team communicated continuously with communities during the development of other products and used the experience ***Q2 User's daily life***: Could not be assessed ***Q3 Co-Design***: Somewhat. The team used collaborated with suppliers and manufacturers early in the development process to find new and novel ideas for costs reduction. No information was found regarding co-design with users ***Q4 Adaptation***: Yes. Modification of supply chain, special financing schemes in collaboration with banks ***Q6 Used existing infrastructure***: Yes. The suppliers, workforce and infrastructure used for the development of exiting products were leveraged ***Q7 Training programmes***: Yes. Franchisees were given training on assembly and servicing ***Q8 Income opportunities***: Somewhat. The company encouraged local franchisees ***Q9 Appropriate awareness***: No. The marketing and positioning of the product were not well received by consumers ***Q10 Services***: Somewhat. Post-purchase services were available ***Q11 Reliability***: No. Although the product met some international guidelines, it was unreliable in the field ***Q12 End of life***: Somewhat. Due to the reduced complexity in assembly than other models ***Q13 Collaboration***: Yes. With suppliers ***Q14 Desirability***: Yes. External design agency was used to design the vehicle Other questions could not be assessed due to inadequate information available

(continued)

Table 25.2 (continued)

Case name and details	Analysis of the case
Case 2—Soccket by Uncharted Play: The product is a football which could harness and store energy when kicked around. The energy can be used to light up an LED or charge up devices later on. The basic need was to provide power in inaccessible and off-grid scenarios in marginal contexts. The indicated reason for product failure was: an unclear understanding of the usage patterns [20, 21], Performance issues and reliability issues [22, 23]. The company has since renamed to uncharted power and is primarily focusing on other stray energy harnessing solutions. Based on the existing media reports [20, 21], we assess the case as follows:	***Q1 Holistic understanding***: Somewhat. The product was aimed at communities, where soccer is the main form of play. However, it was unclear if other aspects and impact on the context was assessed ***Q2 User's daily life***: No. The play-to-light ratio and the fact that one ball would be used by several children during play, but all these children would need light at the end of the day indicate this ***Q3 Co-design***: Somewhat. User test with prototypes and extensive giveaway models was used to improve the design. However, we did not find evidence that co-design activities were used in all phases ***Q4 Adaptation***: Somewhat. In terms of product design and business model, e.g. a donation scheme of buy one give one and play to donate were used ***Q11 Reliability***: No. product was unreliable for several users and broke down after some amount of play in the actual context. Although reports indicated that only around 3% of the products failed ***Q14 Desirability***: Yes. The initial reports of reception and user feedback were positive Other questions could not be assessed due to inadequate information available

(continued)

Table 25.2 (continued)

Case name and details	Analysis of the case
Case 3—Roundabout Playpumps: The product was playground equipment which could mechanically power a water pump. The community could then use the stored water. The product also had an advertisement board attached to it, the revenue from which was planned to be channelled towards product maintenance. The product has been comprehensively analysed in the Ph.D. thesis by Borland [24]. The main reasons for failure were an unclear understanding of the user's lives, product performance, un-envisioned usage patterns and flawed calculation of water usage patterns. Based on Borland's research and some supporting material [24], we analyse the case as follows	***Q1 Holistic understanding***: Somewhat. The promoter hit upon the idea when installing other water pumping solutions in the context. However, there is no evidence that a holistic understanding was pursued after the idea kickoff ***Q2 User's daily life***: No. It is reflected in a large amount of playtime required for pumping and the reluctance of advertisers to advertise in such settings ***Q3 Co-design***: Unclear, but overall reports point to a negative ***Q4 Adaptation***: Yes. Product was locally manufactured ***Q6 Used existing infrastructure***: Yes. Product was locally manufactured ***Q8 Income opportunities***: Somewhat. Indirectly by providing clean water ***Q9 Appropriate awareness***: Yes. Community-level programmes and installations ***Q10 Services***: No. a large number of playpumps failed and could not be maintained due to the initial plan of advertisement not generating enough money ***Q11 Reliability***: No. Many playpumps failed in the harsh conditions of the field ***Q12 End of life***: No. Playpumps were abandoned and were not used as intended ***Q14 Desirability***: No. The system was mostly designed to appeal the funding and supporting agencies than the user Other questions could not be assessed

(continued)

Table 25.2 (continued)

Case name and details	Analysis of the case
Case 4—One Laptop per child: A low-cost laptop designed for the underprivileged children in remote locations of the emerging contexts. The basic need was to provide the children with a means of self learning [25]. The indicated reasons for failure were that an unclear understanding of the context and educational infrastructure in developing world, production and sourcing issues, performance, infrastructure issues and competitor products [26, 27]. We analyse the case based on some existing reports [27–30] and the literature [25, 31, 32]	***Q1 Holistic understanding***: No. An unclear understanding of the context and the infrastructure is one of the reasons cited as a failure ***Q2 User's daily life***: No. The promoters did not consider how the student will use the product in their daily lives and in an educational context ***Q3 Co-Design***: Somewhat. Several prototypes of the product were given to users for getting feedback and design ideas ***Q4 Adaptation***: Yes. The design incorporated a hand crank mechanism to generate power, a novel hardware, operating system and interface ***Q6 Used existing infrastructure***: No. The local infrastructure such as electricity availability, curriculum and educational infrastructure was not considered ***Q7 Training Programmes***: Somewhat. The deployment agencies provided some teacher training in specific countries ***Q8 Income opportunities***: No. The company primarily sold the products to developing nations ***Q10 Services***: No. Lack of services provided in one point of critique of the product ***Q11 Reliability***: Somewhat. Although the product was built tough, the internal hardware and software failed in many cases ***Q14 Desirability***: Yes. The product and the UI were designed by a start designer Yves Béhar Other questions could not be assessed due to inadequate information available

(continued)

Table 25.2 (continued)

Case name and details	Analysis of the case
Case 4—Multix by Polaris: a multi-use carrier and passenger vehicle where the engine power could be used to provide electricity or power various equipment such as water pumps through a connector mechanism. The core need was to provide a multi-purpose means of transportation in rural Indian contexts [33]. The product was a joint venture between Eicher Motors in India and Polaris of US. The joint venture has since been dissolved and the production discontinued in 2018. The main reported reasons for failure were inadequate sales. We assess the product based on a few reports which exits [34, 35]	***Q4 Adaptation***: Yes. The product trunk could be expanded, and the functionality of the connector mechanism suggests this ***Q8 Income opportunities***: Yes. The product enables connection of items such as flour mill and water pumps ***Q10 Services***: Somewhat. General after sales services were provided Other questions could not be assessed due to inadequate information available
Case 5—Simputer: A small handheld computer designed for educational purposes in the Indian context. The core need was to provide a means of data access and computing in rural Indian contexts [36]. The indicated failure was lack of manufacturing facilities in context, perceived risk, lack of training and marketing [37, 38] Our analysis based on some key resources are as follows: [36, 39, 40, 41]	***Q1 Holistic understanding***: Somewhat. The designers considered that a village could have one device used by multiple people ***Q4 Adaptation***: Yes. The device used smart cards and AAA batteries in case of an unreliable power source ***Q6 Used existing infrastructure***: No. This is one of the reasons cited for failure. There was a lack of manufacturing facilities in India at the time ***Q8 Income opportunities***: Somewhat. The nature of the plan would have created job opportunities at the context, e.g. say a device operators at the village level ***Q9 Appropriate awareness***: No. Marketing is cited as a reason for failure ***Q10 Services***: Somewhat. Basic service was provided ***Q11 Reliability***: Yes. The device was well built and suitable for use in the context ***Q14 Desirability***: Somewhat. The device was well engineered, but the other desirability aspects could not be assessed Other questions could not be assessed due to inadequate information available

(continued)

Table 25.2 (continued)

Case name and details	Analysis of the case
Case 6—Aakash tablet (a.k.a Ubislate 7+): An android tablet aimed for educational purposes in Indian contexts. The basic need was to provide a digital device to students in India [38]. The indicated reasons for failure were manufacturing issues, unfavourable media reports, performance and political reasons. Based on some key reports and literature [38], we analyse the product as follows:	***Q1 Holistic understanding***: No. The idea of the device was borrowed from other cheaper tablets and computers ***Q6 Used existing infrastructure***: No. The promoters focused on outsourcing the device to agencies outside of the context ***Q9 Appropriate awareness***: No. Reports do not suggest any unique or appropriate forms of awareness campaign outside of launches and unveilings ***Q11 Reliability***: No. The device was unreliable and underpowered in use ***Q13 Collaboration***: Somewhat. Several agencies collaborated in the development and manufacturing of the device, but this was forced rather than amicable Other questions could not be assessed due to inadequate information available

from the ‘engineering for change’ database, only one case fit our criteria, that of the Uncharted Play Soccket. The remaining 28 examples had either been replaced by a better version of the product, were open-source designs, distributed under a different brand name or simply did not have enough information to evaluate them.

25.6 Discussion of Results

Although we started off to find a significant number of cases examples, we could not find many. This strengthens our assumption that failed case examples are not discussed adequately in the literature or media unless they are high profile ones. In our analysis, we found Tata Nano a fascinating case example. The product was deemed a success at launch and has been praised as a quintessential example of frugal engineering and frugal design [44]. Many academic papers use the example of the success of Tata Nano to frame suggestions and guidelines [16, 45]. Tata Nano was a success during its lifecycle, from idea conception up to commercialisation. However, it failed after it was released into the open competitive market. This indicates that ‘product failure’ can happen at much later stages of deployment as well.

Adapting the suggestion of Dana et al. [46] for dividing the lifecycle of a grassroots innovation project, we can define three stages of failure: Failure at the inception phase, failure at the protective niche phase and failure in the open market. Designers and researchers can analyse their products at these distinct stages and report the shortcomings for analysis and theory building by the research community.

Our analysis shows that most of the failed cases did not meet the design guidelines presented. Thus, these guidelines are invaluable for the designer to assess their projects. Additionally, we see that the failed case examples had a lesser understanding of the holistic context and users’ daily lives. As suggested by many prior articles [3, 12, 13], a deep and holistic understanding of the context and users’ daily lives is essential for successful design in marginal contexts. We suggest that designers approach the process with a researcher’s mindset (and a hypothesis) that their initial idea is not correct to solve the envisioned design problem in the context. Through the course of understanding the context and users’ daily lives, the designer can then disapprove this notion (or land upon the right idea) and end up designing a better product.

In our analysis, we also find that most solutions did not perform adequately in the context. We suggest that a co-design approach and constant testing of the idea in the context are a remedial measure for this. Additionally, strategies such as design for manufacturing, failure modes analysis and reliability engineering tools should be used when developing the product. Correct performance parameters should be prepared with a co-designed approach, and the product should meet this target. Finally, repeated testing of the product prototypes should be done in context to alleviate such problems.

Finally, our analysis of the cases has strengthened the case of developing tools based on the guidelines. As of now, the instructions are relatively holistic, and the novice designers may not clearly understand how to implement them in their projects.

Implementing these guidelines into tools that can be applied at specific stages of a design project is undoubtedly needed. Additionally, a future work related to this study could use an ethnography-centric or case study approach to further uncover learnings from such cases.

25.7 Conclusion

This paper presents an analysis of six cases of failed products designed for the marginal contexts. Firstly, we provide our definition of a 'failed case'. We follow a systematic method for searching relevant case examples in academic and non-academic literature. After collecting several cases, we chose six instances due to the relative availability of reports and their fit to our definition. We highlight several more cases that have been deemed failed in some reports but did not fit our inclusion criteria. To analyse the cases, we formulate a framework based on guidelines for designing products in marginal contexts [13]. We present our analysis in the results section and offer some suggestions to inform the design process in the discussion section. Although some of the cases we select have been analysed by authors previously, we present a novel perspective and analysis.

There are some limitations to this study. First and foremost, this cannot be considered a comprehensive analysis of each case's design process. Additionally, our findings do not indicate causality, nor they can answer questions like 'why do products fail in the market?' Such a comprehensive review, although beneficial for designers, was out of the scope of this paper.

Also, we believe our literature search method biased us to select only the reports, where case examples were mentioned in the abstract. There may be cases that are discussed in the body of the report but were not uncovered since they were not mentioned in the abstract fields.

Finally, we would like to acknowledge that the word 'Failed Product' may have some political and negative connotations, which we have tried to avoid in this article as far as possible. Nonetheless, some may still argue that several aspects of these cases were a success, and we agree with this notion. Our intention is not to ostracize these innovative products or the people behind them, but only to learn from each case example. Our only goal is to strengthen the current understanding of design guidelines for product development in marginal contexts.

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Chapter 26
Perceived Slip Resistance of Flooring

Neelima Gudavalli and Phanisree Vagvala

Abstract The study aims to understand the factors that influence perceptions of elderly persons about flooring slipperiness and to observe if there is a difference between the perceived slip resistance (PSR) and the measured slip resistance (MSR). Methods: 262 flooring samples in residences of 48 elderly persons living independently in communities participated in the study. ASM 925 DCOF slip meter was used to measure MSR. PSR was assessed with a semi-structured questionnaire. Mann–Whitney U test was performed for testing difference between MSR and PSR. Conclusions: The study concluded that the influencing factors for MSR and PSR were not similar. Measured slip resistance was concerned with factors related to the environment. PSR, in addition to the environmental factors, was found to be influenced by individual's sensory and psychological factors which were rarely considered by MSR assessments.

26.1 Introduction

Falls are a leading cause for disability and reduced quality of life in elderly persons. World Health Organization (WHO) report on falls in 2018, stated that older people are the most vulnerable to falls and the consequences leading to serious injuries or death. The report suggested safety interventions to include strategies for falls prevention by creating safer environments [19].

Flooring plays a vital role in the prevention of slips and falls. Elderly persons were the most likely to slip and fall due to age-related gait changes like higher horizontal heel contact velocity and slower transition of whole body [15]. The mismatch between the two entities often resulted in slips and falls. It may be inferred that strategies to

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A. Chakrabarti et al. (eds.), *Design for Tomorrow–Volume 3*,
Smart Innovation, Systems and Technologies 223,
https://doi.org/10.1007/978-981-16-0084-5_26

Table 26.1 Parameters that influence slip resistance of flooring

	Parameter	Threshold value	Influence on slip resistance of flooring
1	Dynamic coefficient of friction (DCOF)	0.42 DCOF	Directly proportional to slip resistance [1]
2	Static coefficient of friction (SCOF)	0.6 SCOF	Directly proportional to slip resistance [1]
3	Required coefficient of friction (RCOF)	–	Increases with decrease in difference between RCOF and DCOF [3, 7]
4	Surface roughness of flooring	17–50 μm	Directly proportional to friction. However, optimum level of surface roughness is recommended for falls prevention [9, 10]
5	Texture and surface topography	–	Directly proportional to friction [9, 12]
6	Material accumulation	N/A	Inversely proportional to friction [4]
7	Wear	N/A	Inversely proportional to DCOF [12, 13]

reduce the horizontal heel contact velocity may reduce slips and falls in elderly persons. This could be achieved by addressing the interface between underfoot and flooring surface for interventions to achieve slip-resistant flooring systems. Table 26.1 refers to the parameters that influence slip resistance of flooring.

26.1.1 Challenges with Slip Resistance Measurement

There are no internationally accepted guidelines for measuring slip resistance. With the varied influences that determine the flooring slipperiness, there is a lack of consistency in standard specification for measurement of slip resistance. The old thumb rule of 0.6 SCOF has been replaced by the new measurement of 0.42 DCOF by the 2012 edition of ANSI A137.1, the American standard specifications for ceramic tile [1]. This standard has a limited application, as DCOF alone cannot determine the various factors that influence slipperiness of a flooring surface. To a certain extent, the DCOF may yield reliable results when paired with testing roughness of the flooring. The surface roughness in the range from 17 to 50 μm has been considered as optimum for level flooring used for walking.

Ample studies were conducted in a laboratory setting to test flooring materials for their properties of slip resistance [8, 16, 17]. However, studies concerning flooring performance in situ are very limited.

Psychological factors like fear of falling and perceptions of elderly persons were rarely explored. Some studies observed behaviors of people when they anticipate a fall. These strategies they adopted to control a fall were found to be hazards by themselves which could lead to accidents.

Head Pitched Down: Elderly who anticipated a fall, pitch their heads down and pay attention to their step rather than being conscious of other potential hazards in their environments [2].

Stiffening Strategy: Elderly persons adopt a 'stiffening strategy' in order to control their posture. They reduce the range of motion of the center of mass, resulting in lowered amplitude and higher frequency of postural sway, leading to falls [20].

Gait change: People change their gait speed and walk with a wide gait and flat foot resulting in loss of balance [5]. False perceptions of floor slipperiness often lead to gait changes such as reduced levels of RCOF that may result in slips and falls [11, 14, 15]. The strategies adapted by elderly people when they perceive a potential fall-hazard, increased the chances of falling. Research in this area may leave an important rationale for researchers and designers in their pursuit for optimal slip-resistant flooring systems.

The present study aims to understand the factors that influence perceptions of elderly persons about flooring slipperiness and to observe if there is a difference between the perceived slip resistance and the measured slip resistance. In the current study, measured slip resistance (MSR) refer to the values derived from measuring the DCOF of flooring, using a standard method of measurement and perceived slip resistance (PSR) refers to the perceptions of the user regarding floor slipperiness.

26.2 Methods

A random sample of 48 active elderly persons who are ambulatory, aged between 60 and 80 years, living independently in communities and who are capable of performing activities of daily living independently have participated in the study. None of the participants reported any type of visual impairment or physical disability. The study locations were the 48 residential environments of the participants. In each house, six rooms were selected for the study. Spaces that are least prone to spills and material accumulation were categorized as Type I spaces, consisting of living room, dining room, and bedroom. Bathroom, kitchen, and laundry were categorized as Type II spaces, as they are most prone to spills and material accumulation.

Ten flooring types with 287 flooring samples were identified in the 48 study locations. Roughness of all floors was tested and floor samples which did not fit the safety roughness range from 17 to 50 μm were excluded. Surface roughness tester SRT-6200 was used for testing roughness. The final sample consisted of 6 types of flooring with a total of 262 floor samples.

Measured Slip resistance (MSR): ASM 925 DCOF slip meter was used to measure dynamic coefficient of friction (DCOF) of the flooring in wet and dry conditions to determine the measured slip resistance. ASM 925 DCOF is based on the standard recommendation by the American standard specifications for ceramic tile [1]. Six readings were taken for each test, in major circulation spaces of the room. Average of the 6 readings was noted as the final value for DCOF. The standard threshold value of 0.42 DCOF was considered to determine the slip resistance.

Perceived slip resistance (PSR): All the participants answered a semi-structured questionnaire prepared to record their perceived slip resistance for each flooring. The questionnaire used a 5-point Likert scale, ranging from 'extremely slippery' to 'not slippery'.

Mann–Whitney U test was used for analyses of significant difference between the MSR and PSR observations. Mann–Whitney U test, also called as Wilcoxon rank sum test, is a nonparametric method used to test difference of observations between two groups. The test is proven applicable for five-point Likert scale data sets [6, 18]. The DCOF observations were coded into 5-point Likert scale for application in the test. 0.42 DCOF being the threshold was coded as neutral (DCOF < 0.30 = 'extremely slippery'; 0.30–0.41 = slippery; 0.42 = neutral, 0.43–0.5 = 'somewhat not slippery', and >0.5 was considered as 'not slippery').

26.3 Results

Measured slip resistance: The results indicated that the mean MSR values of vitrified tile, textured ceramic tile, and limestone, taken in dry conditions indicated that they were slip-resistant (mean DCOF > 0.42) in both Type I and Type II spaces. Polished marble stone was found to be slip-resistant in dry condition for Type I spaces but was not slip-resistant in Type II spaces. The mean MSR values for terrazzo and glazed ceramic tile taken in dry floor condition were not slip-resistant (DCOF < 0.42) in both Type I and Type II spaces (Table 26.2).

The mean MSR values of textured ceramic tile and limestone flooring, taken in wet floor condition indicated that they were slip-resistant (DCOF > 0.42) in both

Table 26.2 Measured slip resistance mean values

Types of flooring	Type I spaces			Type II spaces		
	N	DCOF (Dry)	DCOF (Wet)	*N*	DCOF (Dry)	DCOF (Wet)
Glazed vitrified	39	0.45	0.29	9	0.43	0.28
Textured ceramic	31	0.62	0.59	67	0.49	0.45
Glazed ceramic	9	0.39	0.24	9	0.35	0.23
Terrazzo	28	0.40	0.35	22	0.36	0.30
Limestone	8	0.51	0.44	10	0.50	0.43
Polished marble	19	0.44	0.23	11	0.38	0.20

Table 26.3 Perceived slip resistance median values

Types of flooring	Type I spaces			Type II spaces		
	N	PSR (Dry)	PSR (Wet)	*N*	PSR (Dry)	DCOF (Wet)
Glazed vitrified	39	2	1	9	1	1
Textured ceramic	31	5	4	67	5	4
Glazed ceramic	9	2	1	9	1	1
Terrazzo	28	5	4	22	5	3
Limestone	8	5	4	10	4	3
Polished marble	19	2	1	11	2	1

1 = Extremely Slippery, 2 = Slippery, 3 = Neutral, 4 = Somewhat not slippery, 5 = Not slippery

Type I and Type II spaces. All other flooring samples had DCOF less than the 0.42 threshold value in both Type I and Type II spaces under wet and dry conditions (Table 26.2).

Perceived slip resistance: The 5-point Likert scale values of PSR indicated that textured ceramic tile, terrazzo and limestone, in dry conditions was perceived as slip-resistant in both Type I and Type II spaces. All other flooring types were perceived as slippery. In wet conditions, textured ceramic tile, terrazzo and limestone, was perceived as slip-resistant in both Type I and Type II spaces. All other types of flooring were perceived as 'slippery' or 'extremely slippery' in both Type I and Type II spaces (Table 26.3).

The difference between MSR and PSR observations. A null hypothesis, Ho = 'measured slip resistance and perceived slip resistance are not different' was framed. Mann–Whitney U test for difference in observations of two groups was performed. The results of the test are presented in Table 26.4. Significance level of the test was $\alpha = 0.05$. If the Z value is higher than critical U values, the corresponding null hypothesis can be rejected. In case of sample size less than 20 ($n < 20$), the U (critical) values are taken as 99. In such cases, U (statistics) value should be less than U (critical) in order to reject the null hypothesis.

The Mann–Whitney U test results stated that, the MSR and PSR observations were significantly different for vitrified tile in both wet and dry conditions, textured ceramic tile in wet condition, glazed ceramic tile in dry condition, terrazzo in both wet and dry conditions, limestone in dry condition, and polished marble in dry condition. The null hypothesis could not be rejected for textured ceramic tile in dry condition, glazed ceramic tile in wet condition, limestone in wet condition and polished marble in wet condition (Table 26.3). Hence, there was not enough evidence to state that the MSR and PSR for these four flooring types were significantly different. However,

Table 26.4 Mann–Whitney U test for difference between two observations

Type of flooring	N	U-stat	U-crit $\alpha = 0.05$ ($N < 20$)	U-crit $\alpha = 0.05$ ($N > 20$)	Z	Results
Glazed vitrified (dry)	48	2232	N/A	1.96	7.79	Reject Ho
Glazed vitrified (wet)	48	2304	N/A	1.96	2.16	Reject Ho
Textured ceramic (dry)	98	5511	N/A	1.96	1.78	Cannot reject Ho
Textured ceramic(wet)	98	7141	N/A	1.96	5.89	Reject Ho
Glazed ceramic (dry)	18	324	99	N/A	N/A	Reject Ho
Glazed ceramic (wet)	18	171	99	N/A	N/A	Cannot reject Ho
Terrazzo (dry)	50	2419	N/A	1.96	8.05	Reject Ho
Terrazzo (wet)	50	2479	N/A	1.96	8.47	Reject Ho
Limestone (dry)	18	324	99	N/A	N/A	Reject Ho
Limestone (wet)	18	195	99	N/A	N/A	Cannot reject Ho
Marble (dry)	30	637	N/A	1.96	2.76	Reject Ho
Marble (wet)	30	465	N/A	1.96	0.22	Cannot reject Ho

the results indicated that, majority of the flooring types had significantly different MSR and PSR values.

A notable difference between MSR and PSR values was observed in case of glazed vitrified tile and terrazzo flooring. MSR values of vitrified tile flooring in dry condition indicated slip-resistant properties but the flooring was perceived as slippery by majority of the participants (Fig. 26.1). On the other hand, terrazzo flooring was not slip-resistant in both dry and wet conditions as per MSR assessment but majority of the participants perceived the flooring as slip-resistant (Figs. 26.2, 26.3, 26.4, 26.5 and 26.6).

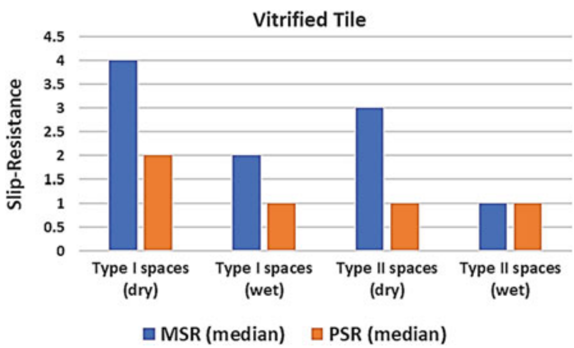


Fig. 26.1 Vitrified flooring: comparison of MSR and PSR median values

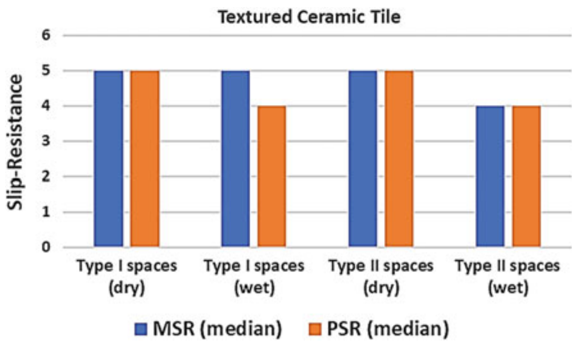


Fig. 26.2 Textured ceramic tile: comparison of MSR and PSR median values

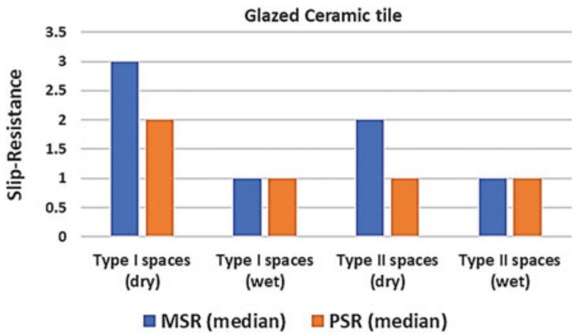


Fig. 26.3 Glazed ceramic tile: comparison of MSR and PSR median values

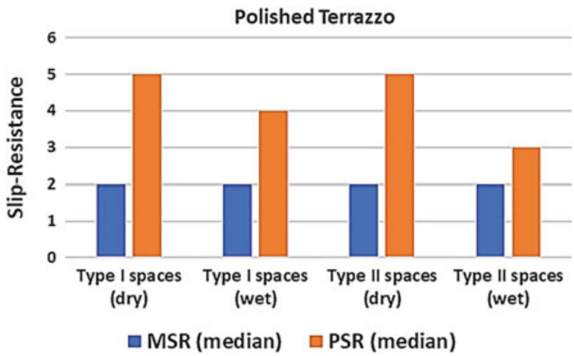


Fig. 26.4 Polished terrazzo: comparison of MSR and PSR median values

Type I spaces: Living, Dining and Bedroom (less prone to spills & material accumulation).

Type II spaces: Bathroom, kitchen and Laundry (more prone to spills & material accumulation).

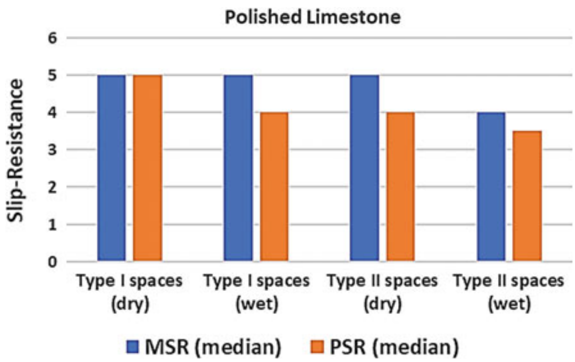


Fig. 26.5 Polished limestone: comparison of MSR and PSR median values

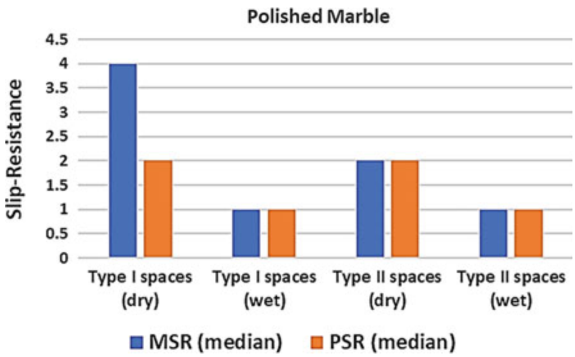


Fig. 26.6 Polished marble: comparison of MSR and PSR median values

26.4 Discussion

Perceived slip resistance is different from measured slip resistance. Measured slip resistance assessed environment conditions like dampness, surface roughness, and friction between the foot and floor. On the other hand, the factors for perceived slip resistance in most cases included the environment conditions as well as sensory and psychological triggers. It was observed that visual triggers like color, pattern, reflected glare; tactile triggers like fleeing cold underfoot; and psychological triggers like having had a previous slip or fall (post-fall syndrome), influenced the perception of the participants regarding slip resistance of flooring (Fig. 26.7). Whereas, the standard measurement systems seldom addressed these human factors.

Influencing factors for MSR and PSR outcomes were not similar. Out of the 48 participants, 27 (56.25%) participants did not have a habit of wearing footwear inside the house due to religious reasons. This had a large bearing on the touch sensation of the flooring. 4 participants using glazed ceramic tile flooring and 7 participants using polished marble flooring reported that 'feeling cold under the foot' as a reason for their low perceived slip resistance of the floor. Feet was reported to have become numb and lost sensation of the floor during cold climatic conditions. It was observed

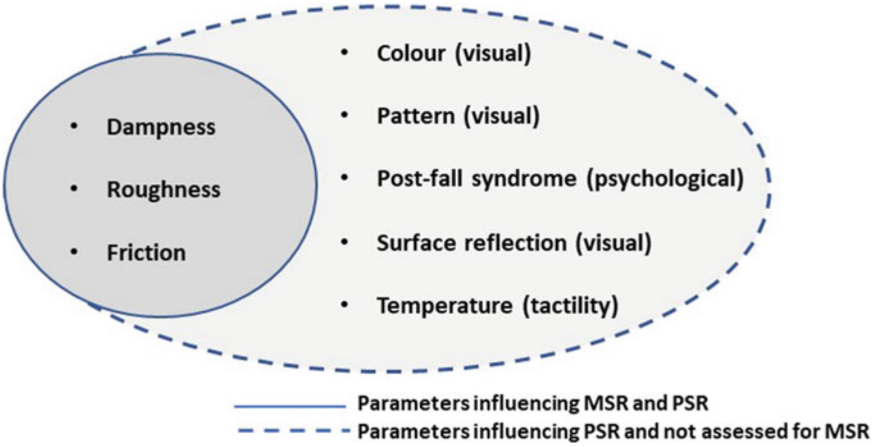


Fig. 26.7 Model for the parameters influencing MSR and PSR for elderly persons

that both polished marble flooring (0.41 DCOF-dry, 0.21 DCOF-wet) and glazed ceramic flooring (0.37 DCOF-dry, 0.23 DCOF-wet) were not slip-resistant as per MSR score. Though both the MSR and PSR yielded same response, the triggers for the outcome were not similar.

Conflicting outcomes of MSR and PSR may lead to potential hazards. Terrazzo flooring is a soft flooring and easily wears over time. In the current study, terrazzo (0.38 DCOF-dry, 0.33 DCOF-wet) was not slip-resistant according to MSR scores in both wet and dry conditions. However, the flooring was perceived as 'not slippery' by 74% of the participants and other 26% said 'somewhat not slippery' in dry floor conditions.

In wet floor conditions, 52% said 'somewhat not slippery,' 36% were 'neutral,' and 10% said 'not slippery.' This mismatch in the MSR and PSR observation for terrazzo flooring could be attributed to the perceptions of the participants which were described as 'rough,' 'no reflective glare,' 'dark color,' and 'pattern' (Fig. 26.9). Though the flooring type did not have efficacy to withstand a slip/fall, it was perceived as not slippery.

Factors influencing PSR in elderly. The mean DCOF of vitrified tile under dry condition was 0.44, which indicates a slip-resistant MSR score. However, 18.75% participants reported that the flooring was 'extremely slippery' and 50% participants said that the flooring was 'slippery' and 29.16% were 'neutral.' Though the vitrified tile had the efficacy to resist slips in dry conditions, it was perceived as not slip-resistant. The triggers for the conflicting perception of low slip resistance were the floor surface having high reflective glare, post-fall syndrome, and being light in color (Fig. 26.8).

The reflective surfaces and lighter colors were associated with low slip resistance like in the case of vitrified tile flooring (Fig. 26.8). On the other hand, darker colors (earthy colors) were perceived as being rough and having higher slip resistance

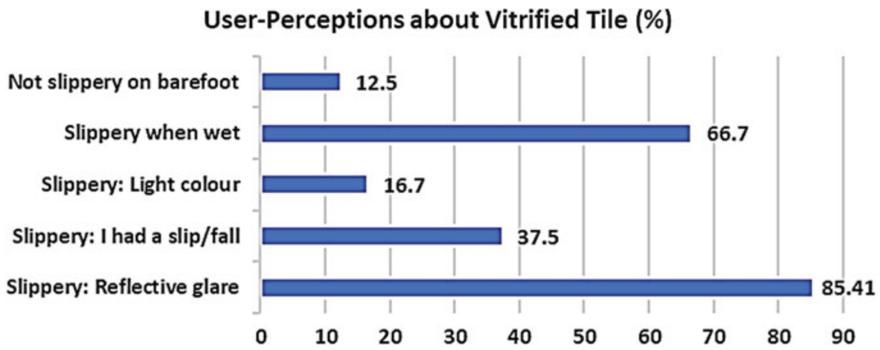


Fig. 26.8 Vitrified tile: user perceptions about floor slipperiness

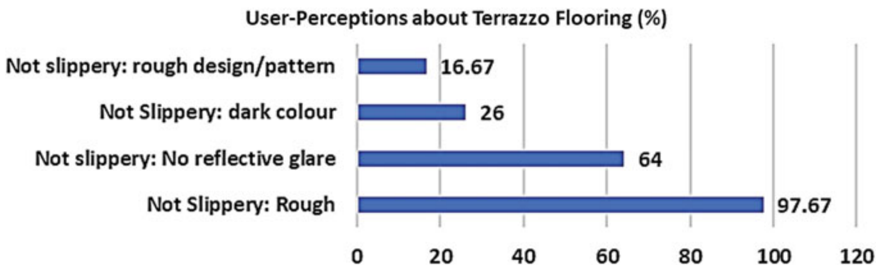


Fig. 26.9 Terrazzo flooring: user perceptions about floor slipperiness

like in the case of terrazzo flooring (Fig. 26.9) and in limestone flooring (Fig. 26.10). Terrazzo surfaces had intricate patterns, which were perceived as roughness by study participants. An analysis of the factors that influence high PSR and those that influence low PSR could lead to important inferences about the characteristics of ideal flooring for elderly people (Fig. 26.11).

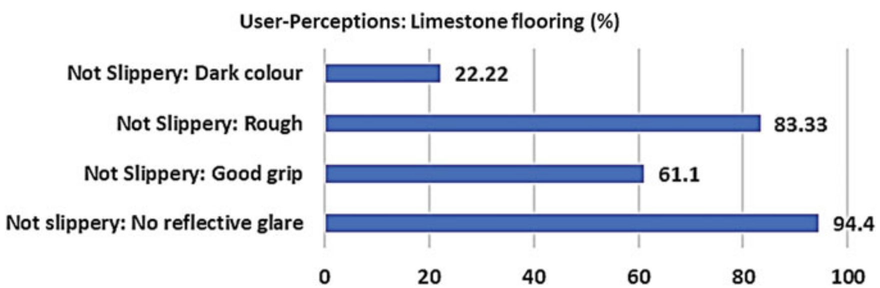
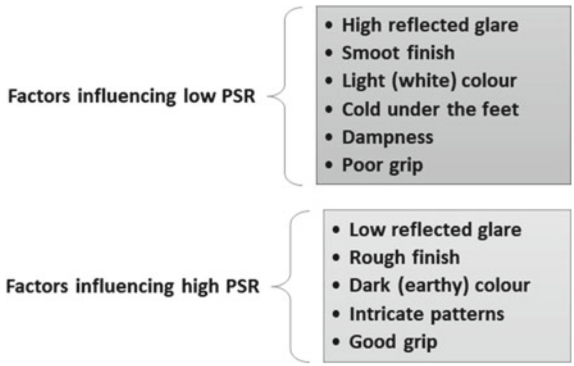


Fig. 26.10 Limestone flooring: user perceptions about flooring slipperiness

Fig. 26.11 Factors influencing Perceived slip resistance of the study participants for flooring



Flooring Performance: Textured ceramic tile flooring was found to be ideal for both Type I and Type II spaces. The MSR and PSR values were found to be slip-resistant in both dry and wet floor conditions. Limestone flooring was the next accepted flooring in the current study. The MSR values of limestone flooring were found to be ideal for both Type I and Type II spaces. However, the flooring was perceived as ‘neutral’ by majority of participants in wet floor conditions. Glazed vitrified tile flooring was found to be slip-resistant in dry floor conditions in both Type I and Type II spaces. However, it was perceived as slippery by participants (Fig. 26.8). Design interventions to include pattern and using darker colors may influence user perception of the flooring slipperiness. Vitrified tile flooring may be recommended for Type I spaces only since its performance in spaces most prone to dampness and material accumulation may not yield slip resistance due to its low MSR values in wet floor conditions. Glazed ceramic flooring, terrazzo flooring, and polished marble stone flooring were found to have low performance in both Type I and Type II spaces.

26.5 Conclusion

Findings from the current study could provide a good basis for design interventions dealing with slip-resistant flooring systems for elderly population. Conclusions of the study may briefly be stated as follows:

- Perceived slip resistance is significantly different from measured slip resistance since the influencing factors of PSR were often not considered for standard assessment of MSR.
- Environmental factors like surface roughness, friction (grip), dampness were common influencing factors for MSR and PSR. Sensory and psychological triggers like color, texture, temperature, and post-fall syndrome were reported by study participants about having an influence on their perceptions of floor slipperiness.

- Wrong judgement of flooring slipperiness could lead to potential hazards.
- Factors influencing low PSR were high reflective glare, smooth finish, light colors, cold under the foot, dampness, and poor grip between floor and foot.
- Factors influencing high PSR were low reflective glare of the surface, rough finish, dark color, pattern, and good grip between floor and foot.
- Textured ceramic tile flooring and limestone flooring were found to be most slip-resistant flooring options in the current study sample. Vitrified tile flooring was suitable for spaces less prone to dampness and material accumulation in dry floor conditions only. Glazed ceramic tile flooring, polished marble flooring, and terrazzo flooring were found to be least slip-resistant flooring options for elderly residential spaces.

It can be concluded that MSR was based on environment factors only and PSR was influenced by factors related to the environment and as well as the individual, the latter being rarely considered in standardized assessments of slip-resistant flooring systems.

Perception of flooring slipperiness must be considered as a possible intervention for falls prevention in elderly persons. Future empirical studies shall address the association of these factors with the perceived slip resistance as they may have an important bearing on well-being of the elderly. Ideal flooring systems should be able to address both physical and psychological aspects of the elderly, apart from addressing factors related to the environment.

Limitations of study. The study was limited to flooring samples that were within the safe range from 17 to 50 μm of roughness. The study tested 6 types of flooring materials, but overlays like vinyl flooring, carpets, and rugs were excluded. The study was limited to indoor spaces only.

Conflict of Interest None of the authors expressed conflict of interest.

Appendix I: Interview Schedule and Data Recording Sheet

1. Age:
2. Gender: Male ☐ Female ☐
3. Have you ever Experienced any falls?

   Yes ☐ No ☐
4. If you answered 'Yes' above, was the reason for your fall due to slipping on the floor?

   Yes ☐ No ☐
5. Do you use footwear inside your house?

   Yes ☐ No ☐
6. Do you believe that flooring plays an important role in preventing people from falling?

   Yes ☐ No ☐ Not Sure ☐

FOLLOWING ARE QUESTIONS REGARDING FLOORING SLIPPERINESS:

7. What is your belief about the slipperiness of the flooring in your living room, when the flooring is **in dry condition**? *(Typical question format for each room)*

☐ Extremely slippery
☐ Slippery
☐ Moderate
☐ Somewhat not slippery
☐ Not Slippery

8. What qualities of this flooring do you think is the reason for your belief? Please mention all. *(Typical question format for each room)*

____

____

TYPICAL MEASURED SLIP RESISTANCE DATA FORMAT FOR EACH FLOORING TYPE:

1. Living Room:
2. Name of the flooring:
3. Surface finish:
4. When was the flooring installed? (years):

Criteria	**1** ↑	**2** ↑	**3** ↑	**4** →	**5** →	**6** →	**Average**
DCOF dry							
DCOF wet							

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Chapter 27
Campaign Design to Nudge Men in Public Spaces in Order to Reduce the Crime Rate Against Women

Upasna Sehji and Sharmistha Banerjee

Abstract Incidents like groping, eve-teasing, etc. are becoming common in public spaces of cities like Delhi. Females are not able to defend themselves in these situations due to various reasons. The research was conducted with the objective to understand what can be done for females in order to protect them. The results of the research emphasized the direction of awareness amongst offenders. It was also revealed that current self-defence solutions are not readily accepted by most of the Indian females. After considering the psychology of both offenders and victims through surveys and the literature review, social nudge was taken as a concept to design the campaign graphics in the public spaces. Graphic concepts were created to tap into the offender's mind by redirecting the flow of thoughts while in public space.

27.1 Introduction

The latest National Crime Records Bureau data reflect how incidents of crime have raised the most against women, and incidents such as rapes have gone up by 12–15%, while other crimes have risen by 3–5% [1, 2]. Violence against women in India is actually more present than it may appear at first glance, as many expressions of violence are not considered crimes or may otherwise go unreported or undocumented. It was seen that the crime against women was recorded highest in Delhi. Hence, there is an immediate need to dive deeper into the area to safeguard women of the society (Fig. 27.1).

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A. Chakrabarti et al. (eds.), *Design for Tomorrow–Volume 3*,
Smart Innovation, Systems and Technologies 223,
https://doi.org/10.1007/978-981-16-0084-5_27

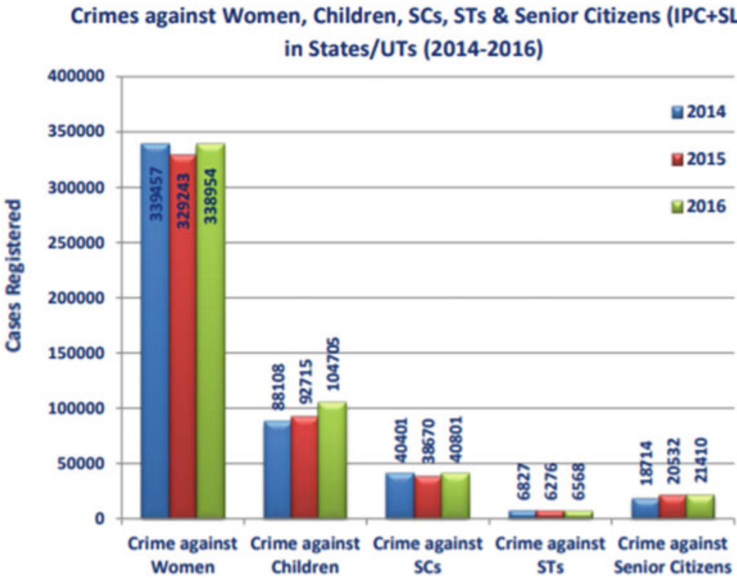

Fig. 27.1 Crimes against women, children, SCs, STs and senior citizens (IPC + SLL) in states/UTs (2014–2016) (*Source* https://ncrb.gov.in/StatPublications/CII/CII2016/pdfs/NEWPDFs/Crime%20in%20India%20-%202016%20Complete%20PDF%20291117.pdf, pp. xxx)

27.1.1 Research Objective

To address the above-mentioned problem, we set out to research on the following:

What can be done for offenders to reduce crime against women?
What are the places where women are most unsafe?
What is currently available for women to safeguard themselves in the public areas?
What is currently being done to change the offender's behaviour?

27.1.2 Nudge Theory

Nudging techniques by Richard Thaler aim to use judgmental heuristics to advantage [3]. In other words, a nudge alters the environment so that when heuristic, or System 1, decision-making is used, the resulting choice will be the most positive or desired outcome. A social proof heuristic refers to the tendency for individuals to look at the behaviour of other people to help guide their behaviour. When we can draw an individual's attention towards a particular option, then that option will become more salient to the individual. Thus, he or she will be more likely to choose that option.

27.1.3 Universal Drive

Although each individual is different and unique, yet our behaviour is gravitated towards our very basic desires [4]. According to Steve Reiss, there are 16 universal human desires which drive our behaviour. The 16 human desires are as follows:

Acceptance (the desire to avoid failure and criticism), beauty (the desire of aesthetically appealing experiences), curiosity (the desire to learn and understand), eating (the desire for food), family (the desire to raise children and spend time with a sibling), honour (the desire for upright character), idealism (the desire to improve society), independence (the desire for self-reliance), order (the desire for structure), physical activity (the desire for muscle exercise), power (the desire for influence or leadership), saving (the desire to collect), tranquillity (the desire to be free of anxiety and pain), vengeance (the desire to confront those who offend).

The project concluded with a campaign design to reduce the crime rate against the women in Delhi. We used the nudge theory by Richard Thaler and Universal drive by Steve Reiss while designing the campaign concept. The concept was designed to bring a positive change in the offender's behaviour by nudging them to introspect their thoughts in the public space.

27.2 Methodology

The project was approached by using a double-diamond design framework, where we started the research by delving deeper into problem areas. We did the literature study which was followed by market surveys and interviews for both victims and offenders. After getting insights from the intensive, research problem statement was written which gave us the direction for the design solution.

27.2.1 Understanding Problem

The domain of crime against women was understood from various lenses, through lens of victim, lens of offender, lens of psychology, lens of biology, lens of society, lens of general citizens and lens of readers.

Firstly, we started by doing the literature study from the victim's and offender's lens. Study included reading various stories by the victims on their own experiences and also on the psychology of both victims and offenders. Which are detailed in Sects. 27.3.1 and 27.3.2. The intent of reading about the victim's psychology was to understand the impact of such events in their daily life, whereas psychology of offenders was to learn about the cognitive processes going on in their mind: what is influencing the cognitive processes, and what are the controllable factors.

We started market research to have a deeper understanding of existing products and services available in the market for safety of females. It was of importance as it helped us to understand the efficiency of current products.

To validate our insights from the above research, we further delve deeper into the reasons and impact of the crime; interviews and focus group studies were conducted to do so. People were selected from various demographics; some were residents of Delhi while others have visited Delhi. Focus study was conducted to make participants feel comfortable and get diverse perspectives. More personal questions were asked in interviews with individuals. We interviewed females with the age group of 18–25 years. 20–30 individual interviews and two focus group studies were conducted. Both focus group studies were conducted with six members in a laboratory setting, and the session was recorded with the permission of the interviewees. The study focused on the perspective of females about safety in society, what makes them feel insecure and the problems faced by them when in public spaces. By this research, we also wanted to understand the psychological impact of the act on females. It is further discussed in detail in Sect. 27.3.1.

To understand how men of the society perceive the current situation on women's safety. A discussion was conducted to get a deeper understanding about the other side of the coin. Questions were asked to understand if at any point in their life they were educated about gender sensitivity in any form. Also to learn how the current campaigns on women safety are being perceived by them. It is further discussed in detail in Sect. 27.3.2.

27.2.2 Insight

The insights gave rise to our problem statement. Insights were mapped using affinity mapping. Map suggested us various directions to go ahead in. The direction aligning with our interview insights was proceeded with.

27.3 Results and Discussion

27.3.1 Victims

The research helped us understand the problems and consequences faced by victims due to eve-teasing and other criminal activities. The problem identified spanned over various areas such as reaction time when females face any situation, fear of eve-teasing leading to more severe consequences like rapes, loss of productivity due to hamper in travel plans and many more [5].

These pain points are mentioned in detail below:

Self-defence—The majority of females were not comfortable using any category of self-defence products available in the market in case of eve-teasing as they said self-defence products gain a lot of attention from the surrounding. The act done by the offender in public is very silent many times and goes unnoticed by the general public present in the vicinity; usage of the product in such situations can lead to false accusations on the female and gaining attention on them rather than the offender. To save themselves from such public humiliation, females tend to avoid the act done by the offenders. It was also found that some females carried tiny pins as a defence tool while they travelled in public transports. According to the pin is a small device and the act of poking does not draw public attention towards them, and at the same time, females get a feeling that offenders were punished for their actions [6].

Reaction time—Victims said that many times the action happens in a very short time period that they go into a mode of shock and do not get much time to think immediately. In this case, victims are not being able to use a self-defence device that does not occur to them at the spur of the moment.

Fear—Eve-teasing increases the fear that this might lead to more severe consequences like rapes. Still some women can raise their voices against offenders; many said that they are scared to raise their voices so that they do not hurt the fragile male ego and get in more trouble.

Environment—Females are more afraid of dark pathways, lobbies, lifts and less crowded spaces as chances of criminal activities and eve-teasing increases in these locations. Many activities are hampered due to an unsafe environment for females to travel anywhere and anytime of the day. Victims are not able to travel freely on any of the days.

Females in the city of Delhi were found to be independent and felt inferior if they carried instruments with alarm or wristbands to protect themselves. Rather they preferred pre-planning to be in a safer environment.

Affinity mapping was done for the insights taken from the research conducted for victims (Chart 27.1).

Behavioural change of offenders was selected as a domain as females are bothered about eve-teasing when they are commuting to their work or elsewhere, and they are not comfortable reacting back to offenders.

Insight: Public spaces need to be made safer by intervening in the domain of behavioural change in offenders.

27.3.2 Offenders

Interviewing men in society and research in psychology helped us understand the perspective of the society.

The discussion with the male peers took place on the subject of campaign design and gender equality. The insights are mentioned below:

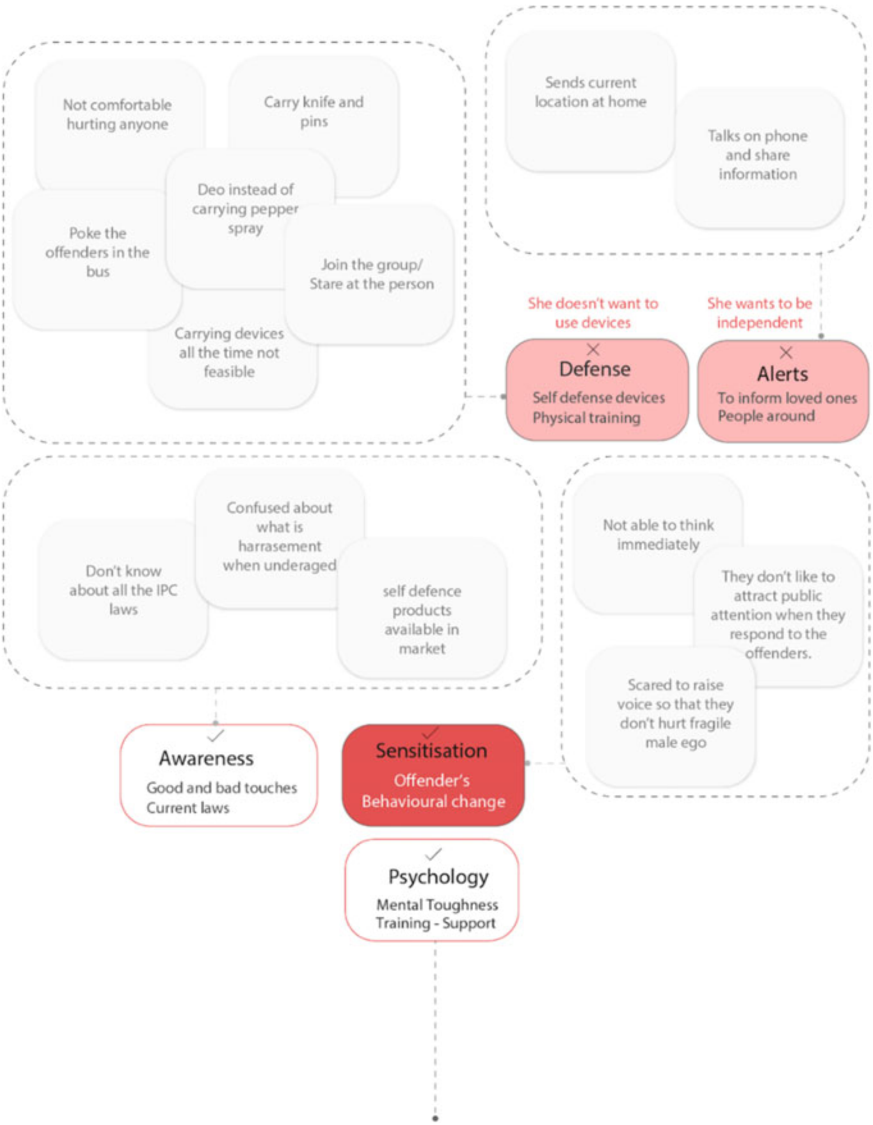

Chart 27.1 Affinity mapping of research conducted with females to find a desired design direction

Campaign design—The current campaigns were studied to understand the existing messages (message type and mode of delivery). Some of the campaigns studied for the research are MARD; ShareTheLoad campaign; The best Men can be; #UnitedByHalf and 'Man Up' [7].

We discussed these campaign messages with male peers (age group 20–30 years) to know how they perceive the messages.

Discussion with male peers suggested that the current campaign messages no longer leave a strong impact on the crowd; all measures are considered another feminist act by most of the men. It was also found that the men in society do not like to be preached and getting instructed.

Gender equality—Teaching gender equality happens during childhood level, and most of it depends on institutional influences; family, school and religion. Gender equality should be taught to the society. From the discussion with male peers and females, it was suggested that the change will take years to see the change in the society, and action needs to be taken presently to reduce the crime rate against women.

The literature review was done to learn about various cognitive processes, which leads to the offender's behaviour.

Started delving deeper into the offender's psychology by studying cognitive processes in the offender, psychologist Noam Shpancer, Ph.D. article 'When Men Attack: Why (and Which) Men Sexually Assault Women', was referred [8].

We also learned about the factors which lead to crime against women [9]. In the book; Understanding violence against women', author mentions that there is no single factor that is responsible for the behaviour among offenders. Some of the factors which contribute are: evolution, physiology and neuropsychology, alcohol, psychopathology and personality traits, attitudes and gender schemas, sex and power motives, social learning, social influences such as sexual scripts and cultural mores.

Domains of cognitive process in offenders were further categorized in controllable and uncontrollable processes (Chart 27.2).

Controllable factors from the previous study were further expanded. A subset of social influence: culture was found to be another important factor leading to crime against women: research says that roots of any crime are found in culture, religion and society norms. Other social factors include hate against group, social scripts, peer pressure, situational cues (such as alcohol consumption) [8, 9, 11].

From the insights, we know that a person's thought process cannot be changed in a fortnight but an influencer at the crime location to redirect the cognitive process of the offender can have an immediate effect on the psychology of the offender. Cognitive studies were done to understand the same [3, 4].

Insight: We can nudge the psychology of the offenders for a short period.

27.4 Conclusion and Design Intervention

From the research, we concluded the following design direction statement:

'A preventive campaign designed for public places, where women feel most unsafe like bus stops, lifts, parking spaces, etc. targeted at offenders who eve-tease women, indirectly nudging them towards behavioural change at that time to reduce the crime rate against the women'.

For concept creation, we used the universal drives to nudge offenders towards behavioural change.

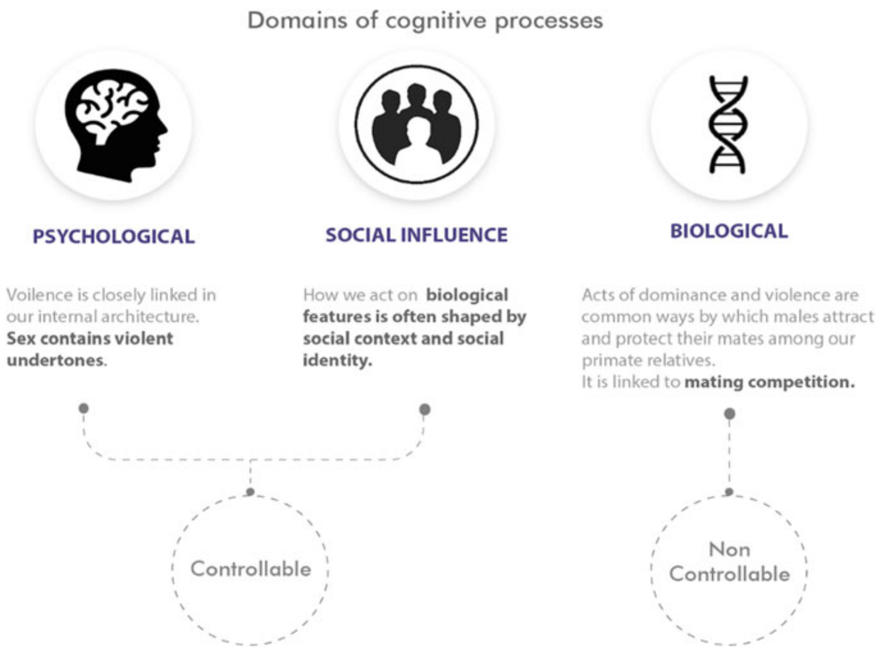

Chart 27.2 Domains of cognitive processes in men [10]

27.4.1 Concept 1—In His Shoe

Universal drive—Family (2) and tranquillity (6).

Concept—In this concept (Fig. 27.2), we create an immersive experience to show a person's family member experiencing an act in public spaces.

Objective—To share the feeling that a male member of the victim's family might experience.

27.4.2 Concept 2—What's Your Story?

Universal drive—Family (2) and tranquillity (6).

Concept—In this concept (Fig. 27.3), we create a positive feeling for women by nudging the men into recalling positive feelings for women in their lives (like a mother, sister, etc.).

Objective—We achieve the same by depicting the most cherished shared childhood memories of the average Indian population. In this case, we use the image of eating mangoes during summer.

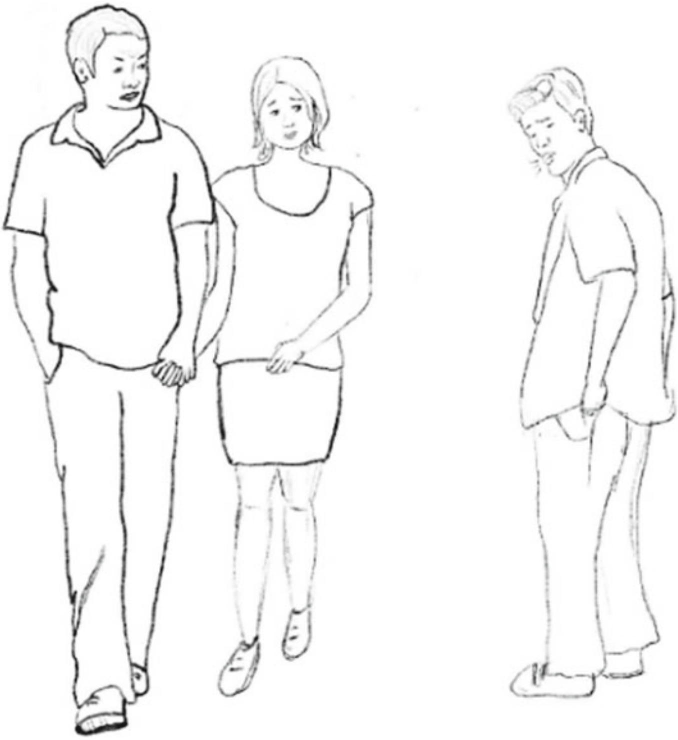

Fig. 27.2 In his shoe

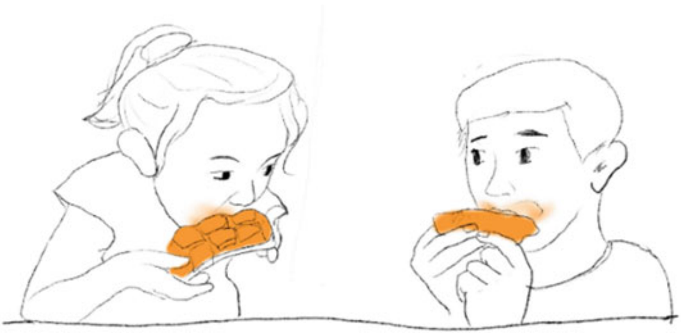

Fig. 27.3 What's your story?

27.4.3 Concept 3—Watch Out Who You Become!

Universal drive—Acceptance (1) and honour (3).

Fig. 27.4 Watch out who you become! [12]

Concept—In this concept (Fig. 27.4), we are narrating a comparison through graphics on the wall and making them look at their reflection.

Objective—Through the graphics and reflection, we aim at making offender introspect their behaviour.

27.5 Future Scope

Concepts presented here are yet to be tested; these concepts are derived from the insight which we got from the design research. Concepts are yet to be made in various local languages. Also, we aim at working with an NGO working in a similar direction.

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Chapter 28
Photoluminescent Pigment Printed Textiles: Designing Urban Homes for Night-Time Navigation

Richa Sharma and Nilanjana Bairagi

Abstract Photoluminescent pigments are rare earth metals that absorb light and emit it slowly as a pale blue/bluish green light over 6–8 h after initial excitation from external light source. These pigments can be incorporated in textiles as prints, but there is limited literature to guide textile and fashion designers on how these pigments may be used to create novel-illuminated patterns of luminescence as prints for home fashion. Therefore, this research aims to systematically study the properties of photoluminescent pigments and develop design concepts on textiles for home fashion using user-centric design research in a real-time setting for night-time navigation. The pilot study indicated that the photoluminescent pigment printed textiles could provide navigational aid and focus lighting in the areas of orientation lighting and edge definition. The study indicates that the textile products in home fashion may be designed that improve the light cognition for all age groups and demographics using photoluminescent pigment textiles. Thereby introducing alternate methods of light sources that promote natural nightlight so as to create a paradigm shift in the way lighting design is perceived by designers and architects.

28.1 Introduction

Photoluminescent pigments are rare earth metals that absorb light and emit it slowly as a pale blue/bluish green light over 6–8 h after initial excitation from external light source. These pigments can be incorporated in textiles in many ways such as filaments, coatings, tapes, vinyl stickers, or printing with suitable binders. But there are limited studies to guide textile and fashion designers on how these pigments may be used for creating novel-illuminated patterns of luminescence as prints for home fashion for night-time navigation.

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A. Chakrabarti et al. (eds.), *Design for Tomorrow–Volume 3*,
Smart Innovation, Systems and Technologies 223,
https://doi.org/10.1007/978-981-16-0084-5_28

Previous experimental research conducted by the authors reports that the luminosity of light emitted by the photoluminescent pigments as textile pigment prints depends on particle size, concentration, and the texture of the fabric. The intensity of luminosity was recorded below 1 lux which is comparable to natural starlight or moonlight. As the concentration of the photoluminescent pigment increases, the luminosity of the printed textile also increases irrespective of the particle size. Also, smaller particle size of the photoluminescent pigment on the fabric results in higher luminosity. The intensity of luminosity was recorded below 1 lux which is comparable to natural starlight or moonlight [1].

In the present study, the data from the experimental findings have been correlated with the user study in the real night-time environment to study visual perception of these prints on home textiles. Systematic studies on the possible design effects that can be achieved on fabrics while printing with photoluminescent pigments have not been reported in literature. Therefore, this research aims to systematically study the properties of photoluminescent pigments and develop design concepts on textiles for home fashion using user-centric design research to aid night-time navigation.

28.2 Research Methodology

This study is focused on developing photoluminescent pigment printed textile product concepts and prototypes that can be perceived by in dim lit environment. The research methodology adopted is user-centred design (UCD) methods to correlate the experimental data with the visual perceptions of users in a real night-time environment to develop the design requirements of the photoluminescent printed textiles.

28.2.1 Materials and Methods

The research study was carried out on 100% cotton, medium weight fabric about 300 g per square metre, an even set with 69 threads per inch of the fabric. The photoluminescent pigments were procured from Jash Marketing, India, with a chemical composition, SrAl2O4:Eu^{2+},Dy^{3+} with a yellowish appearance exhibiting a yellow-green afterglow in the case of Green(G); Sr4Al14O25:Eu^{2+},Dy^{3+} with a yellowish appearance exhibiting an aqua glow in the case of Blue(B) photoluminescent pigment with Eu^{2+},Dy^{3+} as activators or luminescent centres for the phosphors. The emission wavelength of Green and Blue pigment is 520 nm and 490 nm, respectively. The fabric was industrially screen-printed (mesh size 200) with variable concentration of C1(1%), C2(2%), C3(5%), C4(10%) and C5(20%) photoluminescent pigment in the print paste with curing temperature of 120 °C. Printed swatches were used for the study and observations. To assess the durability of photoluminescent print to laundering, accelerated wash fastness test AATCC Test Method 61-2009 (4) was carried out.

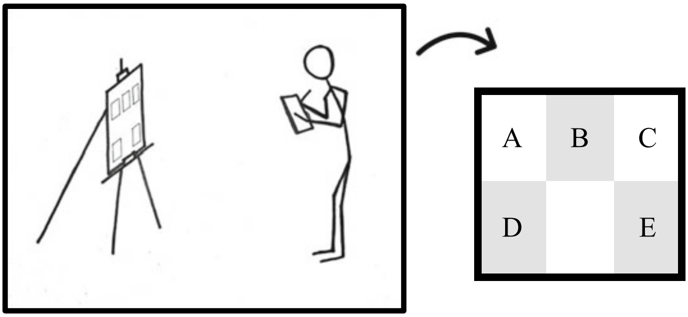

Fig. 28.1 Line diagram of the experimental set up in real-time environment (left); the board with samples with variable concentration randomly placed

The pilot study was done to observe the luminosity of the both Blue and Green photoluminescent pigment prints at variable concentration C1-C5 (1–20%) and four variable particle sizes (B1-B4, G1-G4) with (B1, G1) referring to the smallest particle size of 10–15 μm and (B4, G4) of 50–60 μm, respectively. User feedback was taken to understand the design potential of the photoluminescent prints. The pilot study was conducted with ten participants (user profile placed in the annexure) using non-probability, convenience sampling method, with participants in the age group of 18–60 years who volunteered to participate and consent was given by all the participants. Eight boards were created with five samples of variable concentration placed in each board, randomly arranged as shown in Fig. 28.1.

For the study, the boards were kept in a room with exposure to both indirect sunlight and indoor lights for about 5 h before experiment was conducted. The perception rating was taken on a scale of 5 using questionnaire method with 5 being the best and zero being the least score. Scotopic or dim lighting was maintained inside the room while recording data.

28.3 Research Findings

28.3.1 Findings of User Study

The perception rating of the photoluminescent pigment printed textiles was recorded against variable pigment particle size (B1-B4, G1-G4) with variable pigment concentrations C1-C5 (1–20%) and the results are presented in Fig. 28.2. The results helped in understanding the most appropriate particle size and concentration that can be used for the development of textile prints that would be perceptible by the users. The graph below depicts the Blue and Green pigments at variable concentrations at the *X*-axis and visual perception ratings on the *Y*-axis with 0–5 with 5 being the best.

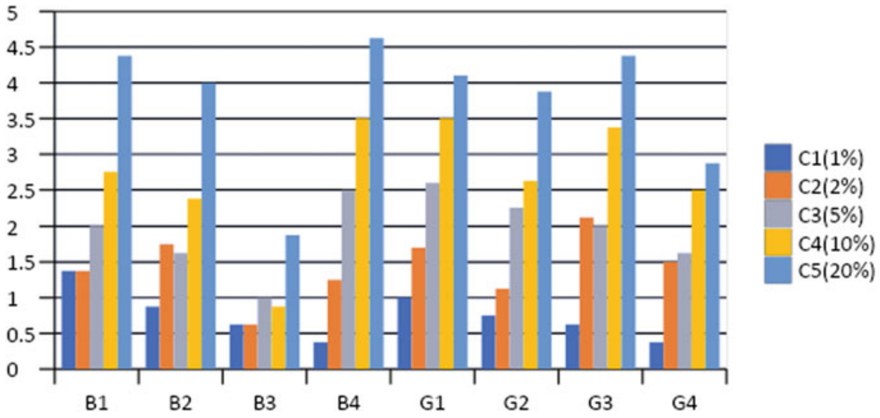

Fig. 28.2 Visual perception rating of blue and green series with respect to increase in pigment concentration

The graph clearly depicts the increase in photoluminescent intensity with increase in concentration irrespective of the pigment size.

As stated by Bamfield [2], the larger the size of the crystals, the better is the absorption and emission processes, due to more potential sites than a small pigment particle. Experimental research reported by the authors also [1] validates that at higher particle size, the Tau or the time constant is higher which means that the particles with higher particle size can sustain their photoluminescence for significantly longer time. The same was also reflected during the user trials. The pilot study correlates the experimental findings with the user perception rating as shown in Fig. 28.3 where it

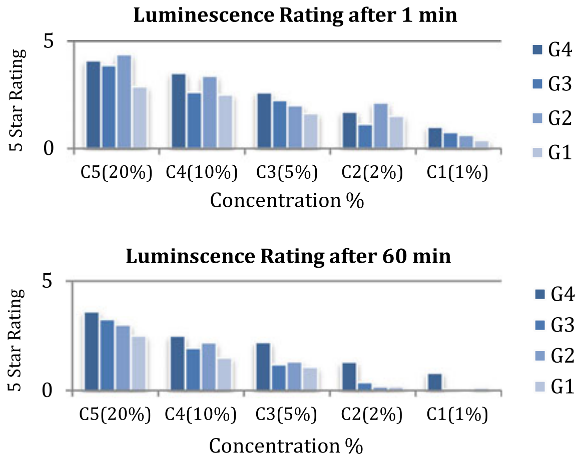

Fig. 28.3 Visual perception rating with respect to time for green pigments

clearly depicts that at G4 (the highest particle size), the visual perception rating is significant even at lower concentrations.

28.3.2 Identification of the Architectural Requirement of the Product

As per the user feedback, the photoluminescent-printed textiles did not form shadows or glare. Photoluminescent prints are perceptible by human eye at a pigment concentration as low as 1% as observed during the study. Therefore, the prints could be used for edge definition and navigation in absence of light in the room. Prints with larger particle size may be used as nightlight as the glow time is significantly higher in comparison to lower particles sizes as found during the study. Therefore, the prints may be used as orientation light at the floor especially for the elderly [3]. The floor-mats or area rugs thus may act as the orientation light close to the floor. Products such as deco pillows and runners may provide edge definition and sufficiency to navigate.

The wash fastness testing using AATCC method followed by evaluation of the lux value of the printed samples showed that the average lux value falls by around 23% after 10–12 washes (laundering cycles) and about 50% by 25 wash cycles. As home furnishings are laundered on an average of 6–8 times per years, the durability of the photoluminescent effect in the print is estimated to be 2–3 years.

The cost of printing fabrics with photoluminescent pigment was also estimated. It is approximately around 50–60 INR per square metre of fabric using screen-printing method in an industrial scale, which is comparable to normal pigment printed textiles. This indicates the economic viability of printing with photoluminescent pigments.

28.3.3 Development of Print Design Using Photoluminescent Pigment on Textiles Using User Perception Studies

Home fashion products come in a wide range of prints, but for the purpose of this study, prints have been broadly categorized in floral, geometric, and textural prints. It was noted that the print designs cannot have fine lines and very intricate detailing as the effect of the print gets lost intermittently and the continuity of the form gets lost during a night-time environment. Geometric, floral, and organic forms along with textural elements were explored as printed patterns. All these prints can be customised and scaled as per requirements from the users and the emerging markets as per trends and forecasts. Creating tonal prints gave a sense of depth with variation in concentration of the photoluminescent pigments.

The user perception also established that very fine lines are not clearly visible and thus the width of the printed line should be minimum of 5 mm for clarity. Also as the photoluminescent print creates a halo effect, hence, the distance between the lines is to be considered while designing. Variation in the tone can be achieved by using variable concentration of pigments. It was also noted that the luminosity of photoluminescent pigment when printed along with coloured pigments reduces the luminosity of the photoluminescent-pigment-printed textile.

28.3.4 Development of Final Prints and Prototypes

The developments of final prints were done at three levels: single screen, dual effect, and tonal effect. In case of single screen, the prints are visible only in low lighting or scotopic light conditions. Dual effect prints were made where two screen designs were explored. One screen print is visible in photopic conditions and second screen is visible in scotopic or dim light environment as seen in Fig. 28.4. This can be explored further by designers to create concepts that work in dual, day and night-time environment.

To explore the tonal print designs without overprinting, the design concepts with different contours were developed to create variable tone and depth with the photoluminescent prints. To create a tonal variation, photoluminescent pigments were used in variable concentrations (20%,10%, and 5%) as seen clearly as three different contours in the third photo of Fig. 28.4, placed at the bottom.

A range of products for living room were designed and developed as prototypes for home fashion with photoluminescent pigments as shown in Fig. 28.5. The user trials showed that the photoluminescent-pigment-printed textiles could serve as navigational aids and also focus lighting in areas of orientation light, edge definition, and as sleep indicators. The users were able to easily navigate through in low-light conditions and during night-time. The soft furnishings such as the table-runners and pillows acted as markers and navigational aids with edge definition to indicate the presence of furniture or rugs. The lampshade was regarded as the most preferred item by the users in term of familiarity and acceptability in homes.

28.4 Conclusion

Photoluminescent pigments are rare earth metals that absorb light and emit it slowly as a pale blue/bluish green light. There are limited studies on how these pigments may be used for creating novel-illuminated patterns of luminescence as prints for home fashion for night-time navigation. Based on experimental research and user-centric research approach, prototypes of products in the field of home fashion with photoluminescent pigment printed textiles were developed. The user trials indicated that the photoluminescent-pigment-printed textiles could serve as navigational aids and focus lighting in the areas of orientation lighting, edge definition and as sleep indicators. Photoluminescent-pigment-printed home fashion products may be used as a source of soft night-time light without glare. Smaller photoluminescent pigment

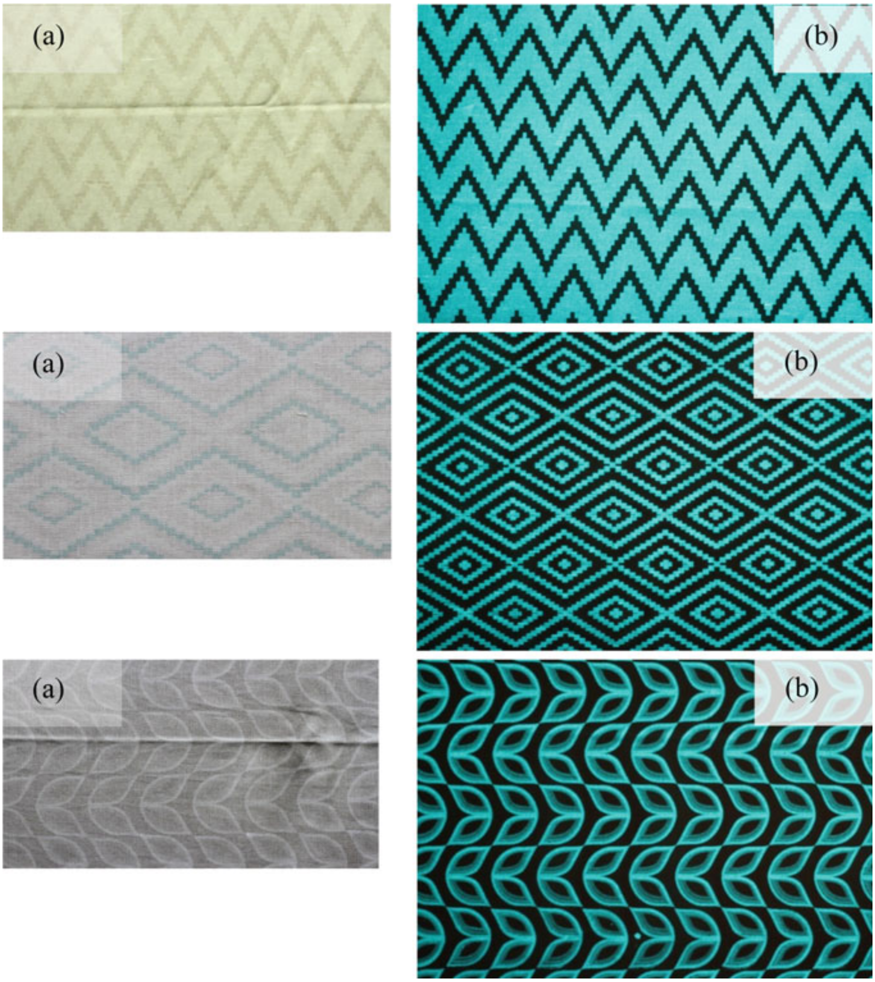

Fig. 28.4 Single screen print (top); print with dual effect (middle); and tonal effect (bottom) in **a** photopic, **b** scotopic light

with particle size of 10–15 μm maybe used for printing on textiles for edge definition and path lighting. The photoluminescent pigment of larger particle size (50–60 μm) may be used for nightlight due to its longer emission time.

While using photoluminescent pigment for printing on textiles, the thickness of the printed lines and the distance between the consecutive lines need to be a minimum of 5 mm for visual clarity. Tonal effects can be printed by printing with variable concentration of the photoluminescent pigment; 5–20% concentrations gave appreciable results and good visual perception. To achieve tonal effects in the prints, printing can be carried out with different pigment concentration in the same product.

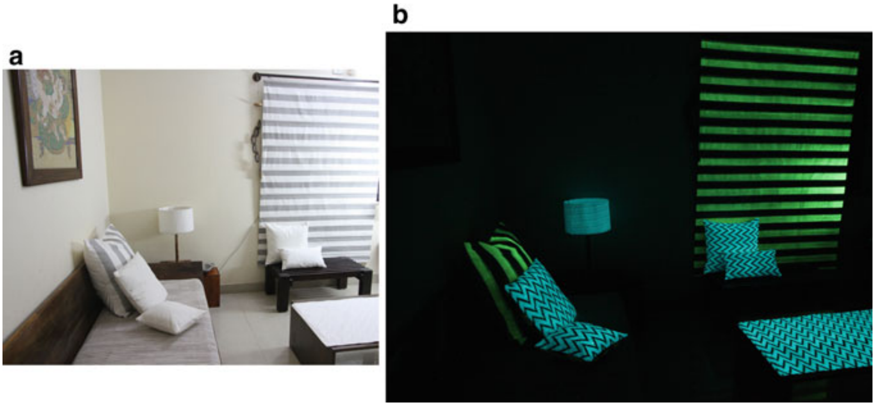

Fig. 28.5 Final prototypes in a living room setting in **a** photopic, **b** scotopic light

Studies in real night-time environment showed that a diverse range of products in home fashion for urban homes may be designed using photoluminescent pigment printed textiles. The research findings and user-centric studies provided an alternative framework for designers and the industry to develop novel products for home fashion using Blue and Green photoluminescent printed pigment printed textile.

Annexure

User profile

Participants for the study	Sex Male (m) Female (f)	Age (yrs)	Vision (eyesight)	Daily activity level	Description of activity	Occupation
P1	F	60	Reading glasses	Moderately active	Walks daily for 20 min	Housewife
P2	F	33	Normal	Active	Brisk walk 45 min daily and yoga	Software engineer
P3	F	40	Normal	Active	Slow walk for 40 min	IT professional
P4	F	37	Normal	Active	Dances regularly for 40 min	Software engineer
P5	F	39	Normal	Moderately active	Walks daily for 20 min	Designer

(continued)

(continued)

Participants for the study	Sex Male (m) Female (f)	Age (yrs)	Vision (eyesight)	Daily activity level	Description of activity	Occupation
P6	F	38	Corrected distance (−3.5)	Moderately active	Walks daily for 30 min	Chartered accountant
P7	F	40	Normal	Moderately active	Does active exercise (Zumba) daily for 20 min	IT professional
P8	F	40	Corrected distance (−2.5)	Average	Only household activities	IT professional
P9	F	38	Normal	Average	Only household activities	Teacher
P10	F	18	Normal	Active	Follows regular fitness schedule for 45 min	Student

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Chapter 29
Manufacturing to Super-Finishing Jewellery Articles: A Study to Define Surface Quality Parameters and Understanding Their Inter-relationship

Parag K. Vyas and Nitya Vyas

Abstract Indian jewellery industry is rapidly adapting new manufacturing methods that give intricate forms with relative ease. With the manufacturing of multiple articles jewellery, there comes a need for consistency of quality in those pieces. A tool to measure various aspects of surface quality is hence needed. In Indian jewellery, surface quality plays an important role and adds to the form in a big way. A superbly finished article attracts and holds attention of a prospect client when presented for visual appreciation. An enunciation and understanding of various process parameters in manufacturing units are essential for good and consistent quality. This paper methodically articulates various parameters and aspects that influence appearance of a quality surface.

29.1 Introduction

Indian jewellery industry is rapidly adopting new manufacturing methods that give intricate forms with affluency. Investment casting is one of such processes that enhance intricacies in complex motif, therefore, well suited for small to medium sized articles. These are between sizes range of 6.0 and 25.0 mm tallness. Though, they can also be as small as 2.0 mm, as in case of a single gemstone and as large as 50.0 mm in case of a compound cluster of smallest semantic units [1]. These dimensions are explicitly explained to build a mental assessment, for ease of reading

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A. Chakrabarti et al. (eds.), *Design for Tomorrow–Volume 3*,
Smart Innovation, Systems and Technologies 223,
https://doi.org/10.1007/978-981-16-0084-5_29

and comprehension. Typically, in case of old jewellery brought in for restoration, various sizes can be seen in a single piece.

Jewellery surface is never observed to be flat, and essentially, a small curvature is fabricated to an article shape, making its surface polish friendly. Many such features of the article form are integral to jewellery design which makes them pleasant to touch, aesthetically appealing and visually attractive. This finishing surface result is intuitively constituted by traditional jewellery workshops, guided by simple engineering methods. The curved surfaces are also created since flat and true surfaces are difficult to produce, finish and maintained. It is also quite easy to detect defects on flat surfaces, such as a deviation from an intended 'ideal' surface. On the other hand, it is rather difficult to judge a form-related deviation on surface of an organic or curved article surface. For example, a small deviation on surface of a cube as compared to movement of bud end apex of a mango. This is one of the reasons that organic and natural forms with slight curvature on the surface are preferred in design of jewellery articles, historically as well as presently. From a scientific perspective, since errors are difficult to detect, they are difficult in detection control and remedial measure as well.

It is emphasized that—form intricacies, as presented for visual appreciation, appeal to potential clients and commonly attract attention [2]. At the same time, details make an article difficult to finish. Interplay of surfaces creates nooks, corners and crevices between adjoining forms and features [2].

Furthermore, it makes articulation of a target finish difficult. As a result, the word 'Finish'—end up being subjective based on different interpretations. It becomes critical, therefore, that during communication between two stakeholders, the terminology is rigorous and understood mutually—as a common agreement on level or standard of the expected finish of an article.

An individual's interpretation also varies/articulate and often leads to dissonance and painful rework. Most common, singular, remedial measure adapted in response to a demand for a 'better finish' is considered more work at polish lathe. This additional work method may not necessarily improve finish, but may sometimes distort the surface beyond repair or make it wavy in surface appearance.

This paper, therefore, takes an in-depth view of jewellery workshops in country and brings forth traditional and modern knowledge during various processes. The investigation methodically lists diverse factors perceived as contributing to 'finish' of jewellery article compares them with domain of engineering and analyses the terminology, definitions to develop a common understanding of terms. The study proposes a matrix for understanding and achieving 'target finishes' in modern Indian jewellery manufacturing processes.

29.2 Background Study

Finish means different things to different people. It is often individually, temporally and regionally differing of understanding. However, it is possible for an observer to have an abstract idea about finish of an article, and they can differentiate between two specimens sample article surfaces by simple observation. An assessment is done by a prospect client routinely in assessing the quality of an article, surface, and its finishing quality plays an important role in the visual evaluation and selection. For example, fruits are chosen for a blemish free and uniform smoothness of surface, acceptable as overall quality. Similarly, paint on walls of a room is judged for homogeneity and unidirectional strokes of a brush. Commonly, quality of surface is an indicator of overall quality of an object. To take the argument further, perfectly edible, tasty and nutritious fruits and vegetables are rejected or not placed on shelf because of non-uniformity or minor blemishes (superstores are particularly sensitive) on their surface.

The literature is silent on methodical listing of surface quality and their articulation for an article of jewellery. However, some tools are methodically listed in the literature [3]. Moreover, Indian scenario is in a state of transition from tradition to modernity, going through a paradigmatic shift, from conventional handmade to limited batch production of cast pieces. There is an additional problem posed due to miniature forms and artistic surfaces making measurement with a tool difficult. Perhaps, in watchmaking, one can assess component surfaces with simple mechanical tools. Surfaces are plane, and mechanisms consist of two-dimensional shapes. In jewellery, it is three dimensional with organic forms; furthermore, they are artistic twists, and twirls are evident. One can observe dimensions within dimensions.

Research question, therefore, pertains to an investigation of different factors and attributes that can be used for defining a quality finish surface in domain of jewellery. There is scope for development of a method or framework to bring in more objectivity in terminology, definition, articulation and control of surfaces.

The need of time is to identify, catalogue and define various aspects of surface finish and put them in right perspective for use by industry professionals and academic institutions.

29.3 Methodology

To study various aspect of a quality surface, in domain of jewellery, several exploratory interviews were done. This was necessary to gain an in-depth knowledge about the subject matter.

The interviews were conducted with domain experts and stakeholders on shop floor as well as the design bureau. Study was exclusively done in a single plant, at Hosur in proximity of Bengaluru, but physically in state of Tamil Nadu. The study was undertaken for a period of two years. The investigation elaborated in present paper is an opening step in devising a research methodology towards terminology and definition building. It is based on in situ observations, with collaborative short meetings [4].

Meticulous, detailed notes were taken, and they served as an interview data record, and references. Some of the notes were made post haste to avoid interruption during flow of discussion with bench workers. This method is most suited research in domain of jewellery. In past exploration by the author, it has been observed that any attempt to videotape, or voice recording leads to normative answering or impedes a natural flow of information. Following are the key inferential observation analysis covering six key visits and semi-formal interview sessions.

- A clear gap was observed between these two sentinels, largely owing to common word sets and lack of common understanding to describe and articulate the understanding of word surface—'finish'. The results also concurred with methodical research notes preserved over years of field study before a formal research was envisaged.
- Subsequently, the literature was reviewed to find if any relevant prior knowledge exists. The literature is scarce and silent.
- Lastly, domain experts were consulted again for importance of matter as a research question, and a positive response about application of research was begotten.

Research methods such as formal questionnaires or modern methods like Internet surveys beget little response or useful information in this domain as past research experience in domain of jewellery suggests.

Inferences and deductions are based on interviews which were cross-checked with subject and participant observations. Study was made more robust by cross-referencing them with domain experts and incorporating the inferences methodically in research. The study also includes extract of extensive discussions with jewellery domain experts and design practitioners, reviewing their comments and suggestions.

The process of experiential learning was also found to be useful, as expounded by Kolb [5, 6] which is widely recognized. This propounds four sequential steps,

- Experience—event, incident or occurrence
- Reflection—reflection on the experience
- Drawing conclusion—sorting, understanding, conclusions and generalizations towards framework building
- Testing—new experiences using framework.

This is shown in Fig. 29.1 as a system diagram

Simple observations and deductions are key elements for proposition of a matrix and lay down norms for articulation of a target finish to be achieved on an article of jewellery. Its foundation is in phenomenology, based on the way people observe phenomenon, in the world they live in [7]. Present study needs more robustness in documentation preparation and preservation over years. However, contents are strong, useful and appreciated by the industry experts. Condensate has valuable contents for industry as evident from their responses during content validation.

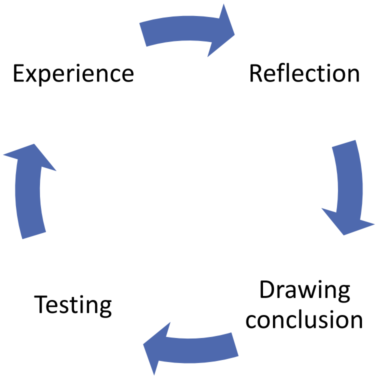

Fig. 29.1 Drawing conclusions from reflections and creating theory and models

29.4 Need of a Matrix

In jewellery showrooms and boutiques, a large to modest variety of jewellery is displayed. Articles such as rings, necklaces and ear studs are displayed vertically on wall mounted shelves or horizontally in glass panelled drawers under the glass counters. A sales representative methodically takes them out for clients and arranges them back in place after viewing. Shops have a soft top ambient lighting, mimicking sunlight, creating a pleasant and welcoming ambience.

Jewellery articles are presented to a potential client on demand by taking them out from display cases and placing them on a dark coloured velvet-lined tray. This provides a soft surface and a contrasting, clear background for visual appreciation. Soft velvet lining prevents accidental scratching in repeated viewing sessions and handling. Scratches greatly reduce the perceived value over time. At times, a single scratch in a critical location of view can render a piece unsalable or needs to be sent for restoration and reconditioning, which is tedious and time-consuming work.

(Exception to this is accelerated ageing of Kundan articles by distressing to give an impression of great age, a family heirloom or antique jewellery. Such deviant examples are not in scope of this study).

A prospect client gets a clear background and glare free lighting as perception tools, for visually evaluating the article. An article is taken in hand for closer inspection, and a clear mirror is placed for appreciating overall appearance when worn. To discerning clients, a jeweller's loupe or a magnifying lens is provided, on demand, for inspection of finer details. But this is relatively rare for usual buyers. It is therefore safe to abstract that tools used by a potential client are background, light and observation both visual and tactile, as well as the wearing experience. Though eyeballing may sound as if it lacks precision, but these measurements through observations are used by many artisans and critics during appraisal. Chair makers and jewellers have used this method very effectively for inspection and correction. This method can be further refined by articulation of various parameters taken into consideration and providing a framework for qualitative or quantitative measurable units as a potential area of research in itself.

As it happens in mechanical engineering, shop floor inspection protocols are kept more stringent as compared to quality control department. This makes shop floor ‘over proof’ reducing rejection during quality checks. Similarly, a jewellery manufacturing unit can benefit greatly from adapting similar procedures. There exists a clear need in this domain for close evaluation and quality check of various aspects of surface quality.

29.5 Proposition of a Matrix

Aligning branches of engineering specifically dealing with mechanical aspects have dealt with defining surface quality effectively by breaking it down into different parameters, attributes and objective aspects. Some parallels can be drawn from the domain of metrology in mechanical engineering, where rather than defining surface finish per se, a measurable aspect such as surface roughness is an indicator of target finish. While there is no single universally acceptable tool to measure finish, there are many tools available to measure roughness of the surface quality.

There are four primary aspects that define surface quality, thereby appearance are, namely surface roughness, waviness, direction of lay and process defects.

Therefore, first attribute of surface is low surface roughness or the absence of pronounced peaks and valleys. This is a good indicator of surface quality and therefore can be taken as one of criterion for defining finish. It can easily be measured by a dial gauge. It is symbolized by an abbreviation ‘Ra’ in common practice in Indian market scenario.

This method of measurement brings in empiricism and provides an objective tool to measure and finish through one of its attributes as low surface roughness. In common parlance/dialect, this is referred to as primary texture as a quality of a surface. Thus, it can be easily adapted as a surface quality parameter in jewellery. It is also possible to control it visually, where no measurements are possible, by providing visual reference sample of scratching patterns within upper and lower control limits of roughness.

Waviness of a surface is second attribute of a quality of surface. It can be understood as deviation from an imaginary, but ideal surface. This attribute is referenced as deviation from an ideal surface. This is called a secondary texture and can be defined as number and type of deviation (positive or negative that is protrusion or depression) per unit length. This also adapted as a surface quality parameter in jewellery and can be methodically evaluated numerically as depression or protrusion over unit length and offers measurability.

Third attribute is direction of lay, which pertains to the directional pattern created by scratches. These can be parallel or perpendicular to long side; at a predetermined angle, cross-hatched, radial or circular are some such examples in common practice. It is also possible to define them in words as orbital, radial and random. These can be

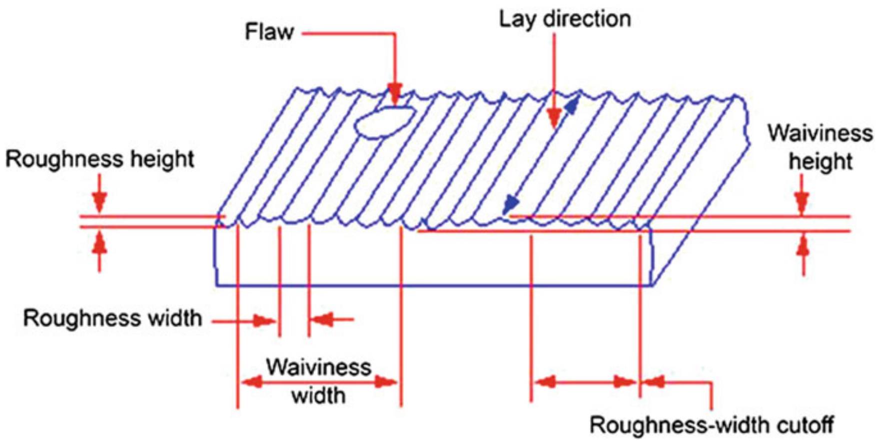

Fig. 29.2 Surface roughness [8]

well defined but remain to some extent subjective. Yet they have a merit as it brings empiricism in domain of jewellery and makes communication a lot easier. These can be adapted with modifications in defining target finish on an article of jewellery. As shown in Fig. 29.2.

A fourth attribute can be added to the above ones which is freedom from occasional localized defects such as: **Pin Holes**—resulting from casting porosity. As shown in Fig. 29.3.

Scratches—during sharp objects grazing, resulting in inadvertent scrapes and unresolved file marks. As shown in Fig. 29.4.

Fig. 29.3 Pin holes—a result of casting porosity [9]

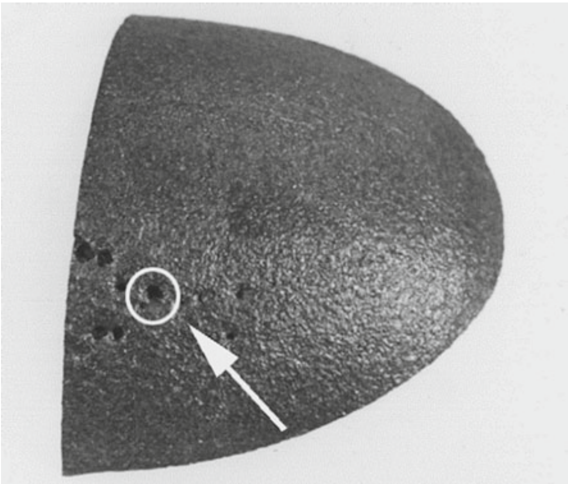

Fig. 29.4 Scratched titanium ring [10]

Dents—as unattended, left indentations as a use of material manipulation/displacement of tools, percussion. As shown in Fig. 29.5.

Distortions—These are surface shrinkages-related defects and deviations from inadvertent directional solidification of cooling metal; this surface defect is especially sensitive to casting of delicate pieces during designing such as rings. As shown in Fig. 29.6. Primary attributes of surface quality are reflected in Fig. 29.7.

The system diagram can also be converted to one depicting their individual weighted averages, but presently beyond the scope of this study, and open up potential future investigation. But a sample can be created, as shown in Fig. 29.8 for visual referencing.

There are also secondary factors that play an important role in the appearance of surface finishes to an observer, and these are,

Fig. 29.5 Dented metal surface [11]

Fig. 29.6 Axial shrinkage, a casting defect [12]

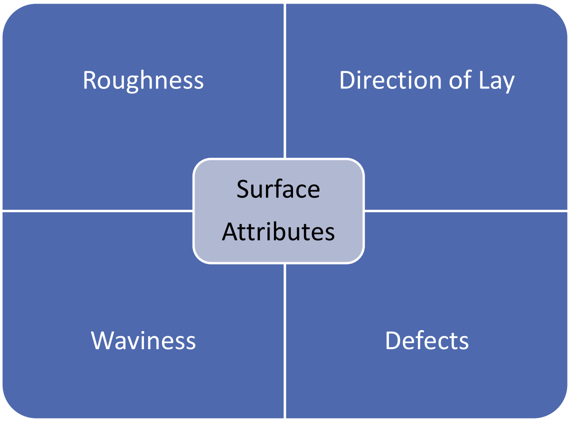

Fig. 29.7 Attributes of quality of a jewellery surface and their influence on appearance of an article

Continuum—This attribute pertains to continuity of a surface, as ordained by the ideal imaginary surface. This activity ensures conformance to the target form. This is important particularly to jewellery as for boutique pieces, handmade, there is only a reference sketch to work with. No engineering drawings are made or can be made for the nature of work which is generally artistic.

Homogeneity—This attribute is the quality of a surface of all same appearance and types of articles. The surface equality is evenly distributed in all directions, in an isotropic look and feel. This is different from direction of lay, which may meander as form transition takes place, yet surface could look same in all directions as with many natural phenomenon such as carpet grass.

Uniformity—The attribute is consistency of appearance throughout body of an object; it is the lack of diversity that creates homogeneity of appearance, e.g. whole surface having uniform well-placed strokes from a tool, e.g. uniform and rhythmic hammer marks on surface of brassware.

Fig. 29.8 Casting surface finish [13]

Examples of jewellery with these attributes can be found in Fig. 29.9.

When these qualities are congruent with above-mentioned surface attributes, it gives a reference point to define, articulate and monitor surface quality [2]. This also paves way for effective communication between various stakeholders in a quality chain.

Fig. 29.9 Examples of continuous, homogeneous and uniform jewellery from the house of 'Van Cleef and Arpels' [14]

29.6 Discussion

The paper lists foundational four factors, three adapted from domain of engineering and one added from the field study investigations to bring in lost wax casting, as a process definition and an important process parameter into the canopy of surface qualities. Roughness and waviness are the attributes that are objective in nature and have measurable aspects in term of linear dimensions. First aspect, roughness, is a difference between peaks and valleys. The second aspect, waviness, is number of deviations, positive or negative per unit length.

Direction of lay (which pertains to longitudinal, transverse or radial direction followed by scratches created by machining or finishing method) can be defined by simple to understand words, and observation confirms same. Defects are bundled with these primary attributes as they are part of process, innate process tolerance determines nature of defects that may arise, e.g. pin holes are a part of lost wax casting as occasional defects.

Continuity, homogeneity and uniformity pertain more to appearance of surface and its perception as compared to measurement aspects. However, they are lucid and qualitative in nature measurable on a Likert scale. Collectively, put together these seven factors give a holistic and qualifying definition of a quality surface. Their individual definition and articulation make the Metrix meritorious in practice.

29.7 Limitation

Formal and methodical research in domain of jewellery is just beginning. There exists a clear gap between theory and practice. It becomes severe, when theory behind the practice is not known or evident. In a field more prone to artistic work, any attempt to measure and quantify meets confrontation, refutation and denial. They impede and limit research in a limited zone.

This study faces limitations due to lack of support in scientific literature in domain of jewellery. Authoritative books and periodicals are not available in this domain to provide contemporary view and foundational knowledge that makes conclusion difficult.

29.8 Merits and Contributions

This study provides a firm theoretical framework to:

- Provide understanding of various factors and attributes used to explain and evaluate surface finish of jewellery articles

- Instigates and develops scientific definitions of various aspects and criterions (lets be specific: scientific definitions of terminology, attributes and evaluative factors of the domain)
- Methodically classifies and provides qualitative measurement and quantitative (objective…) aspects of parameters and attributes
- Developed and proposes a framework to articulate target finish on jewellery surface
- Contributes to the scarcely available literature and paves way for further research in the jewellery domain.

Study gains merits on scientific approach to a subject hitherto dealt with art and craft approach and bring in higher-level objectivity.

Most prominent contribution of this paper is decoding and defining ambiguity in a well-researched study to enable jewellery makers to communicate with rigorous and objectively understood definitions and articulation about target surface finish.

29.9 Future Directions

This research further develops in articulation and defining of processes for horizontal deployment on shop floors in Indian jewellery manufacturing set-ups.

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Part III
Application of Design Knowledge in Practice (Automotive, Aerospace, Biomedical Devices, etc.)

Chapter 30
Can You See My Pain? Evocative Objects for Comprehending Chronic Pain

Jonathan Mathew and Vivek Kant

Abstract Chronic pain presents a rather unique design challenge. Unlike the traditional view of pain, in which it is often to be averted, chronic pain cannot be simply done away with. Thus, the emphasis of our approach is to address pain as revealed and expressed. We adopt a *research by design* approach for creating evocative objects for chronic pain management by developing solidarity. The paper develops on critical perspectives on pain and embodiment in conjunction with the design process to arrive at an evocative object. These objects enable supporting solidarity between the one who suffers and the one who seeks to understand the suffering.

30.1 Introduction—Pain as Revealed

> Thus when one speaks about "one's own physical pain" and about "another person's physical pain," one might almost appear to be speaking about two wholly distinct orders of events. For the person whose pain it is, it is "effortlessly" grasped (that is, even with the most heroic effort it cannot not be grasped); while for the person outside the sufferer's body, what is "effortless" is not grasping it (it is easy to remain wholly unaware of its existence; even with effort, one may remain in doubt about its existence or may retain the astonishing freedom of denying its existence; and, finally, if with the best effort of sustained attention one successfully apprehends it, the aversiveness of the "it" one apprehends will only be a shadowy fraction of the actual "it"). [1]

Chronic pain is an inexplicable state of being and designing for it is a paradox. This is because pain is often dealt with being a state to be averted. What happens when one cannot avoid this state of affairs, when chronic pain becomes a part of one's existence? In such a scenario, often found in palliative care settings or even people

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A. Chakrabarti et al. (eds.), *Design for Tomorrow–Volume 3*,
Smart Innovation, Systems and Technologies 223,
https://doi.org/10.1007/978-981-16-0084-5_30

suffering from ailments such as cancer, pain becomes not an adversary but a cloak of solitude. It is difficult to express it all the time but it lurks in the shadows always making its presence known. While the role of computing technologies in health is on the rise, there is little discussion about the problem of long-term sustained pain [2–4]. This article presents one step toward the discussion of pain in computing, situating it at the nexus of experimental interaction design, embodiment theory and evocative objects. Using a design-based research approach, this paper emphasizes that while it may not be possible to alleviate pain, it is still possible to provide a person long-term solidarity. This is supported through the design of evocative objects drawing upon insights from embodiment approaches in human–computer interaction (HCI). The paper shows that the problem of comprehending and expressing pain is not straight-forward. Thus, this problem does not fall in the category of traditional problem–solution approach of design that gets rid of the pain; rather this article emphasizes that pain as an embodied concept has to be comprehended as revealed [5–7]. Thus, the role of the designed object falls in the category of supporting *revelation through evocation.*

In a succinct manner, the problem of pain in long-term scenarios is as follows—being corporeal in nature, pain cannot be simply explicated. As Scarry's [1] quote above reveals, the problem of expressing pain is one of crossing a chasm between the two worlds of the one in pain and the one trying to fathom the other's pain [1, 8]. In other words, our proposed approach is to recognize that while pain cannot be removed in some circumstances for long-term patients, it can be managed through seeking solidarity [9–12]. Therefore, while the one in pain and the "clueless other" are not physically co-located, they are still connected in the bond of solidarity in knowing and understanding of pain. Often people need these moments of shared insights for dealing with problems of long-term chronic pain. While seeking solidarity is not a straight-forward activity, making the inexplicable pain salient can serve as a design intervention that provides reflection and support in the other person [8, 13–16].

Currently traditional pain scales and novel digital apps address pain management. Numeric pain scale (1–10) is the most common scale and consists of numbers from 1–10 and the patients point out their current pain intensity level. The interpretation of the scale is subjective in nature and differs from patients as well as doctors. Variants of this basic scale include visual analogs such as the Wong-Baker FACES © pain rating scale or color-based pain scale, as well as, more extended scales such as the McGill pain scale that addresses sensory, affective, and evaluative issues for reliability. The healthcare sector has also adapted to the use of mobile technologies within their monitoring systems for patient healthcare management (see [4] for a survey between the years 2005–2015). However, these applications do not address pain in the same manner we have, in evocative terms.

The aim of this current article is to engage with the possibilities of evocating such a reflection. Herein lies an opportunity for a new approach or a medium to express chronic pain where it evokes itself to be public in nature while it exists in the context of use that is private. This could enable people to solicit social support toward these individuals suffering from chronic pain. The aim is to find ways that *facilitate* rather than dictate solidarity. The current article presents the design of an evocative object for expressing pain, for people suffering from sustained and long-term pain, in order to achieve solidarity and move beyond the solitude of oneself. Thus, it emphasizes the challenges of designing interactive objects and highlighting its link to embodied interaction in HCI and computing technology in health.

This article is divided into four main sections. Section 30.2 shows the need for engaging embodiment theory and evocative objects along with the sociocultural situatedness of people in pain. Section 30.3 presents the design process and the final prototype, whereas Sect. 30.4 presents the way forward in terms of avenues for design for chronic pain.

30.2 Dynamics of Pain—Issues for Design

Another manner of formulating our problem is to highlight the inherent challenge of chronic pain. In Elaine Scarry's [1, 8] words, there is a need to search for the semantics of pain that captures its very paradox:

> Whatever pain achieves, it achieves in part through its unsharability, and it ensures this unsharability through its resistance to language. "English," writes Virginia Woolf, "which can express the thoughts of Hamlet and the tragedy of Lear has no words for the shiver or the headache." … Physical pain does not simply resist language but actively destroys it… [1]

Rather than rely on digital apps as manifestations of pain management, e.g. [4], our search for the semantics of pain led us toward the need for rich evocative mediums that depict pain with dignity and for the search of solidarity that seeks compassion rather than solutions. Chronic pain in many cases defies the solution but we aim to provide a medium of expression rather than a syntax of measurement. As such, the insights drawn from the background survey of pain from an embodied, embedded, and socially situated perspective emphasizes that it is revealed and it negotiates the boundaries of the self and the other, public and the private, implicit and the explicit, and internalized and the externalized [2, 5–7, 9–13, 16–20]. It is through the exploration of these various themes of the search for solidarity and empathy of the embodied expression of pain that leads to the need for evocative objects.

30.2.1 Evocative Objects

We live our lives in the middle of everyday things and we are constantly surrounded by them. This culture of material possession carries both emotions and ideas, with this culture spreading over the years only a handful of these objects receive attention to their existence as part of our lives. These objects have been labeled as "Evocative Objects" by Turkle [21]. The notion of an evocative object presents for us the first step toward making the inexplicable pain, explicit. The person suffering from chronic pain finds it difficult to reach out to people after some time but is richly surrounded by objects. Objects with which the person is involved with often serve as intimate connection to life. It is the forging of links with such objects that serves as the first step toward seeking solidarity through interaction. Imagine the bond between siblings, lovers, or other emotionally intimate people; in many such cases, people hold on to keepsakes that evoke memories of things past. Old trinkets, fountain pens, buttons, ribbons, and many more of these sustain the link between the self and the other. The design of evocative objects in this case cannot be simply categorized under the label of "design for emotion." This is because, pain transcends all emotion and cognition and foreshadows them in its corporeal nature. The semantics of chronic pain that we are dealing with is not based on the basis of furtive avoidance but a conjoined reciprocity between the self in pain and the other seeking comprehension. Therefore, our first design challenge is to ask: How do we design such evocative objects that is both at a representational level as well as connects the pained to the other?

30.2.2 Embodied Interactions

> When one hears about another person's physical pain, the events happening within the interior of that person's body may seem to have the remote character of some deep subterranean fact, belonging to an invisible geography that, however portentous, has no reality because it has not yet manifested itself on the visible surface of the earth [...] Physical pain happens, of course, not several miles below our feet or many miles above our heads but within the bodies of persons who inhabit the world through which we each day make our way, and who may at any moment be separated from us by only a space of several inches. [1]

A need for understanding pain as an embodied concept is due to its nature as being squarely located "within" and thus bringing a gulf between the sufferer and the one trying to comprehend the suffering. As Scarry [1] notes, the ones who suffer through their bodies cannot escape it—"it cannot not be grasped." In contrast, the one who does not possess the pained body, even the most valiant of efforts may be thwarted in trying to grasp the essence of pain. Embodied interaction [22, 23] explores the possibility to unify the experience of the physical and tangible worlds to a new medium of interpretation that relates to our daily experiences with the objects around us. As designers, we explore and create new mediums that translate the meaning and action of the intended activity within a sociocultural context. The challenge here as a designer is to answer the question, how can we include the artifacts we design as an active participant into the context of the environments we design for that give rise to new meanings that evolve with time?

30.2.3 Sociocultural Situatedness

> The very temptation to invoke analogies to remote cosmologies (and there is a long tradition of such analogies) is itself a sign of pain's triumph, for it achieves its aversiveness in part by bringing about, even within the radius of several feet, this absolute split between one's sense of one's own reality and the reality of other persons. [1]

Chronic pain-related conditions lead to severe problems in close relationships, which in turn portrays the perception of patients in self-management of their pain through the influence of social factors. Health care is often regarded as private and personal, with varying degree of relationships people have with toward caregivers or loved ones. In India, where the insights are drawn from [24], a majority of people would prefer to hide chronic pain, as their perception of their condition is treated as a stigma in certain social contexts [25–27].

The impact of coping strategies among patients who adopt help from caregivers have a serious residual effect on their treatment compared to self-management of their condition, as it gives them a sense of control [15, 16]. This puts forward a challenge to designers: "Showcasing versus Concealing." Should the new medium we design offer us a new language to communicate with others by being unobtrusive to their sociocultural context of use? How can we search for a lack of language emphasized by Scarry [1, 8]? *What will a design language be for evocative object when it itself defies any language?* Hidden yet salient? Search for solidarity yet shirking from the lack of other people's understanding? This should be considered as a prominent feature of the objects that we attempt to create.

30.3 Design Process

30.3.1 Affinity Analysis and Harris Profile

Based on the literature review and insights about pain, an initial affinity mapping of concepts was conducted. Sorting the initial set of observations to understand the brief overview of how pain can be expressed. This was followed by grouping them according to their affinity to a certain area or domain within expressing pain. These main themes were further translated into possible design criterion for consideration (Table 30.1). These were further narrowed by using a Harris Profile [28, 29] for narrowing the pros and cons of our design ideas and to provide a better understanding of the problem space of chronic pain.

Table 30.1 Partial list of design challenges

Medium to express intended pain level	Repeated use
Mediums resolution: doubts about accuracy	Cognitive translation/difficulty interpreting
Discretion and disclosure	Pliable interactivity
Continuous tracking task	Unobtrusive reporting
Form factor affordance	Sharing with a doctor/caregiver during visits
Intuitive	Impractical or socially inappropriate
Confirmation and feedback	Time consuming
Possibilities of unintentional reporting	Cognitive impairments
Portability	Low-to-little digital competency
Embodied interaction	Functional limitations (vision, motor skills)
Transparent to the participant	Uncomfortable reactions

30.3.2 Fishtrap Model, Final Concept, and Evaluation

The fishtrap model is a systematic process of designing a product form [30]. It structures the designer's activity by forcing them to explore three subsequent levels of detailed meaning: (a) topological level; (b) typological level; and (c) morphological level (Fig. 30.1).

30.3.2.1 Topological Level: Devising the Structural Concept

In this first level, we present a bare bone design where all the component parts are laid out first and ideation happens around them so as to guide the design exploration to stay

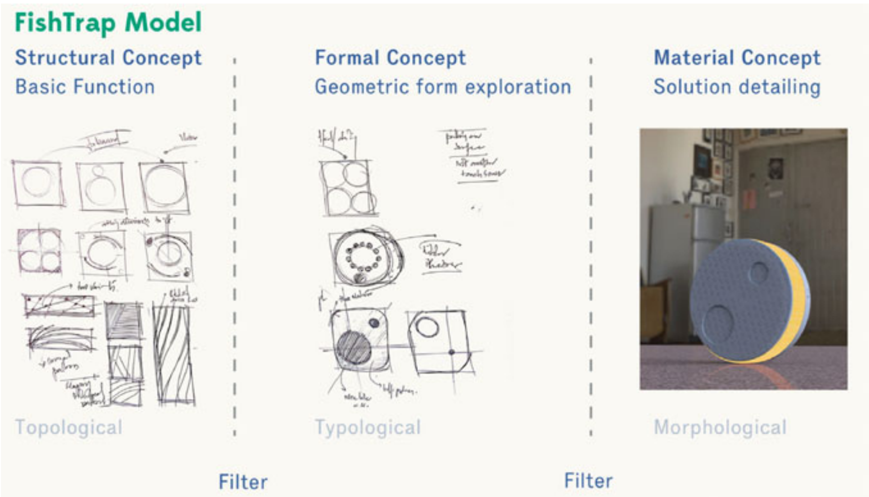

Fig. 30.1 Results of the fishtrap model. The figure shows the steps in a very broad manner. These have been taken from the first author's design book. Also, see Fig. 30.2 for form explorations

within the expected deliverables/outcomes. In our case, we considered the technical and functional limitations while designing the product. The design considerations of the early stages of the development in Fig. 30.3a showcase the ordering of the components based on their functional and structural properties such as what they will do. From a technological perspective, will they move, glow, or change colors? These issues had to be addressed to make considerations about using an electronic prototyping board? In Fig. 30.3a, the basic components considered were the two sensors and the housing unit of the NODEMCU© electronic board that served as the basic technical and functional architecture of our design concept.

30.3.2.2 Typological Level: Devising the Formal Concept

At this second stage, we selected the structural concepts to further develop them into more formal or geometric concepts. We focused on the geometric form explorations while including the design aesthetics that we would want the product to evoke by being in its innate form. Next, the ideas were clustered and further refined to showcase a feature particular to the intended context of use. In our case, the artifact was intended to provoke or evoke solidarity but at the same time through a balance of pain. This was highlighted through the expected form behavior, such as roll/sway or spin or sway for depicting expected turmoil (Fig. 30.2). In this step, we tried multiple explorations of form and tried to converge upon two structural concepts out of which one was finally selected to take on to the next level.

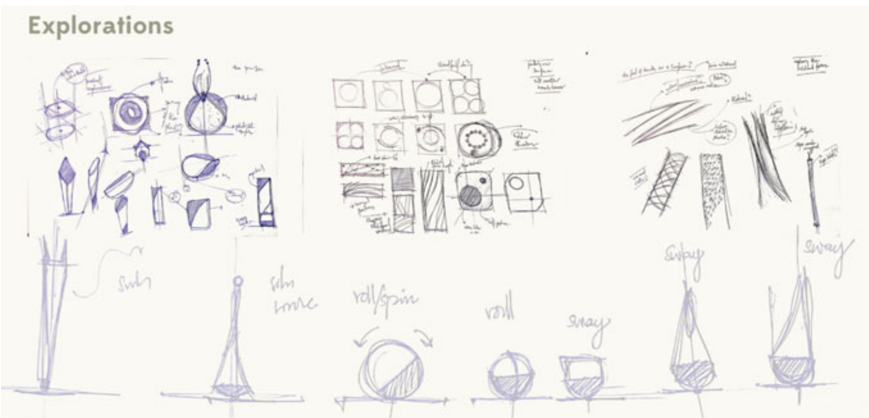

Fig. 30.2 Form explorations in the typological level based on the concept developed in the topological level

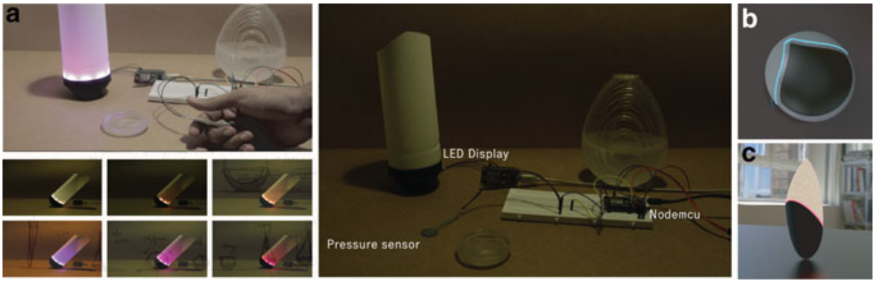

Fig. 30.3 **a** shows working prototype of the concept. **b**, **c** shows the final object concepts. **b** shows the hand-held product that the person suffering from pain will hold; whereas **c** shows the object that serves as the medium for expression for others

30.3.2.3 Morphological Level: Devising the Material Concept

Based on the above two stages, the constraints were in place and the convergent phase of the design stage led us to an evocative design outcome. At this stage, we explored material properties and texture to achieve a finished product concept. Different types of textures, ranging from soft and hard rubbery textures to smooth vinyl textures, were explored that would give the feeling of evocation for both the sender and the receiver. The basic issues explored were what kind of material feel would the person in pail feel like handling. On the reciprocal side, what material should the evocative receiver object be made of that it is able to be recognized as evocative, while being under the constraints of the various previous levels. In other words, there are particular signifiers for objects that we can embed in the form that emphasize it as evocative. While being in the context of use, these forms bring about interactions between objects that provoke reflection and direction to solidarity; failing to do so will lead to ambiguity between action, meaning and comprehension.

30.3.3 Final Concept and Related Video Narrative (Screenshots of the Video Story Boarding)

Iterative cycles of discussions and brainstorming helped us to evolve the final concept. One of the key challenges was that the designed interactions could be uncanny as it puts these users in an unfamiliar environment where this unfamiliarity provokes and evokes in them a mismatch between the manner in which pain is expressed and received. The final idea revolves around two challenges: first, to express chronic pain where the interaction is pliable through the possibility to evocate; second, the possibility to communicate the same to a caregiver through expressive mediums. Thus, the object is designed to help the user reveal their pain to the caregivers or loved ones and help them *understand their own inner turmoil* [1]. The proposed final prototype is a device that communicates pain by collecting pain intensity data from object 1 (manipulated by the person in pain; Fig. 30.3b) and mapping the same on a color scale which is depicted by the evocative object (object 2; Fig. 30.3c), meant for the other seeking comprehension. The question here is whether the device can resonate with the intensity an individual is feeling. As the animated device is triggered, do individuals react with different intensity levels for the same as opposed to one that is the same?

In accordance with the above questions and the results of the fishtrap process, the final concept was developed as a prototype and evaluated (Fig. 30.3a). For the prototype, an IoT-based board ESP8266 was used. The ESP8266 Wi-Fi module gives the microcontroller access to a Wi-Fi network and the ws2812b addressable LEDs. The pressure input was based on a force sensor (force-resistive sensor). An additional integration was the use of micromotors to enable microvibrations. The devices are meant for both the patient and the support group as a subtle indicator of the intensity of expression over a period of time. Here, the evocation and the embodied interaction is designed to trigger interactions between groups or users, where they can rely on each other to communicate the same. These objects could offer a way to help a person express himself to the object and in turn the object translates that expression to other objects that are part of an individuals connected social support group. Later iterations of these objects resulted in more dynamic behavior that draws one's attention in a more subtle way. In this, the object showcased states of being active (upright) and discomfort communicated through an off-center position, with varying gradient of colors to indicate intensity as seen in Fig. 30.4. The final stage is the subtle movement to showcase growing disinterest.

The aim of the evaluation was to understand whether the designed objects will be used as envisioned in its original goals to provide a reflection and comprehension of pain. Apart from the mundane issues of understanding use, the evaluation was geared towards three main questions: (1) Do these objects become evocative? (2) What kind of relationship would they exist in? (3) Would there be recurrent use? In order to understand these questions in terms of the design concept, an evaluative study was conducted. Participants chosen had encountered a close relationship with people living with chronic pain. The participants were young adults (no of participants: 7). They were given three or four scenarios that they would imagine themselves in

Fig. 30.4 Concept video narrative presents a user who's undergoing through chronic pain. It brings up the "*what if I had object that can express the inexplicable too and in turn expresses itself to others.*"

and express their pain and understand the pain of others. This was followed by a detailed session and discussion of prototypes and their use in the various scenarios. The discussion ranged from the manner in which they used the different prototypes (object 1 and 2; Fig. 30.3b, c) to the various possible ways in which this could be used in the future for long-term interaction. The focus of this project was to elicit insights about use rather than to test the usability of the device per se. Their feedback presented us with the need to refine the prototype and provided us with a few important insights. (1) The proposed concepts could be used in closed group relationships. (2) Participants felt that these objects could evoke empathy. (3) The lack of participation from their close dyad of the sufferer and the one seeking comprehension would lead to less recurrent use. Therefore, regular use became a key term to be considered in the usage of these artifacts. These insights provide us with additional direction that could be used to design evocative objects for the revelation of pain.

The final concept was difficult to elaborate only using mediums such as 3D modeling renders and sketches that lack the means of depicting the intricacies of the relationship that these objects would hold in the environment and the context of their use. Therefore, video narrative (Fig. 30.3) was used as a medium to better capture the relationship that we would share with these objects and the meaning we would derive from them along with the action that it provokes. The video narrative presents a user who is suffering from intermittent bouts of chronic pain. The video shows the one undergoing pain, use object 1 to hold, press, and toy within the throes of the agitation. The video also shows object 2 that is with the other person and aims towards expressing the inexplicable pain through a change in its color profile and subtle movements. The video depicts that over a period of time, sharing the pain leads to greater solidarity. Thus, the video narrative seeks to shed insights on the reactions that people would have regarding these objects, their interactions, and the levels of intimacy they would carry.

30.4 Implications and Conclusion

We conclude, by identifying from our research by design approach, four main directions for further research, that need to be addressed while designing for chronic pain as revelation:

1. *Chronic pain through evocation*: Dealing with chronic pain involves a renewed understanding of how to comprehend pain through meaningful experience of the person suffering. Thus, suffering and pain have to be taken together and understood in terms of how they can be evoked and expressed for others through design of evocative objects.
2. *Embodiment of pain and computing devices*: Even though HCI theorists have addressed embodiment, the embodiment of chronic pain is one of the major challenges that is yet to be addressed comprehensively for computing devices.

3. *Sociocultural dimension of expression of chronic pain and design of interaction*: Currently, chronic pain and its sociocultural manifestations are limited in health technology; specifically, from the viewpoint of design for *pain as revelation*, as discussed in the article. There is a need for addressing chronic pain in the sociocultural context it manifests, i.e., in terms of showcasing vs. concealing.
4. *Semantics for pain for computing devices*: Pain while being corporeal circumvents the labels of cognitive and emotional and demands a deeper understanding through a visceral understanding. Formulating a semantics for this visceral dimension is one of the main challenges of design in this realm.

Acknowledgements Vivek Kant's work on this article is supported by Indian Institute of Technology Bombay research grant Spons/ID/10001742-2/2018.

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Chapter 31
Design Thinking for Long-Term Product Planning

Shamit Shrivastav and Rahul Joshi

Abstract Product planning is the foremost and an integral part of the new product development (NPD) process today. The primary role of the product planning function is to define and conceptualize the "right" product—right for the customers, right for the business, right for all the key stakeholders, and right for the environment. The product planning process involves understanding the customer needs through market research, translating those needs into product specifications, and creating a positive business case for the new product. However, with the rapidly changing market scenario, intense competition, the advent of new technologies, and regulatory trends, the conventional product planning process does not always lead to the expected business output. Product planners must get the new product definition right in the first attempt itself. Engineers in the research and development (R and D) function use this product definition to evaluate the feasibility of the design and develop real products. It is, therefore, evident that the margin for error in the product planning process is zero. Design thinking is a human-centered problem-solving approach that can solve a social, economic, environmental, or business problem and uncover high opportunity areas. Using a case study of a leading Indian automotive and construction equipment original equipment manufacturer (OEM), this paper demonstrates how design thinking enabled an organization to conceptualize a new category-creating product that captured significant market share in just two years of launch and how the organization developed it in less than three years. This paper illustrates the potential of the design thinking process for new product development and discusses the possibilities of scaling it to different sectors. The paper also explains the critical roles of a designer in this process when working in a cross-functional team.

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A. Chakrabarti et al. (eds.), *Design for Tomorrow–Volume 3*,
Smart Innovation, Systems and Technologies 223,
https://doi.org/10.1007/978-981-16-0084-5_31

31.1 Introduction

Every business develops an offering for the market; this offering is a product or a service. The offering needs to deliver value to the customers, the company, the environment, and the economy of the country. One product cannot fulfill the needs of all the types of target customer groups. Businesses, therefore, have different kinds of products to cater to different customer segments, and together, these products are called the product portfolio of the company. Product portfolio results from the collaborative efforts of product development functions like R and D and customer-facing functions such as marketing and sales.

According to a McKinsey report [1], more than 25% of total revenue and profits across industries comes from the launch of new products [1]. A successful new product can create a new benchmark in the industry by opening new markets and making it difficult for other companies to enter [2]. The process that drives product development in the organization is called the NPD process. NPD is a stage-gate process [3], executed by a multifunctional team comprised of members from different functions such as design, R and D, sourcing, manufacturing, quality, marketing, sales, and finance.

While the NPD process is well-structured and followed in the manufacturing sector since the 1980s, not many companies have tasted the desired market success with new products. NPD process has undergone many improvements since then companies have tried to balance the market side and the feasibility side activities of the process and even cut down the development time for faster introduction to the market. However, 40% of products fail at launch even after the development and testing, and out of every 7–10 new product concepts, only one is a commercial success [4]; the NPD process thus needs to be investigated. Spotting the right opportunities and creating the right product definition is critical for a new product. Lack of product distinctiveness or unique selling proposition is one of the major reasons of product failure in the market [2]. New product development is important yet challenging for the business in this fast-changing and less predictable world [4]. While practices such as agile development, design thinking, open innovation, lean product development, and lean start-up have been introduced to improve the NPD process, more research in the effective application of these practices is needed.

This paper aims to evaluate the design thinking approach for spotting high potential product opportunities in NPD. The paper also compares the design thinking approach to the existing methods followed in NPD, using a case study of an Indian construction equipment manufacturer (Fig. 31.1).

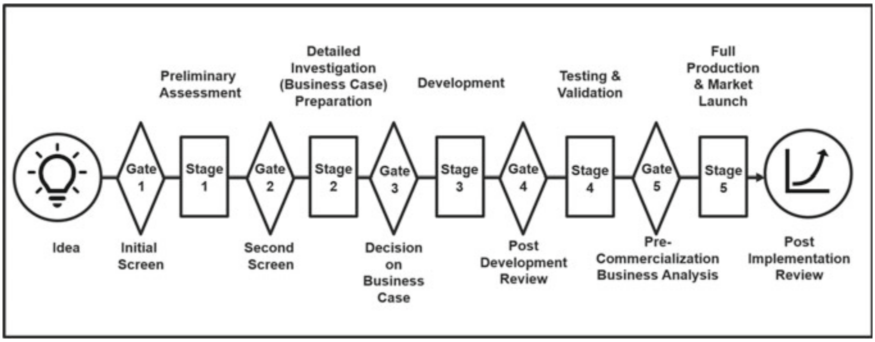

Fig. 31.1 Stage-gate process of new product development [3]

31.2 Product Planning for New Product Development

In product-based companies, customer-facing functions such as marketing and sales have been providing market inputs to the engineering teams. The marketing function analyzes the historical sales data and the market performance of existing products to forecast the demand for new products. Marketing managers' primary goal is to promote the existing products, but the business also expects them to provide market inputs for NPD. Product management and product planning are the two marketing sub-functions that fall at the intersection of marketing and product development. Product managers manage the product portfolio of the company, ensure that current products meet customer needs, improve product profitability, and suggest product improvements. Product planners are responsible for identifying a new market gap, finding unfulfilled customer needs, analyzing market trends, defining the value proposition, and conceptualizing a new product.

31.2.1 Role of Product Planners

Product planners lead the product conceptualization stage of NPD, and then they efficiently transfer the market requirements to product development functions such as engineering and sourcing. Product planners and the product development teams regularly interact to prevent any dilution of the original concept until the end of development. In the last stage of development, product planners test the final prototype with the target customer group, collect feedback, and suggest refinements. They collect critical inputs required for the business case of the new product, an important checkpoint that decides the financial health of the project. These inputs include the market size of the opportunity, cost of the raw materials, processing cost, capital investments for manufacturing, technology licensing, and the target price of the product. The leadership team approves the project only if the business case is healthy, which means that the return on investment (ROI) is positive, and the breakeven can be achieved sooner post the launch.

Product planning function thus finds the customer and the market needs, defines the product specifications, supports the engineering design and development, gathers inputs for the business case, and validates the concept. Documentation of customer voices (VoCs) and insights, product briefs, product specifications, pricing strategy, and business case are other key responsibilities of the product planners.

31.2.2 Limitations of Product Planning Process

Internal and external factors govern the outcomes of the product planning process. Internal factors are in direct control of the organization; they include business strategy, business processes, capabilities of the team, and capacity to invest. Market competition, industry regulations, new technologies, and consumer preferences are the external forces that are subjected to change. Competition in every industry is growing in multiple dimensions—a *known competition* with an entry of more players in the industry and an *unknown competition* with companies unrelated to the industry solving the same customer problem in a different way. Service-based companies such as Ola and Uber are the best examples of unknown competition; as today, they are also a competition for automobile manufacturers. Designing products to meet the tightening regulatory requirements is a difficult challenge for the companies. For example, automotive manufacturers in India are simultaneously working to make cars safer and cleaner with the upcoming crash protection and emission norms. Advanced technologies such as IoT and AI have touched the edge of many industries and soon result in changing product functionality and consumer experience. The increasing diversity of consumer demographics and psychographics has created new market segments, each having varied preferences. Thus, product planners need to be completely familiar with present market conditions and have foresight into future scenarios when identifying new product opportunities. This research intends to throw light on incorporating "design thinking" in the product planning process today, which can result in successful new product concepts tomorrow.

31.3 Design Thinking

A well-known global design consulting firm, IDEO, defines design thinking as a human-centered approach to creative problem-solving. Design thinking, when applied to business, can help formulate the right strategies to meet business goals. Design thinking takes a holistic approach starting with correct problem identification and framing, more in-depth consumer research, structured ideation, and quick prototyping. Design thinking prioritizes grounding design decisions in a thorough understanding of user needs, uses iterative prototyping and problem-solving to explore wicked problems, and employs divergent-convergent thinking [5]. Design thinking process uses three lenses to identify problems or spot opportunities and create solutions—the consumer or the desirability lens, the capabilities or the feasibility lens, and the business impact or viability lens [6].

31.3.1 Application of Design Thinking in a Business Context

In 1973, Thomas J Watson, ex-CEO of IBM, had mentioned: "Good Design is Good Business" [7]. Management scholars first showed interest in the links between business and design in the mid-1980s. According to a study, it was found that the financial performance of the firms investing regularly in design was better [8]. Design thinking applied to business strategy and business transformation involves the visualization of concepts and the actual delivery of new products and services [9]. In his book, *The Business of Design*, Martin [10] sights many examples from P&G, in the year 2001, P&G built a design thinking organization and demonstrated the power of design through various innovation projects [10]. Adoption of design-oriented NPD strategy and a customer-following approach helped LG Electronics develop an award-winning, and high financial impact phone called—Chocolate [11]. Organizations, that have practiced design thinking, have transformed the way they develop products, services, processes, and business models. As mentioned by different scholars, this process has the potential to discover new paradigms for product innovation, resulting in high business impact in terms of revenue generation and competitive advantage.

However, the reach of design thinking within an organization is still minimal. Organizations, that have introduced design thinking, have not been able to harness its complete potential, and thus, it has not found a place in the core business processes of the companies [12]. Design thinking is used for employee training in large companies but not in strategic planning and product development.

31.3.2 Product Planning Using Design Thinking

Both design thinking and NPD have a common purpose of fueling the growth of an organization. Product planning process proposes new product ideas based on the historical sales data, customer feedback of existing products, and market research. Research in this area suggests that success in the new product innovation process cannot be achieved by only analyzing the past and present information available with the company; rather, conceptualizing the future scenarios and creating solutions for these scenarios are also essential. Philosopher Charles Sander Pierce developed a concept called abductive reasoning, according to which, no new idea could be produced by using the past data, and thus thinking in new and different perspectives is required [13]. Martin [10] defined design thinking as a dynamic interplay between

Table 31.1 Conventional product planning and product planning using design thinking

S. No.	Conventional product planning	Product planning using design thinking
1	Thinking boundaries are in the current paradigm	Design thinking helps explore new paradigms; it helps to look at the big picture
2	Process focuses on short-term goals	Process is farsighted and helps achieve long- term goals
3	Breakthrough ideas get filtered out early in the process as they are measured against the business impact	New and innovative ideas are encouraged and deliberated
4	Heavily dependent on secondary sources and historical data	Insights are derived from primary research, trends study, and lateral industry references
5	Process uses reliable methods that have been tried earlier	Process is iterative and teaches to fail quickly and keep improving continuously
6	Idea list includes product improvements and new feature ideas	Process yields ideas on new products, services, and business models
7	Team members are from engineering, management, and technology backgrounds	Designers and innovators also play a critical role and co-create solutions along with engineers, managers, and technologists

analytical mastery, and intuitive originality, and businesses that learn to balance these well will be successful. Martin also believed that designers live in Peirce's world of abduction since they keep discovering new data points, challenge fundamental assumptions, and find new realities [10]. According to the innovative design thinking (IDT) framework, there exist two kinds of proposition for new concept development—analytical and synthetic. Analytical propositions are "definitional" and based on the "known" facts, whereas synthetic propositions are "suggestive" and need to be validated before execution [14].

Design thinking enables unbiased visualization of the future, not a usual practice of product planners today. This research demonstrates how design thinking principles are relevant to the product planning process and compares the design thinking-based product planning approach to the conventional approach (Table 31.1).

31.4 An Indian OEM's Design Thinking Approach for Defining a New Product Category

A leading automotive OEM in India had entered the construction equipment industry with the launch of a Backhoe Loader[1] (BHL) machine in the year 2011. This machine

[1]Backhoe loader is an earthmoving equipment used for construction of roads, canals, and similar construction activities.

was a perfectly engineered product with new features and technologies that none of the other competitors were offering in the market. However, the product failed to capture a sizable market share even after four years of launch. The business tried improving product performance, creating low-cost variants, and increasing the sales and service reach, but the desired business impact could not be met, thus questioning its survival.

The Business Leader concluded that new businesses in the construction equipment industry cannot succeed if they keep playing in the existing product categories. The business thus needed a new product that could create a new category in the industry. A small core team comprising of product planners, product engineers, and a design thinker was thus formulated. The team's primary goal was to identify a new product opportunity that gives the business a large customer base, a strong brand presence, and a sustainable opportunity for many years. The team decided to use an innovative approach for this project instead of a conventional NPD approach defined by the company. The design thinker in the team took ownership of facilitating the innovation process.

31.4.1 Opportunity Identification: Empathy Phase

The team first mapped different construction activities in India and the existing products (construction machinery) that performed these activities. The team categorized the opportunity areas into known and over-leveraged, known to all but leveraged by some, and unknown and unleveraged by the industry. Road construction emerged as one of the underleveraged areas, supported by the critical facts collected using secondary sources listed below.

- In India, more than 84% of the road length is the rural road. Out of 52.5 lakh kilometers of road network only 2.5 lakh kilometers consists of state highways, national highways and expressways, leaving a high percentage of the unpaved road length to be district roads and village roads [15].
- According to Pradhan Mantri Gram Sadak Yojana (PMGSY), a program launched by the former Prime Minister of India Mr. Atal Bihari Vajpayee in December 2000, construction of 3.7 lakh kilometers of new rural road construction was targeted, and a similar number of kilometers of road were to be upgraded by the year 2010 [16]. But even by the year 2014, only 60% of the target was met.

The project team connected with the Subject Matter Experts (SMEs) to investigate the reasons for incomplete target of road construction. A group of[2] Public Works Department (PWD) engineers spoke about the current state of rural roads in India and raised concerns about the lack of affordable mechanization solutions for rural

[2]Public Works Department is a government body responsible for the development and maintenance of the infrastructure in cities, towns and rural areas.

road construction. They arranged a live demonstration of the current road construction process and pointed out the mechanization gaps at various stages.

The speed of construction, quality of roads, and construction cost emerged as significant areas of improvement. Higher dependence on manual laborers, limited length of the road built per day, and the equipment's high price emerged as major challenges in rural road construction. The machinery available in the market could only be used for wider roads—the state highways and the national highways. These machines were expensive, and renting them was unviable for a contractor who made rural roads. The large size of the machines and limited access to remote construction sites made them impracticable.

PWD engineers supported the project team to connect to the engineers at other construction sites at different locations. These research expeditions and interviews with various stakeholders, including engineers, contractors, machine operators, and laborers, helped the project team understand the limitations of the current process and discover new product opportunities.

Claudia Kotchka, Vice President of Design at P&G, in her talk at IIT Chicago (2008), had mentioned a famous quote by a designer, "Don't ask me to build a bridge; Show me the canyon," highlighting the importance of identifying and framing the right problems to solve [17]. *Likewise, the project team approached the need identification stage differently than the standard NPD process. Instead of asking—"How can we make a better road equipment" which would have led the team toward modifying existing products, the team explored answers to the question—"How can we add value to the process of constructing rural roads."*

Combination of contextual interviews and observational techniques was used to understand the current process. The team spoke to the prospective customers—the road contractors and the other insight sources in the ecosystem.

31.4.2 Product Definition: Define Phase

The team had discovered a new whitespace (Fig. 31.2); there was a potential need in the market to address the application of rural road construction. The team synthesized the data gathered in the empathy phase, listed down the product requirements, and defined the desired customer value proposition. The desired solution had to reduce the cost of rural road construction by 30%, enable the contractors to construct one extra kilometer of the road every year (which translated into 15% additional income), and follow the desired construction standards as set up by the state government. The market price was targeted to be one-third the price of the heavier machines available in the market. The business case of the project looked optimistic. The Business Head approved the project proposal in the first meeting and asked the team to fast track the project.

The value proposition was challenging but aspirational and promising. The intention was to create a new product with a winning proposition. Having buy-in from the

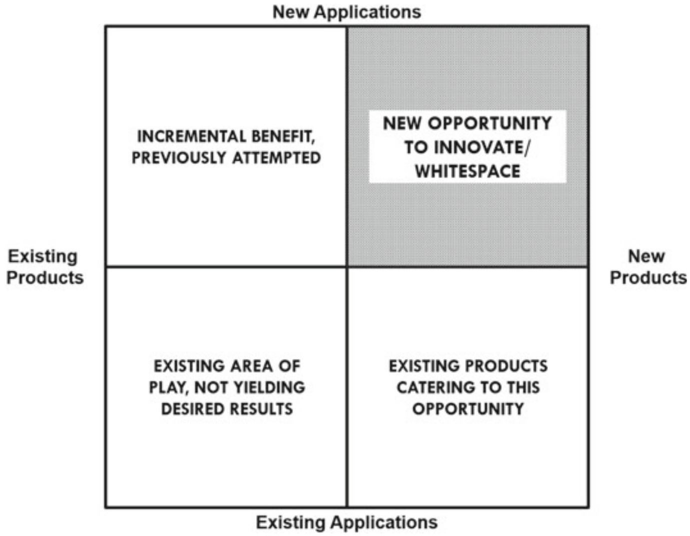

Fig. 31.2 Product opportunity matrix

leadership team is essential to drive innovation projects; in this case, the Business Leader believed in the design thinking process from the beginning of the project.

31.4.3 Product Development: Ideate Phase

The ideation phase was executed with a larger team, comprised of members from engineering, component sourcing, marketing, and customer care. The core team explained the problems of the current methods of road construction to the larger team. The new team members also travelled to some sites for a better understanding of the technical requirements. Together, the team challenged the fundamental assumptions of the conventional product development process to arrive at various ideas under two broad categories—ground-up development and development using available systems and components of other products such as BHL and tractor. The engineering team conducted the feasibility studies and worked out the engineering concepts to meet the desired specifications.

The product development team was highly motivated as they had an opportunity to learn new innovation tools and processes, and they were challenged to work on a new product that would be "industry first" and hence a matter of pride if they deliver it successfully.

31.4.4 Quick Prototyping: Prototyping Phase

The first prototype was built without any engineering drawing but with the objective of checking the intended functionality of the concept. The core team had identified a local fabricator who was providing customization services to other road and farm equipment customers. The company partnered with this expert fabricator to speed up development time and cut down the cost of the prototype. A team of engineers was stationed at the vendor locations until the end of prototype development.

In line with the design thinking principle of "Fail early to succeed sooner" [6], *the product development team deviated from the conventional method of moving from concept to virtual design using CAD to drawings to component development. The team developed the first prototype in a record time of one and a half months; this duration would be six to eight months in a regular project.*

31.4.5 Co-creation with Stakeholders: Testing Phase

Co-creation is defined as "a collaborative new product development (NPD) activity in which consumers actively contribute and select various elements of a new product offering" [18]. The PWD engineers, road contractors, and other ecosystem stakeholders that the team connected within the empathy phase were invited for prototype testing at the company premises. The prototype appealed to the stakeholders, and it was engineered close to their expectations. They suggested making few modifications for its extended application to district roads; changes were incorporated in the next prototype. The involvement of ecosystem stakeholders at every stage of the project had kept no room for failures.

In the testing phase, the team prioritized end-user and stakeholder inputs over the measurement of technical parameters such as endurance and durability. The mandatory tests were conducted only after the final design was signed-off by all the external stakeholders.

31.4.6 Business Impact: Results

The new approach to product development had resulted in positive vibes of the product even before its launch. The co-creation model also opened a new channel to reach out to the customers for sales, and the PWD engineers encouraged the contractors to consider this product. The product empowered the road contractors by delivering significant functional, social, and financial value.

Within two years of launch, the product created a new category in the market, generated revenue of Rs. 75 crores for the business and promised a revenue potential of Rs. 600 crores over the next 6 yrs.

31.5 Discussion

The paper compares two approaches to product planning in NPD, one that depends on more reliable and previously tried out processes to find new opportunities and the other using the design thinking approach that challenges the existing boundaries of the industry to find disruptive opportunities. The paper throws light on how organizations should identify new product opportunities and be open to venturing into the unknown market territories to innovate and drive business growth. The case study described in the paper demonstrates a fundamental shift in product planning strategy from focusing on "high volume and high competition products" in the familiar market space to "moderate to lower volume products with low competition, but high customer pull" in an unfamiliar market space. The findings of the paper also highlight the significance of involving the customers and key stakeholders of the ecosystem at every stage of the product development process. The paper briefly appraises the leadership traits of the business leader and the capabilities of the product planning team. Further research on significance of the leadership persona and organization structure favorable to driving innovation in NPD can be conducted to support the findings of this paper. The research findings are based on a specific example from a construction equipment OEM; however, the approach can also be evaluated for an automotive, consumer good, and other companies into the manufacturing sector.

31.6 Conclusion

The success of the business in the future has a direct correlation to the success of its new products. Product planning is a critical phase in the new product development process; product ideas originate here. Current product planning methods lead to incremental product innovation that has a shorter shelf life and hence limited market success. Design thinking can transform the way organizations develop products, services, processes, and business models. This process brings in a paradigm shift that enables organizations to find new product opportunity areas that can lead to high business impact. Long-term product planning with design thinking approach can define new product categories, develop innovative products give first-mover advantage, and hence a competitive edge to the companies. Consumer needs, market trends, internal capabilities, and business strategy need to be considered together when conceptualizing a new product. Business leaders should drive design thinking practice by initiating innovation projects, forming cross-functional teams, and by building capabilities in design thinking. Designers need to broaden their capabilities beyond the design process and develop knowledge to evaluate the business value of design.

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Chapter 32
Sit-Stand Transfer Difficulty Among Indian Elderly: Design Gaps in Related Assistive Technologies

Charu Maurya and Amarendra Kumar Das

Abstract Sit-to-stand (STS) transfer is one of the most common difficulties faced by the elderly. The present paper aims at identifying the STS transfer difficulty among Indian elderly and also focuses on the need for an appropriate STS transfer aid. The study was undertaken in 2018 on 200 elderly respondents having difficulty in STS movement. Self-structured questionnaire and other scales, viz. Mini-Mental State Examination (MMSE) and Timed Up and Go (TUG), were applied to assess the needs and problems of Indian elderly in STS tasks. The results show that among all the respondents a large number of females in the age group of 60–70 years had STS transfer difficulty. High body mass index (63.5%), osteoarthritis (69%), and vegetarian diet (58%) were noted among respondents. The impaired ability of sit-stand transfer affected their capacity in carrying out important activities of daily living. The elderly also faced trouble in STS movement particularly in western toilet (WT) and Indian toilets (IT). Walking stick users also found difficulty in STS tasks at many places. Thus, a need was identified to develop an assistive aid to help the elderly in STS transfer particularly in WT and IT, along with a modified walking stick, which could serve the dual purpose of mobility and STS transfer.

32.1 Introduction

The elderly population in India is 8.6% of the total population as per Census of India 2011 and is projected to be about 20% by 2050 [1, 2]. The aging population necessitates improvement in health and medical services, facilities and resources as old age is associated with various physiological changes, which result in infirmity, memory loss, the onset of diseases, etc. [3]

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A. Chakrabarti et al. (eds.), *Design for Tomorrow–Volume 3*,
Smart Innovation, Systems and Technologies 223,
https://doi.org/10.1007/978-981-16-0084-5_32

The difficulty in sit-to-stand (STS) tasks is one of the common disabilities that come with the old age. The ability to stand up from a sitting posture without any support requires coordination, balance, and muscular strength of lower limbs [4–6]. Multiple sensorimotor, balance, and psychological factors influence the STS transferability in old age [7]. The elderly with an impaired ability in STS tasks is at an increased risk of fall [8], loss of independence in performing basic daily activities such as toileting, dressing, transferring [9], sarcopenia [10], and mortality [11].

According to the Census of India 2011, one in every twenty Indian citizens aged 60 years and above is either physically or mentally disabled [12, 13] which is one of the main causes of STS movement difficulty. Locomotor and visual disability, the most common disability among the Indian elderly [1], can result in fear of fall [14] and hinder trouble-free STS tasks. The prevalence of knee osteoarthritis and backache, which are prime factors for sit-stand movement problems, has also been reported in approximately 22–39% [15] and 19.8% [16] of the elderly population in India, respectively. The above data indicates that a large section of the elderly population may be facing issues in independent sit-stand transfer tasks in their daily routine.

Several aids such as couch cane, raised seat, toilet frames, security pole, bed rail, armed walker, and stand up walker have been developed to assist the elderly in STS tasks while using toilets, bed, sofa, chair, etc. But most of these aids are not developed in India causing problems in adoption due to their cost, fitting, attitude, local needs, cultural and social suitability [17]. Lack of awareness and negative attitude are other factors that obstruct the usage of such aids [18].

Non-availability of affordable and ergonomic STS transfer aid in India forces the elderly to use a regular walker and walking stick for all STS tasks, including those where the use of such aids is unsuitable like Indian-type squatting toilet. Indian kitchen specifically in rural areas is another place where STS transfer can be strenuous to elderly women as they have to sit on the floor for cooking on *chulha* (stove). Thus, there is a need to develop affordable STS transfer aids to assist the Indian elderly in various daily activities.

32.2 Aims and Objectives

The identification of a problem and need gap analysis are the most important steps in an engineering design process. Therefore, the present study has been undertaken to identify areas/activities of daily living related to STS transfer where the elderly face difficulties. Other objectives of the study were to seek suggestions for design modification in existing aids being used and to ascertain the need for new aid to facilitate STS transfer.

32.3 Methodology

The methodology consisted of identifying the needs of the user regarding STS difficulty through a field survey and market search for gathering information about available products/aids.

32.3.1 Field Survey

Sample size and study location. The field study was undertaken on 200 respondents in Guwahati and Morigaon districts of Assam and Faridabad district of Haryana. The sample size was selected as per WHO recommendation which says that when anthropometric data is used as reference standard a minimum sample of 200 individual is needed [19].

Selection criteria. Convenient sampling method was adopted for the selection of the respondents based on the following selection criteria:

- Elderly over 60 years of age
- Not bedridden or extremely frail
- Intact cognitive function
- Certain difficulty in the sit-stand transfer where difficulty in STS transfer was defined as—a person needed some kind of support, i.e., armrest, nearby furniture, wall, etc., for standing up from a sitting posture.

Selection of tools. A self-structured questionnaire was prepared for acquiring information related to demographic characteristics and prevalent causative factors of STS transfer difficulty among the elderly. Needs and problems related to sit-stand movement trouble were also obtained. Body mass index (BMI) of the respondents was calculated using the standard formula [height (cm)^2/weight (kg)]. Height and weight of individual respondent were measured using a measuring tape and weighing scale respectively.

The other standard scales like Mini-Mental State Examination (MMSE) and Timed Up and Go (TUG) were also applied. MMSE [20] is a 30-point questionnaire (Hindi version) which is used to measure cognitive impairment among the elderly. The elderly who scored more than >19 were taken as respondents. TUG [21] is used to test the impairment in gait and balance which can result in fall. In this test, the subject stands up from a chair, walks for three meters, returns to the chair, and sits down with the time taken in the process being recorded. Duration of more than 14 s is considered as a predictor of fall in the near future.

Pilot study. Questionnaire and other scales were pilot tested on 20 respondents. To check the reliability, the same questionnaire was applied again on those 20 respondents after a gap of 15 days. Test–retest reliability was found to be more than 0.80

[22]. Few questions were also reframed to make it more understandable for the respondents.

From the data obtained, the quantitative variables were expressed in terms of frequency and percentages and response on ordinal scales in terms of mean scores. Cronbach's alpha was calculated for test–retest reliability. Statistical processing of data was done using SPSS v. 25.0.

32.3.2 Market Search

The information regarding available STS transfer aids, cost, features, etc., was collected through primary (visiting) and secondary (Internet) market search. The details about available assistive aids were gathered from e-commerce Web sites/apps (Amazon, Flipkart, eldereaseindia.com, seniority.in, vissco.com, etc.) and by visiting specific markets/retailers in New Delhi and Guwahati. The manufacturers and dealers of assistive aids were surveyed to know of their experience and the requirements of assistive aids for the elderly.

32.4 Results

Table 32.1 shows the demographic characteristics of the respondents having difficulty in STS transfer. A large number (58%) of the respondents were females, with the majority (60.5%) in the age group of 60–70 years with a mean age of 69.38 years. A vegetarian diet was the primary food habit of the majority (58%) of the elderly respondents. Knee osteoarthritis (69%) and backache (25%) were commonly observed among the respondents contributing to STS trouble. Despite this, a majority of the respondents perceived their health to be either good (32%) or fair (39%). With respect to BMI, only 36% of respondents had normal BMI whereas the majority of other respondents were either overweight (30%) or obese (23.5%) causing difficulty in STS transfer. The respondents also performed the Timed Up and Go test where 50.5% of respondents took more than 14 s for completing the test indicating a possibility of a fall in future.

Information about the STS movement performed by the respondents and their experience of comfort and fear in the STS task were also gathered Table 32.2. Results revealed that majority of the respondents were comfortable in STS transfer from the chair, bed, western toilet (WT) and Indian toilet (IT). Indian toilet is a type of toilet where a person sits in a squat posture while defecating while sitting type toilets are often referred to as western toilets Fig. 32.1.

Based on the frequency of use in the daily life of an individual, particularly in old age, STS transfer using chair, bed and in WT and IT were selected. An interesting observation from Table 32.2 is that the elderly responded in affirmative about the need of STS support when it was available like in case of the chair [65% (armrest)] and

Table 32.1 Demographic characteristics of the respondents

Demographic characteristics	Respondents	
	No	Percentage
Age (years)		
60–65	76	38.0
66–70	45	22.5
71–75	43	21.5
76–80	21	10.5
More than 80	15	7.5
Mean + SD	69.38 + 7.21	
Sex		
Male	84	42.0
Female	116	58.0
Marital status		
Married	127	63.5
Widower/widow	73	36.5
Residential status		
Living alone	3	1.5
With spouse	3	1.5
With spouse and children	124	62.0
With children	57	28.5
Old age home	13	6.5
Food habit		
Vegetarian	116	58.0
Non-vegetarian	74	37.0
Eggetarian	10	5.0
Health perception		
Excellent	2	1.0
Very good	13	6.5
Good	64	32.0
Fair	78	39.0
Poor	43	21.5
Current disease/discomfort		
Diabetes	25	12.5
Osteoarthritis	138	69.0
Backache	50	25.0
Vision	4	2.0
Hearing	9	4.5
Cardiovascular	27	13.5

(continued)

Table 32.1 (continued)

Demographic characteristics	Respondents	
	No	Percentage
Any other	105	52.5
BMI		
Underweight (<18.5)	20	10.0
Normal (18.4–24.9)	73	36.5
Overweight (25.0–29.9)	60	30.0
Obese class I (30.0–34.9)	32	16.0
Obese class II (35.0–35.9)	9	4.5
Obese class III (>40)	6	3.0

Table 32.2 Sit-stand transfer activity of the respondents

	Support needed (%)	Comfort level (mean score)	Fear of fall (mean score)	Suggestion for a mechanism/aid (%)
Chair				
Total respondents	65.0	2.25	2.72	26.5
Walking stick users	90.90	1.97	1.54	81.81
Bed				
Total respondents	53.5	2.25	2.72	46.5
Walking stick users	90.90	2.02	1.54	87.50
Western toilet (WT)				
Total respondents	41.87	2.13	2.58	71.88
Walking stick users	67.85	1.93	1.63	72.25
Indian toilet (IT)				
Total respondents	39.58	2.50	2.54	75.75
Walking stick users	80.00	2.20	2.00	83.33

Note Mean score was calculated on 3 points Likert scale
Comfort level—3 (very comfortable), 2 (somewhat comfortable), 1 (not comfortable)
Fear of fall—3 (never), 2 (sometimes), 1 (often)

Fig. 32.1 Sitting type western toilet (L) and Indian type squatting toilet (R)

bed [53.5% (raised height)]. Where such support was not available (but needed) like, in case of WT and IT, only 41.87% and 39.58% of the respondents suggested such a need. However, after showing examples of STS support in WT and IT, majority of respondents expressed interest in a mechanism that can assist in STS movement from WT (71.88%) and IT (75.75%). This indicates that in absence of a visible solution, it may be difficult for the users to identify a need correctly. Hence, it becomes an engineering design requirement to address such a need gap adequately.

A majority of the walking stick users reported having discomfort and fear of falling in STS transfer at all the four places [chair (90.90%), bed (90.90%), WT (67.85%), IT (80.0%)]. Hence, a majority of the walking stick users expressed interest in an STS mechanism that can support them at all places for trouble-free sit-stand movement.

Figure 32.2 illustrates the types of support used by elderly respondents in STS transfer. Among the respondents who needed support in STS transfer from the chair, the majority used armrest. In the case of bed, the height of bed including a bed mattress assisted them in getting up. STS transfer task got more threatening in case of WT and IT where no such support is provided in the design, compelling users to take the support of the wall, floor, nearby door, window, or water tap.

To ascertain the awareness level of respondents regarding available STS transfer aids, images of few popular such aids were shown to them. Figure 32.3 shows an abysmally low level of awareness regarding available aids among the respondents. Very few respondents were aware of the grab bars whereas awareness level was quite low for other available aids as well.

The market survey showed that mostly the aids like walking sticks, walker, wheelchair, crutches, belt and braces and mobility trainer were manufactured for the elderly in India and sold through retail shops, e-commerce portals, and exhibitions. Aluminum and mild steel (MS) were the most preferred material for making aids because of their lightweight, durability, and cost. Though no such aid, which supports in STS transfer, is currently made in India, the manufacturers showed interest in making such aids if they got satisfied by the feasibility and compatibility of the design.

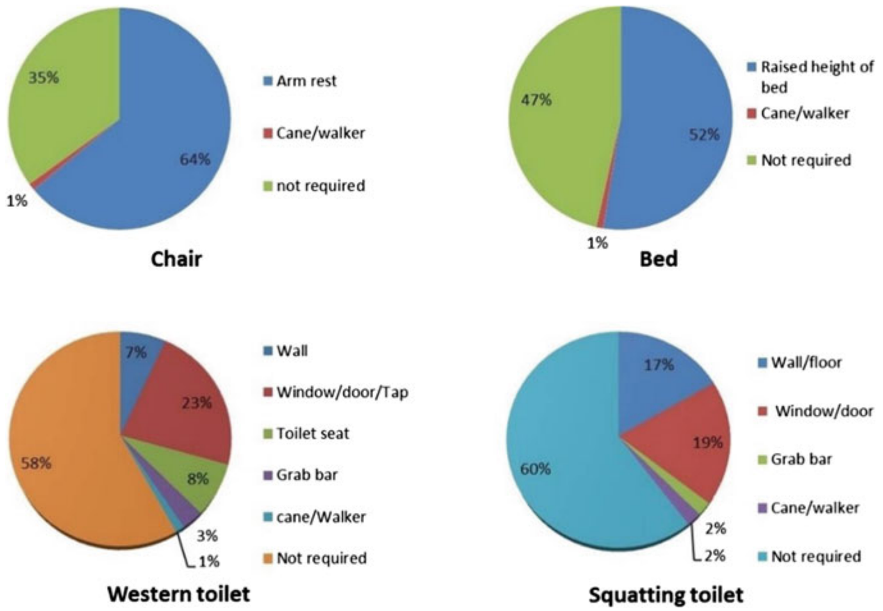

Fig. 32.2 Support required by the elderly respondents in STS transfer

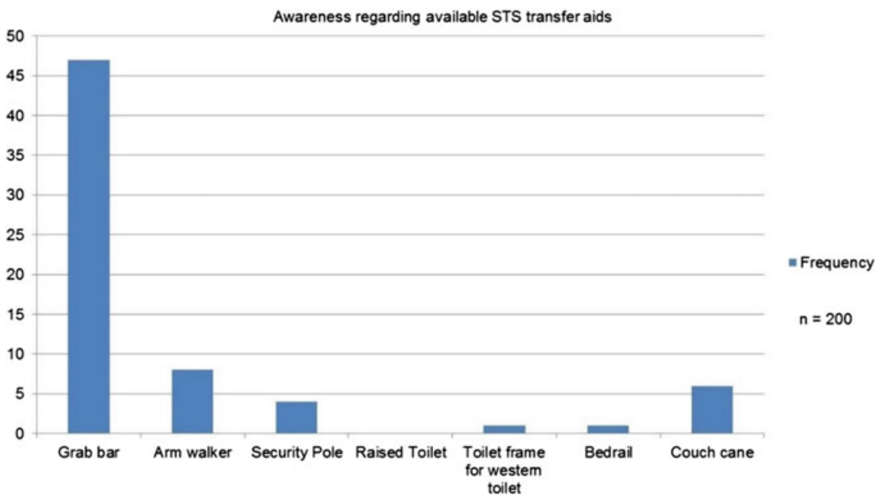

Fig. 32.3 Awareness regarding available STS transfer aids among the respondents

32.5 Discussion

Majority of the elderly respondents in the study facing STS difficulty were females. Boyan et al. in their study also reported that females are prone to STS difficulty due to knee pain caused by differences in hormonal balance, knee anatomy, and kinematics [23]. The ratio of female to male with osteoarthritis was observed to be 4:1 by Sangha [24]. High prevalence of knee arthritis was also reported in women in China (female 15.1% vs. male 6.3%) [25], United States of America (female 13% vs. 10% male) [26], and India (female 55% vs. male 45%) [27]. Reduced strength in lower legs and knees can cause trouble in STS tasks. Nutrition and exercise are important to maintain healthy limbs. Vitamin D is a nutrient required to maintain good bone health [28]. It can be obtained primarily through sunlight and animal sources [29]. Low exposure to sunlight due to lifestyle changes and dependence on a vegetarian diet can cause deficiency of this vitamin among vegetarians [30] which can lead to a decline in bone strength resulting in knee pain and back pain [31]. The findings of our study also showed similar results as the majority of the respondents having STS transfer difficulty were vegetarians.

The presence of other factors responsible for causing STS transfer difficulty was also analyzed. Obesity was measured by calculating the BMI of the respondents. Earlier studies have observed that BMI influences independence in walking due to differences in temporospatial gait parameters [32, 33]. In another study, overweight and obese people were found to be at a greater likelihood to develop knee pain [34] which can affect lower extremity functions [35]. More than 50% of the respondents of our study were found to be either overweight or obese and were suffering from knee osteoarthritis, which is in agreement with the above findings.

Though assistive aids help in performing specific activities and make the elderly more independent, lack of awareness and discrepancy in cost, fit, local need, and cultural suitability hinders the utilization of available aids. The results are consistent with the findings of Kumar et al. [18].

32.6 Design Implications

The findings of the study emphasize the difficulty faced by the elderly in STS movement. In India, two types of toilets, viz. western type sitting toilets and Indian-type squatting toilets, are popular. Sitting style western toilets are preferred by many in old age as sitting is easier to perform than a squat posture of Indian toilets. The support in the form of grab bars, security poles, bed rail, raised seat, toilet frame, etc. (Fig. 32.4), makes the sit-stand transfer tasks comfortable. But the factors of availability, accessibility, affordability, and suitability restrict the usage of these aids as most of the aids are not developed in India [17]. Hence, the problems faced by the Indian elderly particularly in toilets demand the attention of engineering design and research community. To assist the STS movement, an innovative design of commode

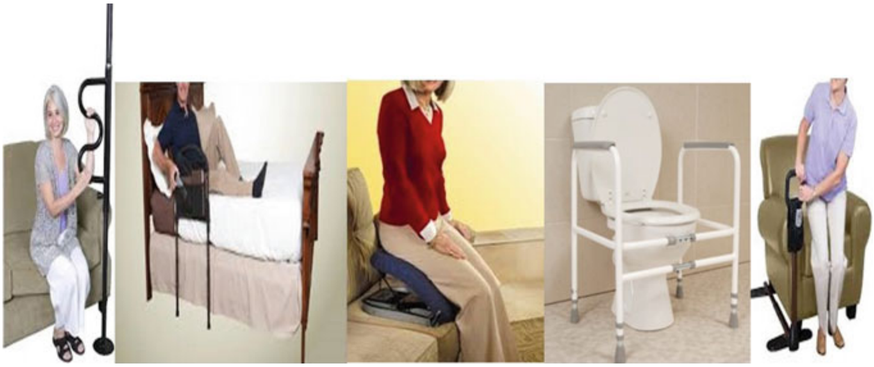

Fig. 32.4 Sit-stand transfer aids for the elderly: left to right—security pole, bed rail, raised seat, toilet frame, couch-cane. Images adapted from https://www.eldereaseindia.com

with an inbuilt armrest similar to the chair may be developed. A pair of portable armrests that can be carried and used whenever required may also be useful.

Indian squatting toilet is the most common type of toilet in India, particularly in rural areas. Squatting in the toilet is also getting popular globally as it positively influences bowel movement time, straining pattern, and complete evacuation of bowels [36]. It also relieves constipation and hemorrhoids [37, 38]. Few products have been designed and developed globally which assist in simulating squat posture in the western toilets such as squatty potty [39], Lillipad squatting platform [40], and WC health [41]. Squatease is another improved design of squat toilet for those who squat on their toes and was widely used by millions during Kumbh Mela (religious gathering) held in Praygraj in 2019 [42]. In squat posture, the whole body weight is on the legs which can be strenuous in the old age. Moreover, the transfer from squatting to standing is difficult to perform with gradually declining muscular strength. Therefore, design intervention is needed to enable our aging population to perform a basic activity of daily living with dignity and comfort.

The findings also emphasize the plight of walking stick users who want assistance at almost every place, i.e., chair, sofa, bed, and toilets. Installation of available assistive aids such as grab bars at every place neither feasible nor affordable to most. Moreover, it cannot solve the STS problem when an elderly goes out of his home. In such a scenario, a portable light device that can be carried at all places will be helpful to them.

32.7 Conclusion

The majority of elderly respondents having difficulty in STS movement were in the age group of 60–70 years indicating the need for supporting aids at an early stage of late adulthood for a large section of the Indian population. As knee osteoarthritis and high BMI were observed among elderly having STS transfer difficulty measures may be adopted at an early stage to mitigate/reduce the negative impact of such factors. To solve the present-day problems of STS transfer, an aid that caters to the cultural, social, and economic needs of the elderly should be developed. The aid should also reduce the discomfort on knees and back muscles and should be made of lightweight high strength material as a large number of elderly respondents reported high BMI and osteoarthritis.

STS transfer aid in WT and IT is a suggested requirement. Sit-stand transfer in WT has become quite comfortable as a number of aids are now available. But the lack of awareness of such aids hampers their diffusion and adoption. Hence, creating awareness about these aids can give benefit to the respondents provided the aids are modified according to cost, fit, culture, and local need. A section of elderly respondents also expressed a requirement for aid for the Indian type of toilet that can be comfortable for squatting posture. Older respondents who use walking stick encounter sit-stand movement trouble at almost all places where STS transfer is needed. Therefore, a modified walking stick that can also serve in STS transfer at all places should also be developed.

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Chapter 33
Understanding and Finding Issues Related to Root Canal Treatment Procedure from a Design Perspective

Priyabrata Rautray, Vikas Sahu, Nibedit Dey, and Deepak John Mathew

Abstract Root canal treatment (RCT) is one of the standard dental procedures commonly done by dentist throughout the world. It involves removing infected pulp tissue from the tooth's pulp chamber and canals, cleaning and shaping of the root canals, disinfection of the hollow canal, and filling it with "gutta-percha" or root canal sealer. Nonetheless, it is found that many of the RCT procedures fail due to inadequacies like missing of root canal orifices, improper cleaning, or difficulties in locating the orifice. In most of the case, the failure of the treatment leads to persistent pain and secondary infection, which ultimately force the patient to undergo a subsequent RCT or extraction. Several clinical immersion sessions were conducted at MNR Dental College and Hospital and Malla Reddy Institute of Dental Sciences to understand the issues and problem-related to this root canal treatment. They were followed by an online questionnaire survey to gather a broader perspective of medical practitioners. After a year-long study, we were able to identify a few areas where design intervention can lead to the overall improvement of the root canal treatment and also can improve the workflow and comfort of the dentist. This research paper documents and highlights the research to find an unmet clinical need. This research project, though in its nascent stage, has shown great potential and with further research and development can lead to the development of a medical device that helps to improve the efficiency of the root canal treatment.

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A. Chakrabarti et al. (eds.), *Design for Tomorrow–Volume 3*,
Smart Innovation, Systems and Technologies 223,
https://doi.org/10.1007/978-981-16-0084-5_33

33.1 Introduction

India, as a developing country, faces a lot of challenges in the health sector and especially dentistry has always been an under-resourced profession with the least amount of government funding. Even though India has one-third of the dental colleges of the world, the disparity of oral health provider to population is relatively high [1]. This situation calls for a new innovative solution to make dentistry more efficient and economical. Oral health is a part of fundamental human rights recognized by the World Health Organization (WHO) and the World Dental Federation (FDI). According to the Global Burden of Disease, oral disease is the most prevalent disease of humans [2, 3]. India is the second most populous country after China, with its distinct ethnic, linguistic, geographic, religious, and demographic feature [4]. The majority of the Indian rural population has limited access to state of the art oral health care where the dentist-to-patient ratio in rural settings is 1:250,000 compared to 1:10,000 in urban environments [5, 6]. Only 5% of dentists work in public services, and the rest 95% are private practitioners providing health care on a fee for service manner [7]. Maximum of the patients either delay the treatment or rely on traditional practitioners "quack" as being the only affordable source [8, 9]. Dental Caries, periodontal disease, and oral cancer are significant categories of oral disease. 50–85% of the population is affected by dental caries, and 60–90% of the general population is affected by the periodontal disease [10].

As a designer and medical innovators, we followed the Stanford biodesign process to understand the challenges and arrive at an unmet clinical need statement. We followed the following steps: strategic focus, need exploration, and need statement development. We did our clinical immersions at MNR Dental College & Hospital, Malla Reddy Institute of Dental Sciences and private dental clinics to understand the potential unmet clinical need of dentistry in India. The importance of clinical immersion, methodology, and observations and findings are explained in Sect. 33.2. After finding the key area of research and the aim of the project was established—a detail literature review of the root canal procedure was done as highlighted in Sect. 33.3. This is followed by Sect. 33.4, which includes users' survey to understand the users' needs, wants, and concerns regarding the procedure. Finally, the research paper concludes with a broader discussion and conclusion in Sect. 33.5.

33.2 Clinical Immersion

Development of medical/clinical solutions and devices is a huge challenge which necessitates not only user understanding but also interdisciplinary understanding. To design a medical device, solution or healthcare delivery system, engineer and designers lack clinical experience. They require help in understanding and finding needs, especially in complex medical and healthcare systems [11–13]. False identification of needs may lead to poor design or unoptimized use of device or system [14].

The first step in the user-centric design process is to identify needs where designers and innovators engage and empathize with stakeholders. Doctors, patients, nurses, paramedical staff, administrators, etc., constitute our stakeholders for this project. This process of empathy and user study can be defined as the clinical immersion process [15, 16]. The end goal of this stage is to identify the unmet clinical need using an empathic approach around healthcare provider and receiver needs, both implicit and tacit [17, 18].

33.2.1 Methodology

To identify the unmet clinical need and to better understand the salient features of dentistry, biodesign methodology was followed. The clinical immersion process started with a careful selection of dental hospitals and clinics within the range of 50 km from IIT Hyderabad were done. MNR Dental College and Malla Reddy Institute of Dental Sciences were identified as academic hospitals, and private clinics around Sangareddy district and Rangareddy district (e.g., Lingampally, Gachibowli, Hitec City) were considered for the clinical immersion. Written approvals were taken from college administration for the immersion program to observe the live treatment procedures. Similarly, consents were taken from the private practitioners of independent clinics to observe their clinical practice. For detail documentation and future study, video recording and photography were done for the whole process, followed by an in-depth discussion with the dentists. Figure 33.1 shows the still images of the clinical immersion. The clinical immersion was divided into four phases:

- Phase 1: Identify the potential domain of dental clinical need.
- Phase 2: Create a list of the possible area of interest.
- Phase 3: Understand the modalities of the solutions.
- Phase 4: Refine and identification of unmet clinical need.

33.2.2 Observations

Phase 1

The initial period of immersion was done to observe general practice methodology in oral health care, and the following were the observations:

Chief complaints of the patients.

- The most common complaint from the patient is for (1) dental pain followed by (2) missing tooth and (3) bleeding gums and mobile tooth.

Fig. 33.1 Images showing the clinical immersion process

- Most of the cases patients come with severe and acute dental pain, and few of them associated with extraoral swelling.
- Patients also come with complaints of missing teeth and want the replacement for the difficulty in eating and aesthetic concerns.
- Patients often complain of bleeding from gums and loose teeth.
- Some of them also complain of bad breath.

Treatments modalities for a different problem

- For dental pain most treatment modalities are
  - Medication—for suppression of infection, inflammation, and pain.
  - Root canal treatment—for non-destructive/conservative approach to preserving the tooth.
  - Extraction—For removal of non-restorable tooth.
- For missing tooth, various modalities like customized removable and fixed prosthesis are made for the patient.
- For bleeding gums, source of inflammation is removed by mechanical intervention like ultrasonic scaling, hand scaling, and root planing
- For bad breath/halitosis, oral prophylaxis is done

After the completion of Phase 1, we selected dental pain as the domain for further research.

Phase 2

In this second phase, we started with dental pain as the area of interest and explored more into the cause and solution to the issue.

Understand the modalities of approach for the selected domain

- The treatment approach for dental pain
  - Maximum of the cases dentists insist on doing root canal treatment to preserve the tooth.
  - First appointments generally involve "access opening and formocresol dressing" to immediately subside pain followed by medication.
  - For a tooth with gross damage, extraction is suggested.
  - Seldomly dentist do single sitting RCT procedure.
  - Medication is suggested to subside infection and pain.

Consequences of post clinical intervention

- Root canal treatment
  - The tooth is saved, and the patient can chew and eat normally.
- Extraction
  - The tooth is lost, and the patient feels inefficient to chew food and require prosthetic replacement of the tooth

From Phase 2 research, we found out that root canal treatment as the core focus area for need identification.

Phase 3

In-depth analysis of the root canal treatment procedure was done to improve the understanding and find a unique area of design intervention.

Understand the modalities of approach for the procedure

- An access opening is done by airotor after anesthetizing the tooth area.
- Root canal orifice is identified, and the canal is negotiated.
- Cleaning and shaping of the root canal are done by endodontic "File."
- The canal is filled with inert material "gutta percha," and the tooth is restored by placing cement and "crown."

The finding of root canal orifice was identified as the niche problem area in root canal treatment where most of the dentists face difficulties.

Phase 4

Understand the modalities of approach for the procedure

- Three methods to identify the canal orifice.
  - Tactile sensation using an endodontic file.
  - Visual inspection—direct vision or indirect vision using a dental mirror.
  - To enhance visibility, magnification instruments are used like dental loupes and microscopes.
  - X-Ray image.

Thus, after following the four phases, we found that root canal visualization was the fundamental problem area that can be addressed by innovative design intervention.

33.3 Root Canal Procedure

In dentistry, root canal treatment is one of the most common treatments. Still, it is prone to failure due to inadequacies like missing of root canal orifices, improper cleaning, or difficulties in locating the orifice. Root canal treatment which is also called endodontic treatment is done when the tooth pulp becomes infected and generally lead to pain, abscess in the associated region, as explained in Fig. 33.2.

The infection can have several reasons such as deep caries, repeated dental procedures on the tooth, faulty crowns, or a crack in the tooth [19–25]. The basic objective of endodontic treatment is to remove the tooth pulp through mechanical and chemical methods and clean the pulp chamber and root canal and fill the inert filling material in the root canal system (Fig. 33.3). One of the objectives of root canal treatment is identification, location, and cleaning of the root canal [26–29]. The root canal system of a tooth is quite complex in its anatomy, especially in molars, as highlighted in Fig. 33.4. Inability to identify and inefficient cleaning of root canal treatment is one

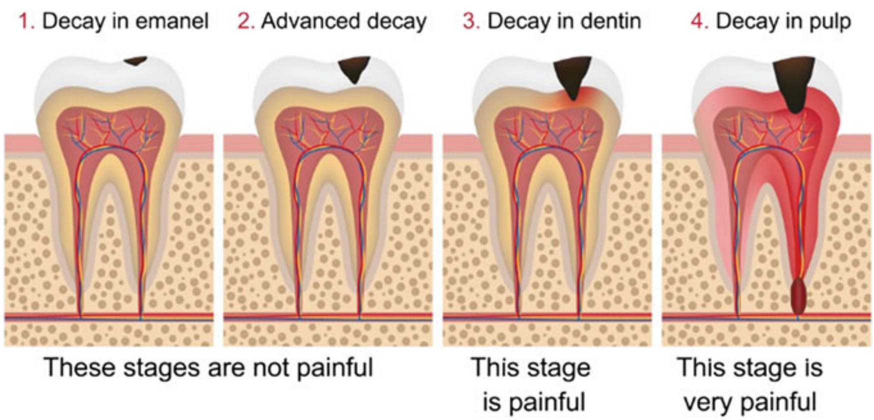

Fig. 33.2 Cause of pain in a tooth (https://addisondentalil.com)

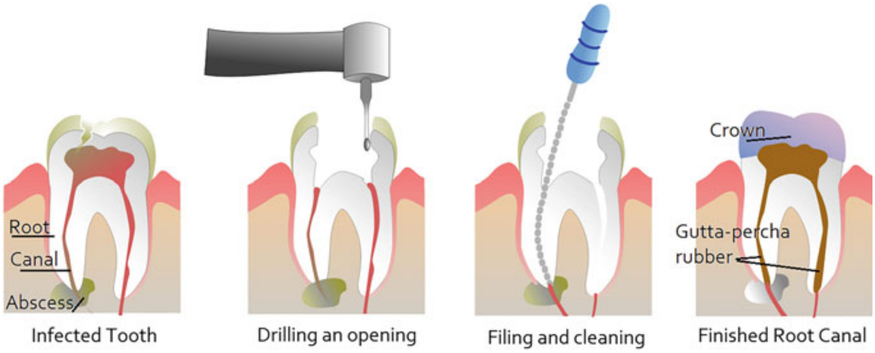

Fig. 33.3 Basic procedure of root canal treatment (https://medicoverdental.hu)

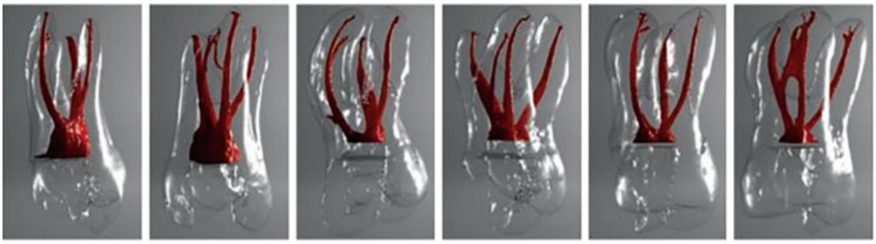

Fig. 33.4 3D models depicting the internal anatomy of maxillary molars [33]

of the major causes for the failure of root canal treatment [30–32]. Failure of the root canal is the second most common cause of tooth loss after periodontitis [26].

33.4 User Survey

Innovators and designers use different techniques and methodologies to develop new products, and user survey is one of the essential ways to create more user-centric and commercially successful results. In this paper, we have used an online survey to validate and gain insights from prospective dentists in India. With the evolution of medical technologies, the whole experience of dentistry is being redefined. This survey was generative research, where users' needs and concerns inform the design team in the early phase of the design process. The online questionnaire was divided into three segments, as shown in Fig. 33.5.

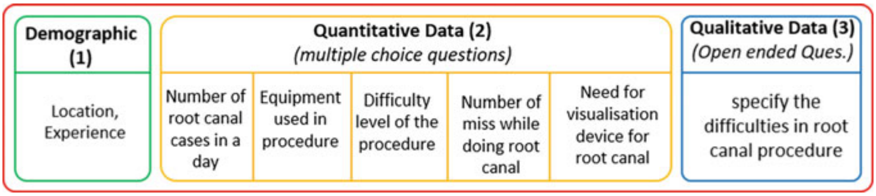

Fig. 33.5 Questionnaire design

33.4.1 Data Representation and Finding

Most of the respondents for our survey were from Hyderabad zone followed by the Mumbai zone and Delhi NCR. Most of our users were at the beginning of their clinical practice with a fair amount of experience, as shown in Fig. 33.6.

Figure 33.7 highlights the numbers of root canal cases handled daily and the instruments used for the procedure.

The survey showed that almost 80% of the participants find the root canal treatment procedure to be not so easy or difficult without and magnification device to visualize. Highlighting that root canal treatment requires more effort from the dentist as it is complicated than other dental procedure. Moreover, 34.4% of participants

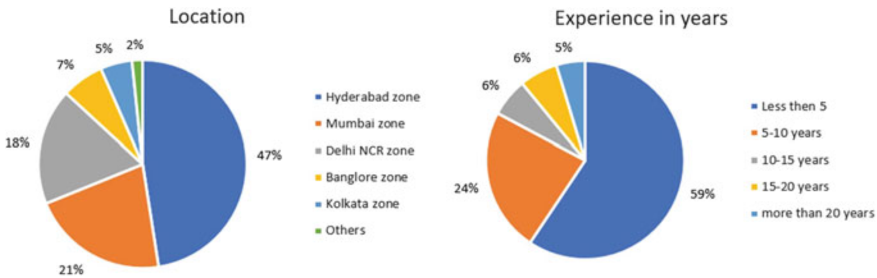

Fig. 33.6 Pie chart showing the distribution of location and experience in years

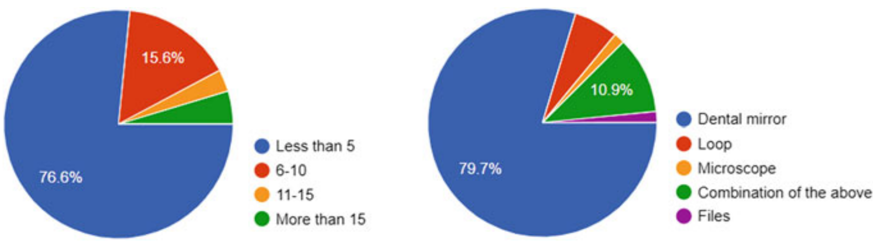

Fig. 33.7 Numbers of root canal cases daily and instruments used

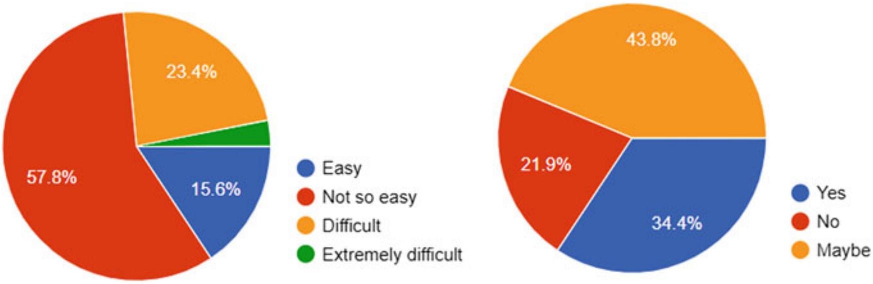

Fig. 33.8 Level of difficulties without magnification and complication in the treatment

face complication while finding the canal during the procedure, and 43.8% of the participants sometimes face similar problems, as highlighted in Fig. 33.8.

When asked about the ease of finding root canals of molar teeth, 56.3% find it not so easy, and 18.8% find it difficult. Thus, we can infer that root canal procedure for molar teeth is more challenging as compared to others. More than half of participants verified that they have come across a few instances of missing root canals and 20.3% said the case of missing root canal during the procedure is quite common issues of the RCT procedure as shown in Fig. 33.9.

Finally, an overwhelming percentage of participants (87.5%) felt that there should be a magnification and visualization device to view the pulp chamber of the root canal for improving the success of finding the root canals and completing the RCT procedure successfully. Thus, after completing the users' survey and clinical immersion, our research highlighted the need for a visual assistive device that would assist the dentist in improving the efficiency and success of RCT procedure (Fig. 33.10).

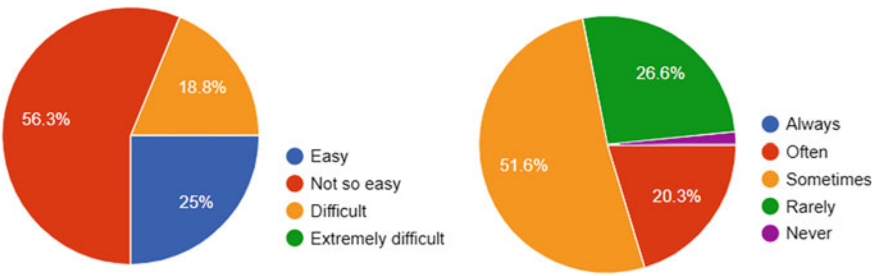

Fig. 33.9 Level of difficulty for molar teeth and cases of missing root canal

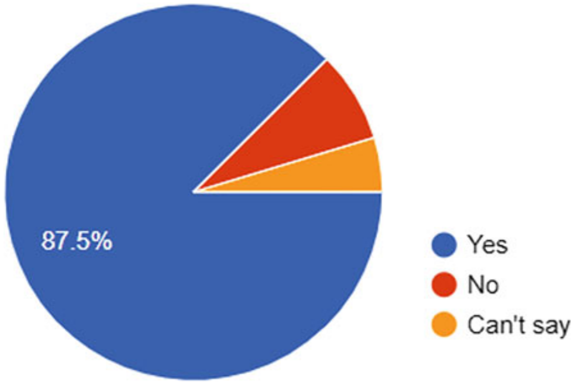

Fig. 33.10 Need for a device to see the pulp chamber clearly

33.5 Discussion and Conclusion

Understanding the unmet needs of a medical procedure and development of medical devices using the design process is one of the safest ways to design and innovate medical device or solution, with a thorough clinical immersion to understand the medical procedure, users' needs, concerns, and wants. Online surveys were conducted to gain further insights into the general practice modality of the dentists. The clinical immersion process provided us better insights to identify the few of the significant challenges faced by dentists in their clinical practice. And after an in-depth study, it was found that visibility of the pulp chamber and root canal orifice is one of the major challenges faced by the dentists. The problem of visibility not only increased the time of the RCT procedure but also lead to failure due to inadequacies like missing of root canal orifices, improper cleaning, or difficulties in locating the orifice. Even though there are various devices available like endodontic microscopes and loups, their usages are limited by multiple reasons like affordability, required training, and comfort [34].

With the identified unmet clinical need for the visualization for pulp chamber and root canal orifice, there is a specified requirement to develop the solution around it. The solution developed should not only focus on visualization but also align with human-centric design approach and associated parameters like affordability, adaptability, etc.

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Chapter 34
Agro-based RC Aircraft

Kiran Kumar Tumbagi and Nishanth Pradyumna

Abstract The paper presents an agricultural-based fixed-wing unmanned aerial vehicle (UAV) which is capable of spraying chemicals (pesticide/fertilizer). Aerial pollination, aerial sowing of seeds and similar tasks can be accomplished by effortless swapping of the payload. It makes these agricultural tasks simple, cost-effective and time-efficient. UAV reduces contact with pesticide during spraying and also eliminates the use of manned aircraft. Thus increases the safety of humans by preventing the ill effects of chemicals (pesticides) and fatal accidents of manned aircraft. Paper emphasizes the importance of UAV in the agricultural sector to ensure human safety and to increase the efficiency of farming. It incorporates aircraft design, specifications, performance, flight envelope, flow analysis, structural analysis and its ability to accommodate sufficient payload for the purpose. It also encapsulates the cost breakdown to analyze its affordability and cost-effectiveness.

34.1 Introduction

Pesticides/insecticides are used to avoid damage by pests/insects. According to a report released on 9 June 2020, the locust swarm was responsible for crop infection in 2, 80,000 hectares across 13 countries before arrival in India [1, 2]. Crop monitoring is essential to look after the health of crops. These tasks are important in agriculture to get good quality and quantity of yield. While performing these tasks by using man force is tedious and has ill effects on health, carrying out the same task using manned aircraft is inefficient. The most common problems with their statistics are stated below,

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A. Chakrabarti et al. (eds.), *Design for Tomorrow–Volume 3*,
Smart Innovation, Systems and Technologies 223,
https://doi.org/10.1007/978-981-16-0084-5_34

- Excessive or long-term exposure to pesticides have major ill-effects on human health and can cause death: data gathered from the Directorate of Plant Protection, Quarantine and storage, Government of India, during 2005–06 to 2009–10, total pesticides consumed in India is 210,600 metric tonnes of technical grade material [3]. While pesticides are good for plants, they are harmful and have a catastrophic impact on human health including sterility, Alzheimer's and Parkinson's disease, hormone disruption, cancer, birth defects, neurological effects and death. Every year, an average of 200,000 people perishes by coming in contact with pesticides [4, 5].
- Using manned agricultural aircraft makes the work faster, avoids contact between chemicals (pesticides) and human but they are not suitable in all localities for many reasons including an insufficient and/or unsuitable runway for take-off/landing, a lot of obstruction due to poles/trees, cost-effectiveness and most importantly it comes with a high risk of fatal accidents: According to agaviation magazine of National Agricultural Aviation Association (NAAA, USA), US government investigative agency-NTSB reported that the year 2017 had 67 agricultural aviation accidents [6]. A report on the safety of agricultural aircraft operations by the national transport and safety board showed that the year 2013 had 78 accidents [7].

Unmanned aerial vehicles (UAVs)/remote controlled aircrafts (RC Aircrafts) are the solutions to the hitherto stated problems. The average human walking speed is about 4.5 kmph [8]. UAV offers complete mobility to fly across the field and is cost-effective. It also provides human safety by preventing exposure to pesticides, in case of spraying by farmers/workers, and avoids fatal accidents of manned agricultural aircraft (involving onboard pilot). While monitoring the health of crops grown over vast area requires considerable time and effort, UAV with suitable equipment makes it simple and effortless. The employment of unmanned aerial vehicles in the agricultural sector can benefit conspicuously, and it has the flair to improve economic and environmental sustainability, plant knowledge, the efficiency of input [9].

Many designs, optimizations and devices were found during the literature survey to solve the stated problem statements but were outdated and relied on either ground vehicle whose mobility is limited amidst crops, multi-rotor UAVs whose performance and flight time are proven to be poor when compared to fixed-wing UAVs, or relied on manned aircraft. One of them was conceptual design and CFD analysis of a new prototype of agricultural aircraft [10] published in 2018 which presents a detailed methodology for designing the aircraft, numerical approach of the aerodynamic simulations and discusses the results of lift and drag coefficients and vortices distribution of a manned aircraft.

34.2 Methodology

A systematic approach is followed to obtain the optimal design. The flowchart in Fig. 34.1 illustrates the process of designing the UAV in brief. Mission analysis being the first step of the process and CAD design and analysis being the last. Each step of the process is explained in detail below.

34.2.1 Mission Analysis

Thorough understanding of problem statements allowed us to set the objectives for the project. Problem statements are stated in the Introduction. Objectives are to design and analyze an aircraft which is suitable for the agricultural purpose to spray chemicals, monitor crops, etc. Hence, improving and advancing the farming techniques to save time and complete the work efficiently using UAV.

34.2.2 Design Requirements

An aircraft with easy swappable payload mechanism can accommodate different payloads such as pesticide spraying mechanism, crop-monitoring equipment, land surveying equipment, etc., with maximum weight of 4 kg.

34.2.3 Weight Estimation

Estimation of weight is essential and plays a vital role in configuration selection of the airfoil, wing plan-form, wing dimensions and propulsion system. Net mass was estimated to be 4.8 kg, and the net moment due to components is -0.002 N-mm about C/4 where CG of fully assembled aircraft is positioned. Algebraic sum of net-moment due to components and maximum aerodynamic moment experienced is considered to balance the moment of the aircraft by horizontal stabilizer (Table 34.1).

Fig. 34.1 Flowchart of methodology

Table 34.1 Weight estimation and moment balance sheet

Components	Mass (in kg)	X_{CG} (in mm)	Moment (in N-mm)
Motor + Propeller	0.254	−326	−812.307
Battery + Receiver	0.696	−134.5	−918.334
Electronic speed controller	0.068	−251	−167.437
2 × Aileron servo	0.038	0	0
Elevator servo	0.019	830.2	154.741
Rudder servo	0.019	830	154.704
Fuselage + Boom	0.550	10	53.955
Wing	0.250	20	49.050
Main landing gear	0.14	216	296.654
Nose landing gear	0.6	−100	−588.600
Payload	2.000	0	0
Tail	0.200	906	1777.572
Net mass	4.834	Net moment	−0.002

Table 34.2 Airfoil configuration selection

	DAE-31	S1223	Eppler 420
Coefficient of Lift	Less	High	Moderate
Coefficient of drag	Less	High	Moderate
Stall angle	Lower	Higher	Intermediate

34.2.4 Configuration Selection

Shortlisted configurations are compared, and the configuration with more number of the desired characteristic is highlighted (in bold, italics) and chosen.

34.2.4.1 Airfoil

Airfoils with suitable characteristics are chosen and shortlisted from the website, airfoiltools.com; this website is a collection of numerous airfoils with their characteristics. *S1223* has high coefficient of lift and high stall angle that suits the purpose to lift more payload. The downside of high drag coefficient is compensated by high lift coefficient and higher stall angle (Table 34.2).

34.2.4.2 Wing Plan-Form

Rectangular, unlike other plan-forms, it does not require varying the size of structural supports inside the wing (I-sections, L-sections, etc.). It is easy to manufacture,

Table 34.3 Wing Plan-form configuration selection

	Elliptical	Tapered	Rectangular
Lift	Moderate	Less	High
Drag	Less	Moderate	High
Ease of fabrication	Hard	Intermediate	Easy

Table 34.4 Tail configuration selection

	V	U	Inverted-T
Structural strength	Less	Moderate	More
Efficiency	Less	More	Moderate
Weight	Heavy	Moderate	Light

Table 34.5 Fuselage configuration selection

	Semi-monocoque	Slab sided	Truss
Structural strength	Moderate	Less	More
Aerodynamic efficiency	More	Moderate	Less
Weight	Light	Moderate	Heavy

greater lift is obtained with a short span which compensates for high drag (Table 34.3).

34.2.4.3 Tail

Inverted T is fairly efficient with less number of stringers and I-sections; hence, conventional (inverted-T) tail is structurally strong and light in weight while providing good stability (Table 34.4).

34.2.4.4 Fuselage

Semi-monocoque fuselage is aerodynamically efficient; it is light in weight while adding less drag and providing the required structural strength (Table 34.5).

34.2.4.5 Electronics

Motor-propeller combination consumes a power of 1000 watts and provides a thrust of 34.335 N. Maximum flight time of 5 min 39 s is provided by the battery, which is sufficient to take-off, spray pesticide and land the aircraft, as the time to empty full

Table 34.6 Electronic configurations

Components	Configuration
Motor	PROPDRIVE v2 4248 650 KV brushless outrunner
Propeller	XOAR PJM-E 13 × 6 electric propeller
Servos	HS-82 MG metal-gear servo
Battery	Gens ace 5000 mAh 18.5 V 60C 5 s Lipo
ESC	60A ESC, 5.5 V/4A UBEC
Sprayer-motor	DC 12 V motor with 100PSI pressure

tank (2 L) is only 2 min 56 s within which the pesticide sprayed from aircraft covers 1.22 acres of land (Table 34.6).

34.2.5 Control, Stability and Performance

Stability and control are crucial to have a successful flight. Control surfaces are calculated to provide adequate command over roll, pitch and yaw; their dimensions and control derivatives are listed in Table 34.7. The designed aircraft is statically and dynamically stable; typical stability range and calculated values are listed in Table 34.8.

Potential of the designed aircraft is expressed in Table 34.9 and Fig. 34.2. Aerodynamic and structural limitations of the aircraft are expressed in V–n diagram, also known as flight envelope. Load factor equal to 1 is the level flight condition. The curve OABE and OHGF shows the maximum velocity that an aircraft can safely operate for the corresponding load factor. Exceeding Vmax leads to structural failure as shown in Fig. 34.2.

Table 34.7 Control surface parameters

Control surface	Dimensions	Control derivative	Calculated values (per radian)
Aileron	300 mm * 76.2 mm	Roll ($C_{L\delta a}$)	0.266
Elevator	506.84 mm * 49.42 mm	Pitch ($C_{m\delta e}$)	– 0.965
Rudder	283 mm * 56.61 mm	Directional ($C_{n\delta r}$)	– 0.025

Table 34.8 Stability parameters

Parameter	Symbol	Typical range (per Radian)	Values (per radian)
Static longitudinal stability	$C_{m\alpha}$	−0.3 to −1.5	−0.601
Dynamic longitudinal stability	C_{mq}	−5 to −40	−13.9
Static directional stability	$C_{n\beta}$	+0.05 to +0.4	+0.051
Dynamic directional stability	C_{nr}	−0.1 to −1	−0.146

Table 34.9 Performance parameters

Performance parameter	Value	Performance parameter	Value
Cruise velocity (V_c)	15 m/s	Take-off ground roll	8.84 m
Thrust required at V_c	9.07 N	Landing ground roll	7.07 m
Thrust available at V_c	34.335 N	Flare velocity	13.14 m/s
Power required at V_c	136.05 W	Take-off velocity	18 m/s
Power available at V_c	515.025 W	Rate of climb	8.79 m/s

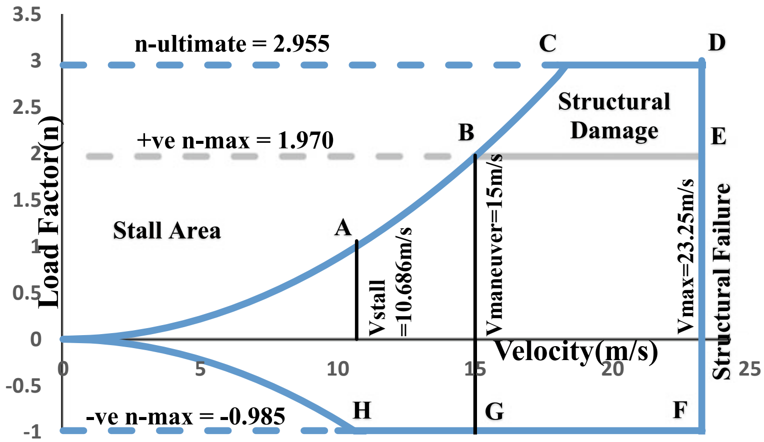

Fig. 34.2 V–n diagram (flight envelope)

34.2.6 *CAD Design and Analysis*

34.2.6.1 Wing

The wing is designed in 2 pieces which can be slid into the fuselage by a telescopic method. This is done to ensure easy transportation of the aircraft. As shown in Fig. 34.3, each wing has 8 ribs. An I-section passes through C/4 of the wing, an L section in the rear which not only acts as a load-bearing element but also makes it easy to add hinges and fix the ailerons. It has a leading edge of 10 mm and a trailing edge of 15 mm. A carbon fibre spar of 8 mm diameter passes through the wing which acts as the main load-bearing element.

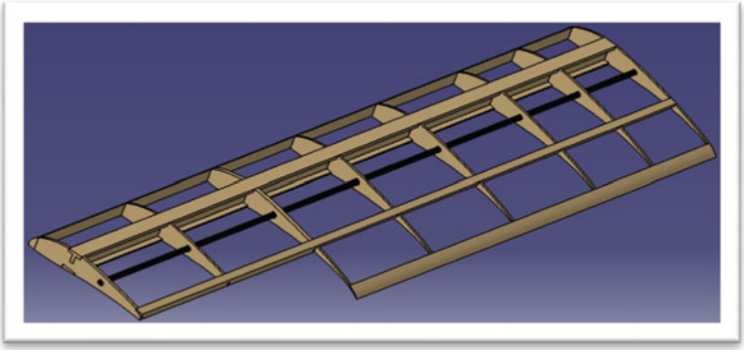

Fig. 34.3 Structural design of the semi-span wing

34.2.6.2 Fuselage

The fuselage is made of 2 sections, the front part is to house the electronics and the rear part houses the payload. The CG of payload and the CG of aircraft coincide; as a result, the plane can be flown with varying payloads or without payload.

The semi-monocoque fuselage design ensures good strength and aerodynamics. As shown in Fig. 34.4, the front section of the fuselage has one bulkhead, three formers and is interconnected by 6 stringers. The second section has 8 formers, 6 stringers, and it contains the wing box. The formers are circular in shape and have a maximum diameter of 172 mm, and the length of the fuselage including the boom is 1210 mm. A boom passes through from the fourth former onwards and is permanently fixed to the fuselage. All formers are made of aeroply, and the stringers

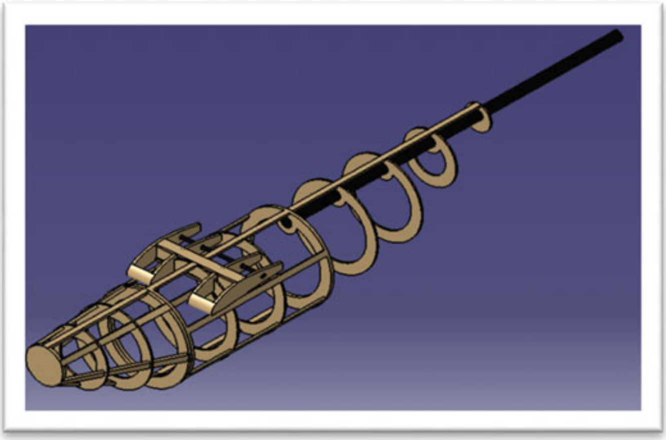

Fig. 34.4 Structural design of fuselage with a boom

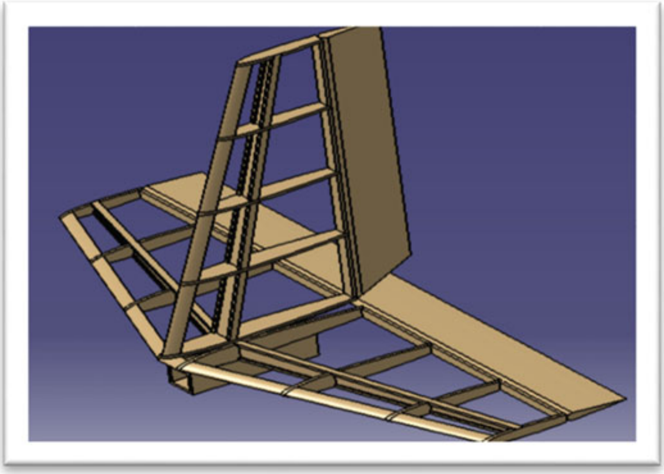

Fig. 34.5 Structural design of the tail

are made of balsa. 3 mm thick balsa sheets and aeroply sheets of varying thickness are laser cut into stringers and formers, assembled using a rail and slot mechanism and joined using cyanoacrylate. The load bearing formers that hold the landing gear, and motor-mount were reinforced by using a thicker aeroply sheet.

34.2.6.3 Empennage

Figure 34.5 shows the assembled empennage. The horizontal stabilizer and vertical stabilizer have a total of 8 and 5 ribs, respectively. Both horizontal and vertical stabilizer have a balsa I section passing through C/4 of each rib, a 10 mm leading edge and a 3 mm web placed at a position where elevators and rudder begin, to add hinges. The rudder has a 30° cut to provide maximum deflection to the elevator. Further, a fixture provided below the horizontal stabilizer facilitates easy attachment of the boom and empennage. Horizontal stabilizer has a negative angle of incidence of 6.5° to balance the overall moment of 4554 N-mm of the aircraft during the cruise.

34.2.6.4 Assembly

All structures were given sufficient tolerances ranging from 0.5 mm to 2 mm as per the need for the structure, to make sure that we have no hindrances while fabricating and as a result we had zero clashes between the parts in Catia assembly. A covering film is added on the structure, which acts as a skin for the air-craft. Figure 34.6 shows the structural design and the surface design of the UAV. The wing and tail is assembled with the fuselage by using telescoping method, and their freedom is

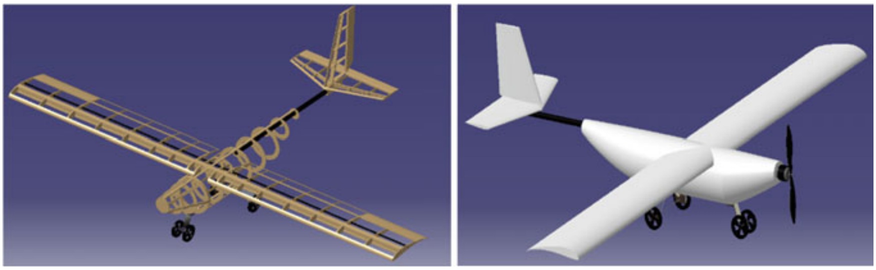

Fig. 34.6 Detailed structural design (left) and detailed surface design (right)

Table 34.10 Overall dimensions of the aircraft

Overall dimensions	Length = 1386 mm	Width = 2000 mm	Height = 537 mm
Wing	Span = 2000 mm	MAC = 254 mm	Angle of Incidence = 3.5 degrees
Horizontal stabilizer	Span = 506.84 mm	MAC = 164.73 mm	
Vertical stabilizer	Span = 283 mm	MAC = 188.71 mm	

arrested using nuts and bolts. Fully assembled aircraft has the overall dimensions as listed in Table 34.10.

34.2.6.5 Structural Analysis of Semi-span Wing

Considering the wing as a cantilever beam a structural analysis was performed by adding a load of 120 N (calculated using ultimate load factor) on the tip of the wing and fixing the root of the wing showed that the maximum stress was on the carbon fibre spar. The maximum stress on the carbon fibre spar is 525.28 MPa, whereas the ultimate tensile stress of carbon fibre is 1500 MPa. Hence, the wing has a factor of safety of 2.85 (Fig. 34.7).

34.2.6.6 Aerodynamic Analysis of the Wing

The enclosure size was taken as 70 * 20 * 20 m in x-, y- and z-directions, respectively. Sufficient care was taken to make sure the mesh quality is good. The skewness of the wing was 0.85. A sizing of 10 mm was given to the wing, and an inflation layer with a $y+$ value of 1 with a growth rate of 20% was added to capture the boundary layer. Mesh independence test revealed that this setting is a perfect trade-off between computation time and accuracy. We chose a pressure-based steady-state simulation, and the aircraft was analyzed at cruise velocity using Spalart–Allmaras model [11]. Since the flow is incompressible and the analysis is performed at a low mach number, to reduce the computational cost a pressure based solver is selected. The result of the analysis provided a lift of 83.955 N and a drag of 5.655 N.

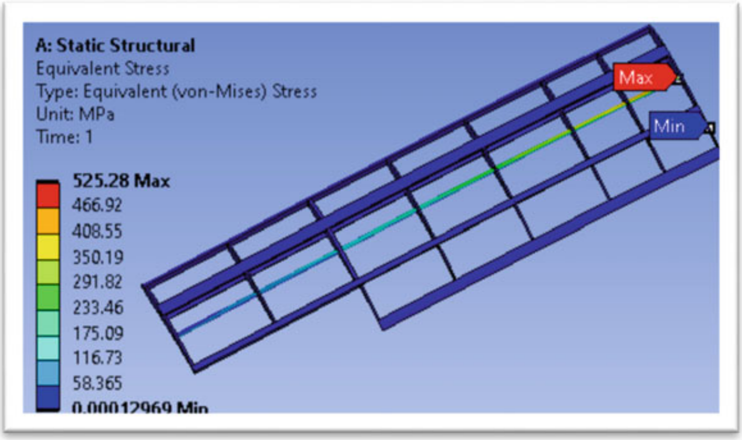

Fig. 34.7 Structural analysis of semi-span wing

34.2.6.7 Aerodynamic Analysis of Fully Assembled Aircraft

The initial settings and fluent inputs of this analysis are similar to the analysis of the wing. The model had a skewness of 0.9, and an inflation layer was given to the wing with $y + 1$. The result of the analysis provided lift of 74.38 N and a drag of 8.42 N. From the streamlines, we were able to tell that the tail was not falling under the wake region of the wing (Fig. 34.8).

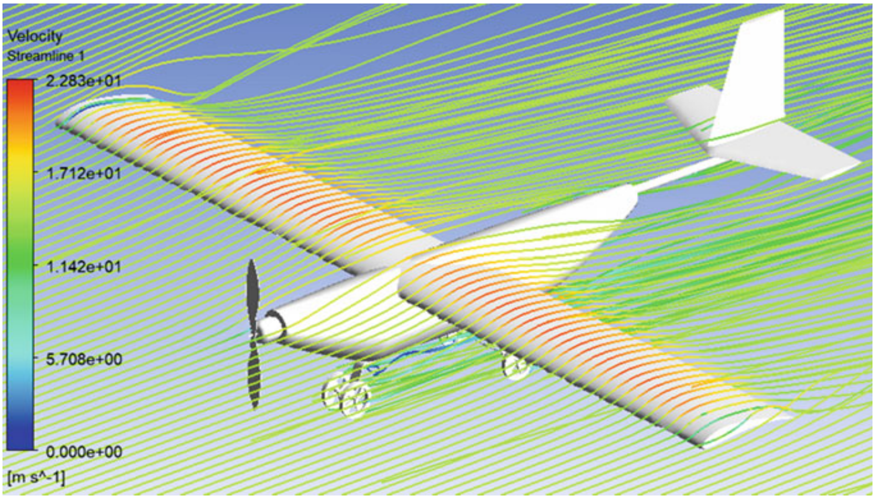

Fig. 34.8 Streamlines of the aircraft

Table 34.11 Payload properties

Parameter	Values
Overall length	220 mm
Overall width	140 mm
Overall height	100 mm
Maximum capacity	2.2 l
Time to empty the full tank	2 min 56 s
Area sprayed in 2 min 56 s	4941 m^2 (1.22 acres)

Fig. 34.9 Flowchart explaining the spraying mechanism

34.3 Payload Properties and Spraying Mechanism

Payload properties of designed chemical (pesticide) spraying tank are shown in Table 34.11. The payload can be easily swapped; other payloads which can be used are crop-monitoring equipment, artificial pollination set-up, land surveying and mapping equipment. Aircraft can carry maximum of 4 kg of payload, while maintaining sufficient factor of safety for the aircraft to fly at its peak performance, which meets the design requirement as stated in Sect. 34.2.2. Maximum payload carrying capacity of the aircraft is designed for 4 kg in order to accommodate varying types of payload such as pesticide spraying mechanism, crop-monitoring equipment and so on. Payload lifting capacity can be increased beyond 4 kg by changing the configurations (electronics, airfoil, wing area) as per the requirements.

Figure 34.9 depicts the process of signal transmission to switch ON/OFF the sprayer. Spraying mechanism consists of nozzles, pipes, a tank and a DC 12 V motor which sprays the chemical with 100PSI pressure. Designed payload tank can accommodate up to 2.2 L of chemical which can be efficiently sprayed over 1.22 acres of land in 2 min 56 s. To spray chemical (pesticide), aircraft can be autonomously guided or manually flown over the agricultural area. Either way, spraying can be switched ON/OFF manually using transmitter channel (switch) or can be made autonomous by setting the area of action and autonomously switch ON/OFF using appropriate mapping software.

34.4 Cost Break-Down

Total cost is computed to be Rs. 20,230, and its breakdown is shown in Table 34.12.

Table 34.12 Cost breakdown

Components	Cost (Rs)
Balsa	1500
Aeroply	2360
Carbon fibre	3200
Motor + Propeller	3270
4 × Servo	6050
ESC	2000
Aluminium	1000
Chemical spraying kit	850
Total cost	20,230

34.5 Conclusion

The designed aircraft meets the requirement stated in Sect.34.2.2. It can spray pesticide over 1.22 acres of land within 2 min 56 s. Therefore, this design of RC aircraft provides solution to the problems faced by farmers such as ill effects of pesticides, energy and time consumed, fatal accidents of manned agricultural aircrafts and other problems stated in Sect. 34.1. It should be noted that payload of the aircraft can be changed (for different work activities) or increased as per the requirement, consequently, the effective area of spraying can be increased.

Taking into account of recent events of 2020 (COVID-19 and Locust Swarms), this aircraft can also be used to spray disinfectant (to sterilize the localities and to reduce transmission of a contagious disease) along with spraying pesticides to kill locust swarms and other pests/insects. The world is moving towards advancing technology to increase the effectiveness and efficiency of the work done. Abiding by the world's need, agro-based RC aircraft hold tremendous potential in various sectors including agriculture for the present and future.

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Chapter 35
Assistive Devices for One-Handed People Using Desktop Manufacturing Methods

Khyati Priya and Pankaj Upadhyay

Abstract *Introduction* In this paper, we present the process, outcome, and learning from a project for developing assistive products using desktop manufacturing methods (which includes additive manufacturing/3D printing, laser cutting, CNC machining). The project focused on people with disability leading to the restricted use of one hand, e.g., one-hand amputees, hemiplegics, and people with congenital anomalies. Six assistive devices were developed for the above user group which are as follows: shoelace tying device, lace tying device, modified scale, dupatta-pinning device, button hook, and toothbrush holder. *Methodology* The development of all the devices followed a typical user-centric design process which started with empathizing with the users and conducting an interview with them, shortlisting areas for intervention, ideating and conceptualizing, iterative prototyping, testing with people who were asked to use only one limb while trying out the device, and finally receiving feedback from the intended users of the products. *Feedback and Results* Feedback on the devices was taken remotely. Three participants with disability in one upper limb were asked to rate each of the selected prototype on six different parameters such as the perceived ease of use, efficiency of problem solving, and intuitive design on a Likert scale, and comment upon them. *Conclusion and Discussion* We discuss the strengths and weaknesses of the inclusive design process we followed, the advantages of desktop manufacturing methods, and how they can be exploited in designing and production of customized assistive devices. Finally, we discuss the implications and future scope of the project.

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A. Chakrabarti et al. (eds.), *Design for Tomorrow–Volume 3*,
Smart Innovation, Systems and Technologies 223,
https://doi.org/10.1007/978-981-16-0084-5_35

35.1 Introduction

As per World Health Organization, disabilities is a broad term comprising impairments, activity limitations, and participation restrictions. In addition, disability is not just a health problem but a complex phenomenon reflecting the interaction between features of a person's body and features of the society in which he or she lives [1]. Thus, to some extent, disability, in addition to being a physical limitation, is also a result of not so well designed products and environments.

Universal design can be defined as the design of buildings, products, and environments to make them accessible to all people regardless of age, disability, or other factors [2]. However, most designs around us are not universal in nature which causes them to be inaccessible to certain groups of people who face disadvantage while using them or are unable to use them at all. Though it is always preferable to have universal designs, it is not always possible to integrate all accessibility features into one design. The result is that certain groups of people such as those with permanent or temporary disabilities and elderly population are incapable of performing certain tasks.

One such group of people is one-handed people. Most of the devices that we use daily, devices as simple as a shampoo bottle and complex ones like bicycle, require usage of, and intricate coordination between two hands. Thus, people suffering from disabilities leading to restricted usage of one hand (one-hand amputees, hemiplegics, or those born with congenital defects) face a great deal of difficulty in performing many such activities. A lot of these people, therefore, are dependent on their caregivers even for performing simple tasks such as cutting nails or tying hair.

In this paper, we discuss how we used the desktop manufacturing techniques (CNC machining, laser cutting, and 3D printing) for producing assistive devices, criteria for selecting and shortlisting designs, remote feedback received on the designs, and why desktop manufacturing method can be useful.

35.2 Research

35.2.1 Background Study

A literature review of products developed for people with upper limb disabilities reveals the existence of a lot of prosthetics and orthoses manufactured using the method of 3D printing [3–7]. Additive manufacturing technology offers the advantage of producing low cost customized devices. Furthermore, devices with complex geometrical structure can be printed with ease, and the print can be lightweight [4]. For production of these assistive devices, one of the methodologies followed was acquisition of anatomical data of intended user by the method of 3D scanning, 3D modeling and printing, and the evaluation of product [3]. While these devices work well to solve the intended problem, for example, providing support for rehabilitation

[6], they often fail to help the physically disabled perform day-to-day life activities with greater ease.

Some assistive devices helping the physically challenged perform day-to-day life activities are commercially available. OneHandCanDo cutting board consists of straps to hold vegetables in place while they are being cut [8]. Clip different is an electrically operated device to chip finger nails automatically [9]. Bra buddy is a device meant to help women put on their bras using a single hand [10]. Button hook [11] and myself belts [12] are devices to help people put on buttons and belts one-handedly.

The drawbacks of these products are their high costs and limited availability. Although these products are available for online purchase, most of them are not available globally (i.e., they are available for sale and shipping in only certain areas, e.g., North America). Moreover, the cost of all of these products is several times more than that of a conventional product for abled people. One reason for high cost may be their low scale of production.

35.2.2 Primary Research

Structured interviews were conducted with three adult one-hand amputees. Qualitative questions were asked to the participants. The questions were focused on knowing the activities they performed with ease and the ones they faced difficulties in, their best and most frustrating times of the day, assistive devices they use and if it works for them, and their method of performing various tasks.

The following table gives a few details about the volunteers who consented to participate in either the interview, or consented to give feedback about the developed devices, or did both (Table 35.1).

The interview revealed that they did face problems performing day-to-day life activities. While the best time of their day included activities like reading, writing, praying, having coffee, or playing games, the most frustrating time of the day included washing hair, doing laundry, or putting on a lot of winter clothes. There are a few activities in which participants always need help in, namely putting up necklaces, squeezing oil from container, and rolling up sleeves. There are other activities which participants find difficult—bagging groceries at store, doing dishes with one hand,

Table 35.1 Details of participants

Pseudonym	Age, gender	Disability	Interview	Feedback
P1	22, M	Hemimelia	Yes	Yes
P2	37, F	Acheiria	Yes	No
P3	32, F	Incomplete Hemimelia	Yes	No
P4	27, F	Incomplete Hemimelia	No	Yes
P5	23, F	Amelia	No	Yes

putting up laces, putting up buttons or zippers located at back, cutting food using fork and knife, using ketchup or shampoo sachets, curling hair, drying hair using a hair blower, etc. There are yet other activities that participants avoid doing because they find it pretty much difficult—like using shoes, or track pants with laces.

All participants have found some unique solutions to their problems: attaching the drum stick to the stump (partial hand) for playing drums, using stump as a tool in the kitchen (for juicing and mashing), using a small container for putting in shampoo from bottle, etc.

All the participants stated that they had tried a prosthetic. P1 said that the weight and numerous wires did not appeal to him. P2's prosthetic does not work like she needs it to, so she does not use it. P3 said that her prosthetic was not assistive at all—it was cumbersome and slow. However, it was evident that the participants did have some preference for certain products like pump bottle for shampoo and conditioners, and automatic can openers.

35.3 Methodology

A total of six assistive devices was conceptualized and prototyped for people with one functional hand. They are as follows: shoelace tying device, lace tying device, modified scale, dupatta-pinning device, button hook, and toothbrush holder. The process that was followed while developing these devices is detailed in the flowchart in Fig. 35.1. We went from designing a product for a very specific context to a more generalized situation. All the prototypes that were developed were tried out by one to three able-bodied persons who were asked to use only one hand while interacting with the device. The successful prototypes were shortlisted for a feedback from the actual users.

A total of eighteen prototypes tackling six different problems were manufactured. Figure 35.2 shows the photographs of these prototypes. Some of the initial prototypes were discarded because they worked in very specific contexts or did not work as expected. For example, shoelace tying device prototype 1 worked only along with a particular shoe; a few initial prototypes of scale failed. Some prototypes were designed keeping a specific context in mind but were found suitable for usage in more general situations also, e.g., button hook and dupatta-pinning device. Given below is a brief description of the prototypes manufactured, comments on their design by authors on basis of their limited trials on the able-bodied, and whether these designs were shortlisted for the next stage of taking feedback from the targeted user group.

Table 35.2 shows the functional needs met by each device.

1. Shoelace tying device: A total of five prototypes was developed. Prototype 1 is slipped onto side collar of one shoe. A knot at the end of one lace, as shown, holds it tightly in place. The prototype was discarded because prototype dimensions were dependent upon the dimensions of a particular shoe such as its collar width and diameter of laces. Moreover, unknotting the knot at one end of lace is difficult using one hand. The next four prototypes (2.1, 2.2, 2.3a, and 2.3b) have a clipping

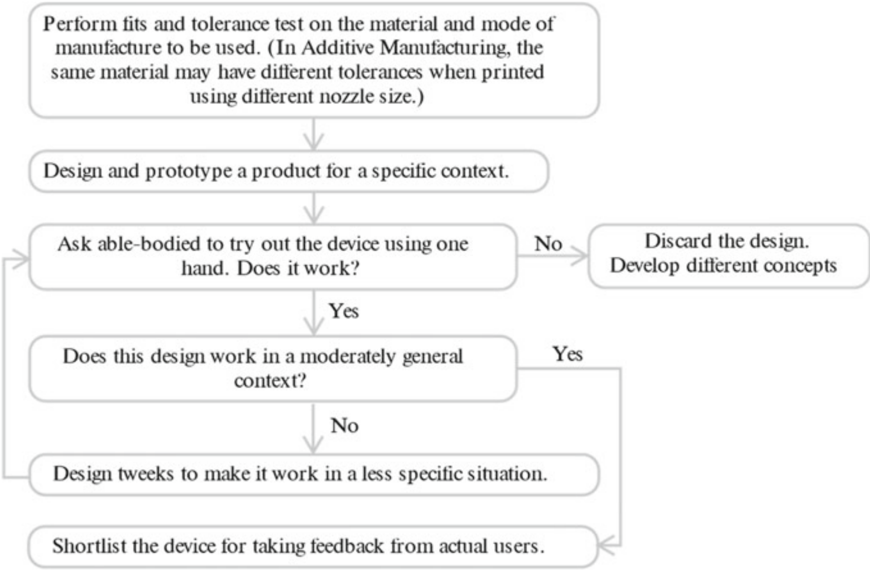

Fig. 35.1 Methodology followed while designing the devices

structure because of which the product can be used along with multiple shoes having different collar widths. A hook, a safety pin, and a buckle-like structure holds one lace in place in the prototypes, respectively, while the one hand can be used to tie the shoelaces. 2.3b is a slightly modified version of 2.3a to make the process of insertion of laces into the device easier. These four prototypes were tried by one to two adult able-bodied persons and they worked as intended. However, it was felt that prototype 2.2 may not be suitable for children.

2. Lace tying device: The design of this device is an extension of shoelace tying device where the clip dimensions have been modified to suit its usage along with clothes. Prototypes 1.1 and 1.2 were tried by one abled person. It was felt that the lace might slide off the hook in prototype 1.2 if it is not attached to the device tightly.

3. Dupatta-pinning device: Only one prototype of this device was developed. A magnet embedded inside the device holds the two pieces together when brought close. The device was tried by two people and worked as expected.

4. Modified scale: As many as six prototypes of this device were developed. Prototype 1 is scale holder meant to hold conventional scale in place. This was discarded because device dimensions dependent upon dimensions of scale and it failed in assisting in drawing a line at an angle. Prototype 2 consists of a knob present in the scale that can be pulled, the scale be rotated at the required angle, and the knob pushed down. The aim was to aid in drawing lines at an angle. Scale 3a is made up of a plastic clip attached to a scale. Scale 3a one was designed for thin notebooks, and its usage along with thicker ones lead to a raised end. Hence, in prototype 3b, a slightly modified version, the scale is bent at an angle to compensate

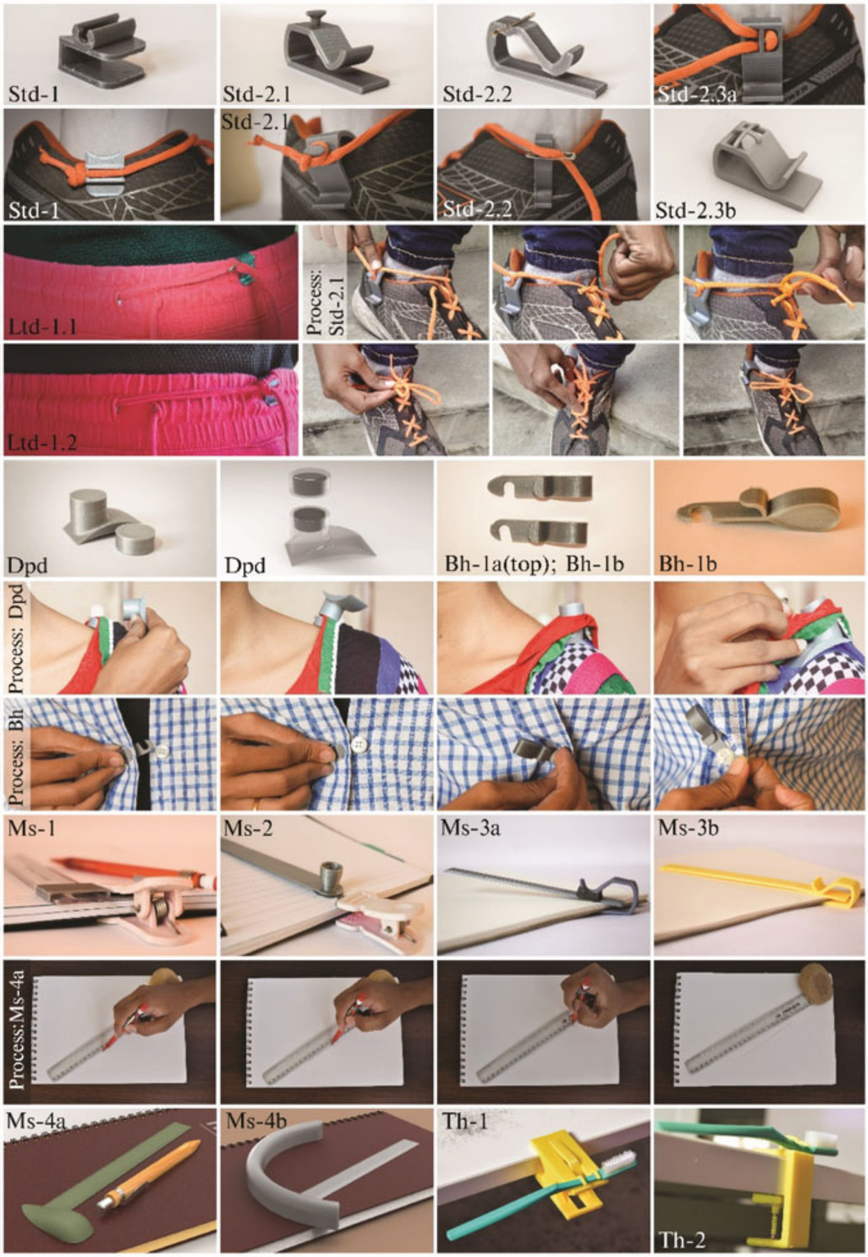

Fig. 35.2 Photographs/renders of prototypes developed. Abbreviations used: Std = shoelace tying device; Ltd = lace tying device; Dpd = dupatta-pinning device; Bh = button hook; Ms = modified scale; Th = toothbrush holder

Table 35.2 Functional decomposition of devices

Task	Functional requirement	Device
Tie up shoelace	Clamp the lace temporarily	Shoelace tying device
Tie up laces	Clamp the lace temporarily	Lace tying device
Pin up dupattas	Bring together two pieces of cloth and overturn	Dupatta-pinning device
Draw a line	Fix the scale with sufficient force	Modified scale
Button up	Assist in the action of buttoning up	Button hook
Apply toothpaste	Hold the toothbrush in one place	Toothbrush holder

for the raised end. When this was used by able-bodied persons, it was realized that it might be a bit difficult to clip the device to a notebook using one hand.

In prototype 4a, the wrist is kept on the curved surface with a little force to hold the scale in place. However, forearm should be aligned to the scale for this one to work; therefore, drawing horizontal lines difficult. So, prototype 4b was developed in which wrist can be placed anywhere on the semi-circular structure. Hence, lines at angles can be drawn. None of the last three prototypes were not discarded as it was felt that feedback from actual users of the device might be different.

5. Button hook: The device comprises a cut in the front, a hook in the middle, and a handle at back. Trials of 1a led to design of 1b. Prototype 1b is a slightly modified version of 1a with a shorter head and a skewed cut, changes to make the device work a little better. 1b was selected for taking feedback from intended user group.

6. Toothbrush holder: Toothbrush holder 1 contains a plastic C-shaped structure in the clip that acts like a spring in the printed clip, hence making it suitable for its usage along with a range of table thicknesses. In toothbrush holder 2, a metal spring holds the device in place. Trials of this device revealed that prototype 1 had a greater adaptability with tables than prototype 2. However, none of the two prototypes were discarded.

Out of the total eighteen developed prototypes, twelve were selected for taking feedback.

35.4 Feedback and Results

Three participants gave feedback on the selected products remotely. For all the shortlisted devices, six questions were asked which are given below. Furthermore, participants were also given an option to comment on the device, if they wished to.

(Q1) I perceive that it is easy to learn to use the device.
(Q2) I think that it is easy and intuitive to use the device.
(Q3) The device is expected to be of use in accomplishing the desired task.
(Q4) I would prefer using this device over the devices/methods I have been using till now.

Table 35.3 Results of feedback received from users

Device	Q1	Q2	Q3	Q4	Q5	Q6
	P1, P4, P5					
Shoelace tying device 2.1	3, 2, 4	3, 2, 4	4, 3, 4	3 ,2, 4	4, 2, 4	5, 3, 5
Shoelace tying device 2.2	3, 2, 4	3, 2, 4	4, 3, 4	3, 2, 4	4, 2, 4	5, 3, 4
Shoelace tying device 2.3b	3, 5, 4	3, 5, 4	4, 5, 4	3, 5, 4	4, 5, 4	5, 5, 4
Lace tying device 1.1	3, 2, 3	3, 3, 3	4, 4, 4	4, 2, 4	4, 4, 4	5, 4, 3
Lace tying device 1.2	3, 4, 4	3, 4, 4	4, 4, 4	4, 4, 4	5, 4, 4	5, 4, 4
Dupatta-pinning device	5, 5, 4	5, 5, 4	5, 5, 4	0, 5, 3	5, 5, 4	0, 5, 4
Modified scale 3b	4, 2, 4	4, 2, 4	4, 2, 4	4, 2, 5	4, 2, 4	4, 2, 5
Modified scale 4a	4, 2, 4	4, 2, 4	4, 2, 4	4, 2, 4	4, 2, 4	3, 2, 4
Modified scale 4b	4, 4, 4	4, 4, 4	4, 4, 4	4, 4, 4	4, 4, 4	4, 4, 4
Button hook 1b	4, 4, 2	4, 4, 2	3, 4, 3	4, 4, 3	4, 4, 3	5, 4, 3
Toothbrush holder 1	5, 4, 4	5, 4, 4	5, 4, 4	5, 4, 4	5, 4, 4	5, 4, 4
Toothbrush holder 2	4, 4, 4	4, 4, 4	4, 4, 4	4, 4, 4	5, 4, 4	5, 4, 4

(Q5) I'd recommend this device to anyone who needs it.
(Q6) This device is likely to make me less dependent on other people.

Table 35.3 details the response received from P1, P4, and P5 for the six questions. For each question, participants were asked to choose one of the given options: strongly disagree (1); disagre e (2); neutral (3); agree (4); strongly agree (5); NA (0).

For the shoelace tying device, P1 said he thought using prototype 2.1 and 2.3b was time consuming and he had doubts about how tightly the device would hold the laces. He also said that it could be problematic operating safety pin using one hand in prototype 2.2. As per P4, the first two prototypes were complicated and difficult to use, but 2.3b was "aesthetically pleasing and easy to use." However, P5 found all the three prototypes to be useful and said that designs would be very helpful for her.

For lace tying device, P4 and P5 perceived that prototype 1.2 would be easier to use than 1.1. P5 added that 1.1 looked fragile and thought that the safety pin was at a risk of popping out.

P4 said she felt that the dupatta-pinning device was a very useful device and tackled an indeed problematic situation. P5 felt the device was useful, but at the same time was "quite big" to use along with dresses.

Scale 3b and 4a received mixed responses. Both P1 and P4 said they felt that clipping 3b using one hand would be difficult and using 4a, according to P1, would require "the same amount of efforts as keeping hand directly on a conventional scale." P4 felt that 4b was a helpful design. However, as per P5, all the three designs "were impressive and helpful."

P4 thought that button hook was efficient and added that it might help her put up buttons on back with greater ease. P5 said that the device seemed "a bit hard and confusing" to use.

While P1 said that toothbrush holder 1 seemed easier to use than toothbrush holder 2, P4 and P5 perceived both the devices to be efficient and useful.

35.5 Conclusion

Though user testing of the devices was not done, we can still conclude that a lot of these devices would work because all of them were tried by able-bodied people who used only one hand while interacting with the device, and at least one prototype of each of the developed devices received positive feedback from intended users.

The devices which received the best and the worst feedbacks from target group are dupatta-pinning device and scale 4a, respectively. For devices for which more than one prototype was shortlisted, here are the prototypes which received better feedbacks than others: shoelace tying device 2.3b, lace tying device 1.2, scale 4b, and toothbrush holder 1. Overall, dupatta-pinning device, toothbrush holder 1, toothbrush holder 2, shoelace tying device 2.3b, and modified scale 4b received mostly positive reviews and were perceived to be useful devices, while shoelace tying device 2.1, shoelace tying device 2.2, modified scale 3b, modified scale 4a and button hook received mixed feedback.

According to P1 and P5, ten of the twelve developed prototypes were likely to make them less dependent on other people. As per P4, eight of them would do. Furthermore, P1, P4, and P5 would prefer using eight, seven, and ten of the developed devices, respectively, over other devices/methods they have been using till now.

35.6 Discussion

The authors present the process followed for the development of assistive devices. A survey was conducted initially, followed by shortlisting areas for intervention, conceptualizing, prototyping, user testing on abled people, selecting designs for receiving feedback from intended user group, and finally receiving remote feedback from one-handed people. From the feedback received, one may conclude that the developed devices are assistive to the users and are likely to perform better than the methods/devices they are using at present. A drawback of the methodology we followed is that the feedback was based on the perception of users about the products and not based on interacting with the devices physically. User-testing the products with the actual users may yield different, and in fact, more reliable results.

All the devices were designed to be manufactured using desktop manufacturing techniques which offer an advantage of creating customized products on a small scale with a greater ease as compared to traditional manufacturing methods, a benefit highly suitable for inclusive design. In addition to the technical and economic feasibility, they also save the costs incurred in the transportation of products and make the devices available to any part of the world as the component files can be transferred digitally, thus making the designs more accessible to a wider population.

While performing a background study, it was noted that very few products were available in the specific area chosen for this project (assistive devices for one-handed people using desktop manufacturing methods). Although only six products were designed in this project, it is hoped that these products will inspire many more in the field, not just for the specific kind of disability that we have chosen, but for other kinds of physical limitations as well. Design and evaluation of more, simple yet useful assistive devices, is left as future work. There is a great scope for producing customized and non-customized assistive devices using methods such as additive manufacturing.

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Chapter 36
Design Intervention in Farm Equipment: Using a Studio Research Approach to Design a Sustainable, Human-Powered Solution for Small and Marginal Indian Farmers

Sanket Pai, Sugandh Malhotra, Selby Coxon, and Robbie Napper

Abstract Small and marginal farmers play an essential role in the Indian agrarian economy. However, climate change, inflation, inadequate supply, volatile market, deterioration of land and water resources, rising input costs and post-harvest losses along with lack of appropriate technology have led to an agrarian crisis in recent years. Small and marginal farmers are unable to use modern solutions due to issues like rising labour costs, lack of capital and unavailability of appropriate technology. Also, as the men migrate from villages to cities, Indian agriculture is becoming increasingly feminized. Hence, there is an urgent need for developing sustainable, appropriate and affordable farm tools which are gender-friendly, effective and efficient. A designer needs to understand various parameters for designing and evaluation of solutions to design and develop appropriate, affordable and context-specific interventions. These parameters range from technical to social, and the process for developing the parameters is described in this paper. Initially, data from various sources were collected and represented visually in mind maps with overlays to understand different layers of activities, existing solutions and needs. These overlays, along with a design futures framework, were used as a reference point to generate parameters which would inform and drive various directions for ideation and evaluation during the design process. The authors have used the user needs pyramid resulting out of the

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A. Chakrabarti et al. (eds.), *Design for Tomorrow–Volume 3*,
Smart Innovation, Systems and Technologies 223,
https://doi.org/10.1007/978-981-16-0084-5_36

identified parameters to generate a design specification for farm implements. The factors used to generate the specification consider not just the technical aspects but also the socioeconomic and cultural aspects.

36.1 Introduction

India has traditionally been an agrarian country at heart. Almost 50 percent of the Indian population depends directly or indirectly on agriculture and allied activities for livelihood. However, agriculture as a sector contributes to only 12 percent of the country's GDP [9]. The reasons are multiple, owing partially to changes in industrial and economic strategy. Since independence, governments have introduced multiple reforms to boost and safeguard the sector [5, 9]. Despite these efforts, the country is currently going through an agrarian crisis along with an alarming rate of farmer suicides.

The current problems in the agriculture sector can be attributed to a few significant factors, which include, complex relations between fragmented landholdings (i.e. a piece of land that is owned or rented), climatic variations, rising input costs (e.g. machinery, fertilizers and seeds, etc.), lack of credit, and post-harvest losses. These factors, along with the lack of alternative off-farm employment and agricultural diversification [9], are contributing to the agrarian crisis. In addition, inefficient supply chain, volatile markets, deterioration of land and water resources, lack of appropriate technology, and low income are also contributing factors to the crisis [4, 9, 14]. These issues collectively create much stress on the livelihood of farmers, especially farmers with small and marginal landholding.

36.1.1 Small and Marginal Farmers of India

Indian government classifies farmers with landholding between one to two hectares, and less than one hectare, as small and marginal farmers, respectively. These farmers collectively represent 86.21 percent of all Indian farmers with a 47.34 percent share of the total operated area [9]. Due to the fragmentation of landholdings and land division among children with each new generation, the number of small farmers is steadily increasing. Along with the rise of small farms, the average size of the farm has reduced from 1.15 ha in 2010–11 to 1.08 ha in 2015–16 [9], which can impact the yield and ability of the farmers to afford farm inputs. This steady reduction is expected to continue in the coming years.

Despite a thrust towards farm mechanization, small farmers still tend to rely primarily on traditional tools and methods. Most small and marginal farmers have limited capital, lack finances and cannot afford farm machinery or running costs of fuel or electricity-powered equipment [9]. Since the farm size is small, large tractors cannot be used due to lack of approach roads. Though farm implements like power tiller and motorized threshers reduce drudgery and enhance efficiency, small farmers struggle to maintain a balance between investment towards expensive farm equipment and crop yield.

Small farmers tend to rely on locally manufactured hand tools and traditional farm implements like the sickle. In rural India, most local artisans lack the modern technical capability of product development and hence are not able to adhere to safety and design standards while manufacturing farm implements. These design deficiencies in hand tools along with awkward posture and longer working hours lead to many musculoskeletal disorders and injuries on farms [10]. The lack of appropriate tools and ergonomic considerations leading to injuries becomes even more conspicuous as the involvement of women in agriculture is increasing.

36.1.2 Feminization of Indian Agriculture

Indian agriculture is increasingly becoming more feminized as male farmers migrate to urban areas for other opportunities [3, 11]. Rural women are expected to handle household chores, child care, livestock management and farm activities. Although women handle activities of cleaning of fields, field preparation, sowing, intercultural practices, weeding, harvesting, picking, cleaning of grains and drying of grains, they are considered as workers and not farmers [2, 3, 14]. The tasks that women typically undertake do not require a vast amount of physical strength, but they do require hand skill and involve long hours of work. In peak and lean agricultural seasons, women spend 7–8 h and 4–5 h a day, respectively, out of 12–14 h working on agriculture with just an hour of a break [21].

It is necessary to consider gendered social roles while trying to develop agricultural tools. Since women handle household chores and childcare while working on the farm, they usually tend to perform activities that can be quickly started and stopped without affecting the output [1]. For example, using hand tools for harvesting or weeding allows them to take breaks when required for other duties without affecting the quality of work. This need has an impact on the tools that they prefer using for these activities. The traditional tools used by farmers are usually light, handheld, human-powered, unlike the heavier tools driven by a motor or a draught animal. Use of these traditional tools, however, leads to increased drudgery, health risks and low efficiency, which results in the reduction of income.

36.1.3 Need for Gender-Friendly Appropriate Equipment

Most of the old as well as new agricultural equipment is designed by, and for, men. Most tools and machines which require primarily upper body strength, grip strength or bursts of power, tend to privilege male bodies. The upper body mass of men is 75% greater than the women's, whereas for women, most lean body mass is concentrated in the lower body [17]. The lack of attention to ergonomics while designing these tools also leads to a higher risk of farm injuries for women. There is a clear need for women-friendly tools and equipment which will reduce drudgery while increasing efficiency, productivity and minimize injuries [7, 9, 20, 21]. If gender friendliness of tools is not considered while designing, there is always a chance of reluctance of technology adoption by women. This reluctance can also stem from factors like education, sociocultural norms and man's appropriation of technology which enable continued gender inequities in the farming sector [12].

In the agricultural sector, there is an urgent need to develop low cost, context-specific, gender-friendly tools for small farmers which are also responsive to socio-cultural circumstances [9, 18–20]. Since the design process involves understanding context-specific needs, user-centric approach and an iterative approach to developing interventions which involve prototyping and testing, a design approach could lead to the development of an appropriate intervention for small farmers.

36.1.4 Aim of the Research

In order to design appropriate solutions for small-scale farmers, a design researcher needs to understand the changing dynamics of needs and wants of these farmers. It is pertinent that a user-centric approach is adapted to ensure that all the identified needs are met holistically, and the gaps in existing approaches are identified. However, the users may not always be able to identify their own needs, as a more holistic and broader view of the problem is required to develop lasting successful solutions. Our research aimed to understand and map the parameters that affect tool design, with the aim of informing a design checklist and framework for developing sustainable, appropriate solutions for the rural areas.

36.2 Methodology

This research focused on understanding and defining the factors that a designer needs to consider when conceptualizing farm machinery for small and marginal farmers in India. We wanted a slightly different perspective on the problem of designing tools as we felt the existing approach of developing farm tools was not holistic. Data regarding farm activities, tools used and needs of small farmers were collected through literature review and semistructured interviews of resource persons of 3 NGOs, namely (1) BAIF Development Research Foundation in Jawahar, Palghar district, (2) Gram Gaurav Pratisthan at Purandar, Pune district of Maharashtra and (3) Shivganga Samagra Gramvikas Parishad (SSGP) in Jhabua district, Madhya Pradesh. These NGOs work with small and marginal farmers and train them in concepts of cooperative projects and organic farming. Using qualitative data regarding needs and issues of small-scale farming gathered from literature and analysis of tools developed by small farmers, we defined a list of parameters which would inform or drive design decisions. We then used an existing design futures framework [8] to classify the parameters into technical, human and environmental categories. This framework provides designers with drivers that can be used to forecast future possibilities. We selected this framework as it was a robust generic framework containing human, technical and environmental parameters to be considered while designing for the future in order to generate sustainable, meaningful solutions. To understand the scope of research through design for this domain, we then plotted the parameters on a user needs pyramid (Fig. 36.4), which helped to develop design specifications for the next phases of the research.

36.2.1 Common Set of Farm Activities

Stages in farming any crop are broadly divided into three segments, pre-production, growth and post-production. Pre-production deals with all the activities undertaken by the farmer before planting the seeds. Growth includes all the activities of planting, growing, nurturing and protecting the crop till harvest. Post-production involves all activities from harvest to transportation from the farm. Small and marginal farmers tend to do a higher crop diversification compared to larger farms because they are mostly subsistence farmers and grow multiple types of crops at the same time [3]. Therefore, we wanted to understand the most common activities across different types of crops. We determined the seven important crops of India for this research based on annual production, crop type and information available about farm activities. Various activities under the three segments of pre-production, growth and post-production were mapped for seven principal crops. These crops were selected based on production and diversity. We selected crops from food grains (rice and wheat), cash crops (sugarcane and cotton), coarse cereal (finger millet), pulses (chickpea) and oilseed (groundnut). Then a common set of activities was extracted from these maps.

36.2.2 Analysis of Tools Designed by Farmers

In Maharashtra, Gram Gaurav Pratishthan in Naigao village of Pune district has collected tools which were designed by farmers of surrounding villages (Fig. 36.1) The farmers have developed their tools with the help of the local metal workshops. By and large, the tools are developed for post-harvest activities like cutting, plucking and drying. However, some tools have been designed for weeding and harrowing. The activities which involve drudgery and have a lack of appropriate tools seem to be the pain points which led to these designs. We focused on material, manufacturing process and safety apart from usability aspects while studying these tools.

Fig. 36.1 Tools developed by farmers at Naigao village, Maharashtra, India (*Image source* Author)

36.2.3 Defining Parameters

In order to generate product specification for tools to be developed, a robust list of factors was required, which holistically address the technical as well as cultural and social needs. Based on the insights from available literature and analysis of existing solutions, a list of parameters was prepared, which could lead to more holistic appropriate solutions. In order to classify these parameters, existing design frameworks like the framework of product experience [4], design futures framework [8], humanistic values model [16] and a framework for the design of products for low-income economies [23] were studied.

We then mapped the parameters onto the design futures (DeF) framework under human, technological and environmental considerations. This framework was selected as it was robust, detailed and could be easily adapted for the research domain. This framework contains 18 design drivers, classified under human, technical and environmental values and is a comprehensive framework that can be used for forecasting design possibilities that are both meaningful and appropriate [8]. The affinity of each derived parameter was checked concerning the factors arising out of human, technological and environmental considerations. The parameters were then classified under these three considerations to create a matrix. The purpose was to create a tentative generic checklist for designing farm implements which can later be validated by trials of implements developed using the checklist.

36.2.4 User Needs Pyramid

There was a need to further classify the parameters in order to determine the scope of the design specification for the farm tool. We decided to use a hierarchy of user needs so that we can determine a way to assign priority to different parameters based on the context. Based on the data from literature and NGOs, we then tried to classify the parameters using Aaron Walter's hierarchy of user needs pyramid [22], which is derived from Maslow's hierarchy of needs. This hierarchy proposes that the basic needs of functionality and reliability should be fulfilled before tackling higher needs of usability and pleasure. We mapped the parameters on the user needs pyramid to decide the focus to generate design specifications for the solutions and to decide a boundary for the studio research phase.

36.3 Results

A common set of farm activities was identified by studying the seven principal crops (Fig. 36.2).

Analysis of existing tools revealed that the activities which have a lack of appropriate existing tools had driven these designs. Most of these tools are made using locally available material as well as recycled waste. The tools are robust, have minimal moving parts, and are context-specific. Also, they are simple in construction

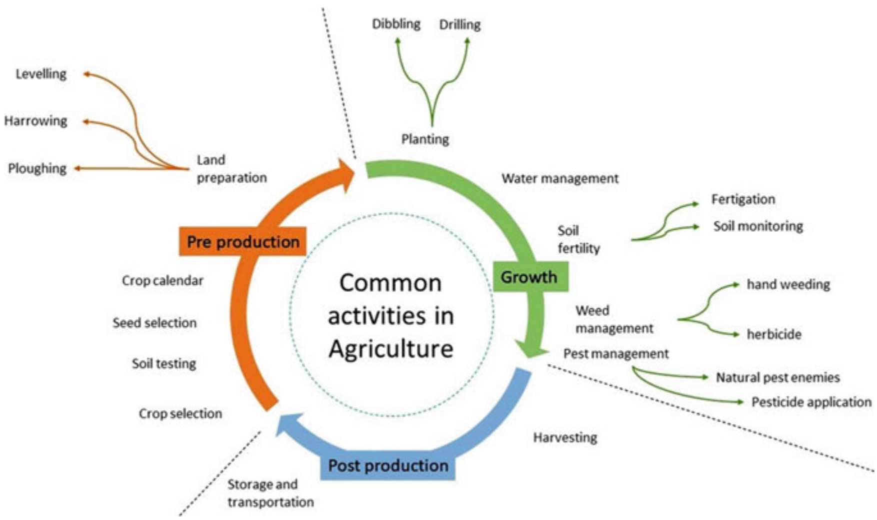

Fig. 36.2 Common activities in the farming of seven selected crops (rice, wheat, cotton, sugarcane, finger millet, chickpea and groundnut)

which allows ease of local manufacture and repair. The following list of parameters was derived from data analysis.

- Ease of using: The machine should be easy to use and operate.
- Ease of learning: Learning to operate/use takes minimum time, or learning curve is gradual when a new machine is introduced.
- Ease of manufacture: The machine should be manufactured using a local technical ability or using readily available manufacturing processes.
- Ease of recharge/refuel: The tool/machine should use readily available fuel /power sources (use of diesel/kerosene or larger efficient batteries that can be recharged manually).
- Cost of manufacture: Using the economy of scale or standard readily available base material/ mechanisms (e.g. bicycle sprockets and ratchet).
- Capital costs: Purchase of land, equipment, building or construction (e.g. bunds, canals, wells, fences and sheds).
- Running costs: maintenance costs, labour costs, rent, fuel/fodder cost, etc.
- Ergonomic design: comfortable to use/operate with minimal risk of injury along with a reduction in effort, gender-friendly.
- Functional aesthetic: a form which is culturally and functionally appropriate.
- Type of ownership: personal, shared, institutional.
- Portable: Easy to move/transport across diverse terrain.
- Utility: able to do multiple tasks for similar crops or the same task for a wide range of crops or useful for on-farm as well as off-farm activities.
- Modular/quick change over: able to quickly reconfigure for different tasks or ability to quickly change attachments.
- Robust: less likely to fail/works under different climatic conditions.
- Use of farm animals: using draught animals which provide farm power as well as a source of fertilizer and pesticide through excrement.
- Locally available raw material: Using material available in or around the farm and the village.
- Locally repairable: can be repaired using local know-how or readily available standard spare parts/ materials.
- Easy to dismantle/dispose of: biodegradable materials/easy to dismantle different materials for scrap and recycle.
- Easy to recycle/upcycle: using standard materials which can be reused for other purposes, the form of parts allows additional utility after dismantle.

The parameters were then grouped (Fig. 36.3) using human, technical and environmental considerations from the design futures framework.

A user needs pyramid was generated (Fig. 36.4) by classifying these parameters using a hierarchy of user needs.

HUMAN								
Parameters	Personal					Social		Cultural
	Joy of using	Styling	Comfort	Convenience	Safety & Hygiene	Affordability	Social Advancement	Cultural advancement
Ease of maintenance	☐	☐	☐	☑	☐	☐	☐	☐
Ease of using	☐	☐	☐	☑	☐	☐	☐	☐
Ease of learning	☐	☐	☐	☑	☐	☐	☐	☐
Portable	☐	☐	☐	☑	☐	☐	☐	☐
Ergonomic design	☐	☐	☑	☐	☑	☐	☑	☐
Type of ownership	☐	☐	☐	☑	☐	☑	☑	☐
Running costs	☐	☐	☐	☐	☐	☑	☐	☐
Capital costs	☐	☐	☐	☐	☐	☑	☐	☐
Functional aesthetic	☑	☑	☐	☐	☐	☐	☐	☑
Utility	☐	☐	☐	☑	☐	☑	☐	☐

TECHNOLOGY								
Parameters	Production		Mechanisms		Physical structure		Energy	Principle
	Maintenance	Manufacturing	Control Systems	Mechanisms	Stucture	Materials	Energy Sources	Scientific principle
Ease of manufacture	☐	☑	☐	☐	☐	☑	☐	☐
Locally repairable	☑	☐	☐	☑	☐	☑	☐	☐
Robust	☑	☐	☐	☑	☑	☑	☐	☐
Modular (flexible)	☑	☐	☐	☑	☑	☐	☐	☐
Cost of manufacture	☐	☑	☐	☐	☐	☑	☐	☐
Ease of recharge/refuel	☐	☐	☐	☐	☐	☐	☑	☐

ENVIRONMENT			
Parameters	Source	Sink	Renewal
	As resource	Reduce deterioration	Renewal
Locally available raw material	☑	☐	☑
Easy to dispose	☐	☑	☐
Easy to recycle/upcycle	☐	☑	☐
Use of farm animals*	☐	☐	☑
Low emission/pollution	☐	☑	☐

* considering ethical treatment

Fig. 36.3 Parameters classified using DeF framework

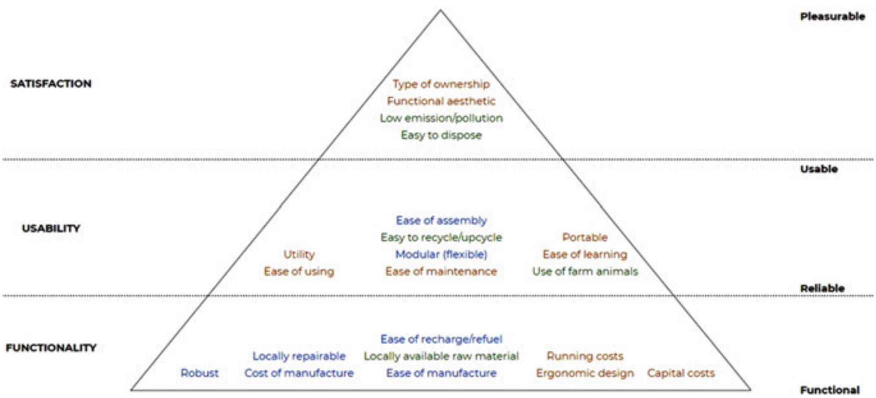

Fig. 36.4 Parameters organized using 'user needs pyramid'

36.4 Discussion

When we started this research, the initial aim was to understand and map the parameters which affect tool design in the farming sector. However, we discovered during the literature study that we needed to also understand socio-cultural norms and environmental factors along with technical issues in order to ensure effective dissemination of the intervention that we intend to design. Effective dissemination of technology improves if it is socially just and responsive to both sociocultural circumstances [18] and socioeconomic realities by encouraging cooperative enterprise and minimising risk-taking [19].

We surmise that some of the parameters generated in the process will have a significant impact on ensuring effective technology dissemination along with improving the way farm activities are currently executed. For example,

- Ease of manufacture does not just focus on technical aspects but also the appropriateness of materials and processes chosen in order to ensure that a local craftsperson can use existing skills and knowledge along with locally available, upcycled material to build and repair the machine.
- Functional aesthetic also involves ensuring that the machine does not look too masculine or industrial but the form would enable ease of accessibility to all genders and would take cues from products that the farmers are already comfortable using in and around the household.

Both these parameters were derived from existing literature [5, 23] as well as analysis of tools developed by farmers.

- Ease of use will ensure that the machine does not just privilege male body in the way it is operated [17] but is gender-friendly and allows intermittent use to enable other normalized gender roles to be performed like child care or cooking [1]. Hence, a designer needs to be mindful of not the tool which does the required task effectively but also its use does not disrupt other daily activities of the farmer.
- Type of ownership can be modified depending on the context, and the way technology is disseminated to ensure that costly products or products which are utilized once per agricultural cycle can be owned and managed by community or self-help groups, e.g. cooperative group-farming enterprise where resources and knowledge can be shared while retaining land ownership [13, 15, 19].

We think these parameters can be a good starting point to ensure that various interconnections and complexities of what the tool or solution would mean to a small farmer could be explored during the design process.

The research highlights how gendered social roles and cultural norms have affected solutions being generated in this domain. It stresses the need to create opportunities for developing sustainable, appropriate, context-specific, gender-friendly solutions which are not just efficient and effective but in the long run may help ameliorate gender inequities.

Based on these insights, we surmise that any solutions for small and marginal farm activities should ideally fulfil the following specifications:

- Ergonomic, gender-friendly and easy to use
- Affordable, efficient and effective (compared to existing popular solutions)
- Able to handle at least two different crops with minimal change parts
- Lightweight and portable
- Is locally manufacturable or at least repairable
- Uses human power as an energy source.

We have used the outcomes of the paper and have followed a studio research process for designing a human-powered device for threshing rice and wheat. We are currently in the process of refining the design and developing a prototype for testing this device in the field.

The results presented in this paper would help other researchers, designers and engineers in terms of awareness regarding different factors that would affect the direction of problem identification and generation of a holistic intervention. In the long run, the factors could also help small and marginal farmers identify and select the appropriate type of solutions based on their needs.

36.5 Conclusion

The research began with the intention of understanding and mapping various parameters which affect farm tool design for Indian small and marginal farmers.

The authors have used data from various sources to define and classify the factors to be considered while designing farm implements for small and marginal Indian farmers. The data gathered highlights the need to develop context-specific, gender-friendly, appropriate solutions to encourage effective technology dissemination and use. The generated factors consider not just the technical aspects but also the socio-economic and cultural aspects. Further research in this direction would help in refining the identified parameters and in generating a design framework which could aid designers and engineers to develop holistic solutions in this domain.

However, the insights derived from this project are primarily based on secondary data. Conducting workshops with NGOs and farmers along with field visits across various locations with diverse conditions in different times of agricultural cycle is required to improve the quality of data collected and gain deeper insights. The identified parameters and their hierarchy could be further refined and verified using a panel of experts in the field and farmers from other parts of the country.

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Chapter 37
A Design Research Study to Understand Factors Affecting Tool Design for Small-Scale Rice Farming in Western Maharashtra

Sanket Pai, Sugandh Malhotra, Selby Coxon, and Robbie Napper

Abstract Due to issues of small land size and dependence on traditional tools and methods, small and marginal farmers continuously struggle to maintain a balance between the investment towards this expensive equipment and their crop yield. These issues highlight the need for intervention in the small-scale rice farming domain. Literature study, along with a discussion with a resource person from one NGO from the western region of the state of Maharashtra, was used to gain a preliminary understanding of on-the-ground realities and issues affecting small-scale rice farming. The information collected from these sources were then mapped to generate morphological representations of activities and tools. These were visually represented as overlays on a mind map to understand the current state of tool usage and deficiencies in farm implements. The authors have used the design methods to visualise the rice farming activities and tools used. The map with overlay can be used as a reliable reference point for generating parameters which affect farm tool design for small and marginal rice farmers.

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A. Chakrabarti et al. (eds.), *Design for Tomorrow–Volume 3*,
Smart Innovation, Systems and Technologies 223,
https://doi.org/10.1007/978-981-16-0084-5_37

37.1 Introduction

India is a country known for its diversity. This diversity also reflects in the agricultural domain where the land condition, climate, crops, farming techniques and methods vary across the country. India is the second-largest producer of rice in the world. In 2013–2014 the country's rice production was 106.7 million tonnes (43.4%) out of (combining both Kharif and Rabi season) 245.8 million tonnes of total food grain production [9]. Majority of rice farmers in India, however, have small or marginal scale farms (land area of fewer than 2 ha).

37.1.1 State of Indian Agriculture

India has traditionally been an agrarian country at heart. Agriculture and allied activities comprise farming/cultivation, livestock, fisheries, forestry and logging, along with agricultural products and inputs (i.e. agricultural service, fertiliser and pesticide industries). Agriculture is carried out throughout the year in three distinct cropping seasons of Kharif, Rabi and Zaid (Table 37.1).

Apart from types of season, crops are broadly classified into four broad categories: (a) food crops (wheat, rice, coarse cereals and pulses), (b) cash crops (sugar cane, tobacco, cotton, jute and oilseeds), (c) plantation crops (coffee, coconut, cashew, tea and rubber) and (d) horticultural crops (fruits and vegetables). Due to varied topography, climate variation and a large variety of crops grown across the country, Indian agriculture is very diverse with many variations in agricultural traditions, methods and tools.

Almost 50% of the population depends directly or indirectly on agriculture and allied activities for livelihood. However, agriculture and allied activities contribute to only 12% of the country's GDP [2]. India is currently facing an agrarian crisis which has led to an alarming increase in the rate of farmer suicides. Increase in the

Table 37.1 Agricultural seasons in India

Season	Duration	Crop criteria	Common crops
Kharif	June/July to Sept/Oct	Crops which require hot weather and much water	Rice, jowar, bajra, maize, cotton, groundnut, jute, sugar cane, turmeric and pulses
Rabi	Oct/Nov to April/May	Crops which require a warm climate for germination and cold climate for growth	Wheat, oat, gram, pea, barley, tomato, onion, oilseeds
Zaid	March to June	Crops which mature early	Cucumber, bitter gourd, pumpkin, watermelon, muskmelon, moong dal

Data source https://testbook.com/blog/crops-in-india-gk-notes-pdf/ (as seen on 30/10/2018) number of small farm sizes which limit the yield and affect the ability of farmers to afford agricultural inputs is one of the major contributing factors to the crises along with rising costs, post-harvest losses and climatic variations [9].

37.1.2 Small and Marginal Farmers

Indian government classifies farmers into five broad categories based on the size of landholding (Table 37.2). Out of these five size groups, small and marginal farmers collectively represent 86.21% of all Indian farmers with a total operated area share of 47.34% [9]. Due to the fragmentation of landholdings and land division among children with each generation, the number of small farmers is steadily increasing. Along with the rise of small farms, the average size of the farm has reduced from 1.15 ha in 2010–2011 to 1.08 ha in 2015–2016 [9]. This steady reduction is expected to continue in the coming years.

Most of these farmers depend on their land for sustenance as well as livelihood. Household food needs primarily determine the cropping pattern on small farms. Hence, four-fifths of the small farm tends to be used for food crop cultivation, and small farmers contribute to the crop diversification and food security of the country [5]. Small farms have an average household size of five people and rely predominantly on the family for farm-labour requirements as they cannot afford outside labour. Since they depend on the land for sustenance, they tend to be more efficient than large farms at livestock management and cultivating crops. However, due to the small size of the land, the income generated is not sufficient for the family [7]. Since only 47% of rural households own land, some of these small farmers also work on larger farms as labourers [4].

Cultivating small farms is quite challenging. These challenges include but are not limited to, lack of capital to afford machinery and its maintenance, low yield with high input cost, climate change, lack of water resources, lack of awareness and unavailability of appropriate technology [4, 6, 9, 10]. Most of the small farmers also suffer from low literacy rate, lack of awareness about technology, government schemes and policies. The low level of education in rural areas also creates a barrier to attempts of public dissemination of technology or knowledge.

Table 37.2 Farmer size groups based on of landholding size

S. No	Size group	Size of landholding (in ha.)
1	Marginal	less than 1
2	Small	1 < 2
3	Semi-medium	2 < 4
4	Medium	4 < 10
5	Large	10<

Data Source https://agcensus.nic.in/document/agcen1516/T1_ac_2015_16.pdf (as seen on 02/08/2018)

To meet market demands and increase income, small farmers tend to shift from subsistence farming to commercial farming. This change in output to meet market demands has led to a reduction in area under food crops and an increase in the production of non-food and cash crops. The shift to commercial crops always carries a higher risk of enormous losses from crop failure and market volatility due to both global and local factors. Small farmers, hence, tend to grow vegetables as commercial crops apart from safe crops like rice and wheat. The vegetable crops are more labour intensive but provide faster and regular returns [7]. There is an urgent need for better institutional support, appropriate technology and new robust farming models and strategies to support small farmers and to prevent a future food security crisis.

In Maharashtra, 79.52% of farmers have small and marginal land holding and cultivate 44.9% of the total area under agriculture. The average size of holding of small and marginal farmers is 1.33 and 0.44 ha, respectively [1]. Also, due to increased fragmentation of land, the number of small and marginal farmers is expected to grow in the future. Due to the small size of land, these farmers struggle to balance the yield with input costs.

The primary input costs for rice farming are land, labour, quality seeds, fertilisers, irrigation, pesticides, farm machinery and equipment and agricultural credit. Most small farmers are unable to afford modern machinery and tend to rely on traditional tools and techniques. Design intervention in this domain could help in optimum use of resources and time, along with a reduction in drudgery. There is a need for innovative solutions in the form of customised context-specific farm machinery and equipment for different regions [9]. Hence, the authors have decided to focus on the aspect of farm machinery and equipment.

37.1.3 Rice Farming in Western Maharashtra

Rice (Oryza sativa) has a wide physical adaptivity and can be grown under diverse soil and climatic conditions [3]. It is the most ubiquitous and hence important food crop in India with more than 430 rice varieties and hybrids. In Maharashtra, rice is the second most important crop and is mostly grown under rainfed conditions during the Kharif season of June–August to October–December. Rice is also a good source of income for small farmers, and along with the grain, the other by-products of rice farming have multiple uses. For example, farmers use rice straw after threshing the grain, for thatching roofs, as a fuel source, as feed for drought animals and as biofertiliser. Chopped straw is also used in the paper industry and for mushroom cultivation.

Rice is grown in four regions of Maharashtra, namely Konkan, western Maharashtra, Marathwada and Vidarbha. Out of these four, Konkan and western Maharashtra account for 49.51% of the area under rice farming but produced 73.89% of the total rice produced [11]. In the regions of Konkan and western Maharashtra, most of the rice is grown under assured rainfed conditions. The common cropping system in these regions for rainfed rice is rice-fallow and pulses [11]. The economic condition and well-being of the farmers practising rainfed cultivation are directly dependent on climatic conditions. Rural poverty is also very high in these regions with most of the farmers having small and marginal land holding (less than 2 ha). Hence, these farmers get severely affected in case of any fluctuations in the monsoon along with other issues of lack of capital, small land size and lack of affordable technology.

37.1.4 Research Aim

The aim of the research was to conduct a study of one crop in one part of a state to observe and understand the design direction to be taken to develop farm implements for small farmers. Therefore, we decided to consider small-scale rice farming in Western Maharashtra as a starting point for research. There was a need to understand the activity of rice farming along with the common farm implements in order to identify possible avenues of design interventions. The objective of this paper is to document the mapping of these identified activities and tools used by the farmers.

37.2 Methodology

This research started with a literature review and study of reports of Indian government as well as other agencies to understand the current state of rice farming, and small-scale farmers in the country. The authors felt that using design methods would be an easier way of assessing and understanding the data collected from various sources of information to determine possible avenues of design intervention. We looked at ways of visualising the data like using morphological charts and tables. However, we felt a mind map for a more intuitive and designerly way of representing the data which could then be used as a prompt during farmer's workshops and interviews. A map was created depicting the stages of rice farming to understand the flow of activities as well as different operations, to aid the visualisation of this data.

Commonly available tools used at each stage were then added to this map. The information regarding tools and stages of rice was taken mostly from various sources like resource person at BAIF Development Research Foundation (formerly known as Bharatiya Agro Industries Foundation), report on Indian small-scale farmers by Food and Agricultural Association of the united nations (FAO) [10] and a website about paddy farming in India [8] along with image search using the Internet (ref. appendix). These tools were then added to the map by linking them to the activities where they are used. The addition of tools helped create an overlay which showed choices available in the form of techniques for some activities and also linked all the activities to the most commonly used tools.

37.3 Outcomes

A map of stages of rice farming (Fig. 37.1), as well as tools used at each stage (Fig. 37.2), was prepared for better data visualisation. Farming can be broadly divided into three major stages:

1. Pre-production, which involves preparing the land for sowing seeds.
2. Growth, which involves activities from sowing and tending the plant till it reaches harvest stage.
3. Post-production, which involves harvesting and post-harvest activities till storage and transport of the crop.

These form the first layer of the map. The next level classifies the 13 rice farming activities into these three categories. The third layer either breaks down the activities into further steps or provides options in techniques for some activities (Fig. 37.1).

The overlay provides common options available while selecting tools and equipment for the various rice farming activities (Fig. 37.2). The small and marginal farmers usually rent larger equipment from Custom Hiring Centres if possible or rely on traditional tools and equipment.

The overlay of tools (Fig. 37.2) clearly shows that while we have a lot of different type of equipment and tools for activities of pre-production and harvesting, there

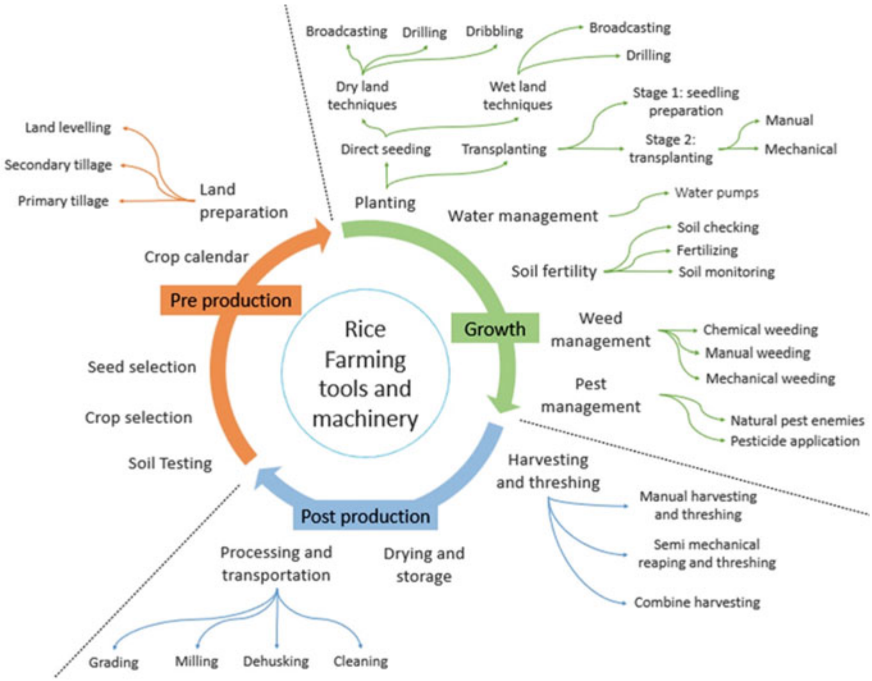

Fig. 37.1 A map of various stages and activities of rice farming

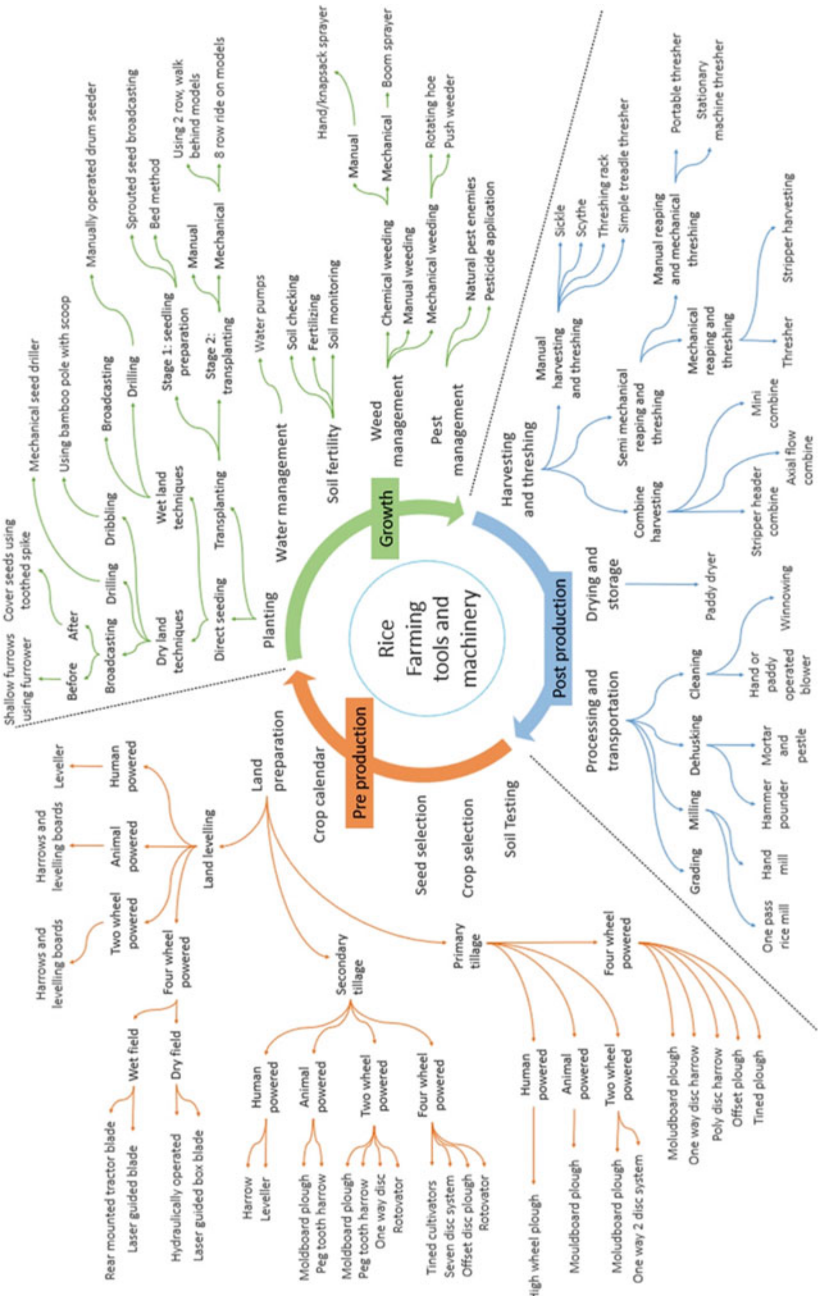

Fig. 37.2 A map of tools used in various stages of rice farming

seems to be a lack of appropriate solutions for activities like weeding, transplanting and irrigation which would cater to the needs of small and marginal rice farmers.

Modern machinery and equipment are available for most of the farm activities. However, these machines are either too costly or require a skilled operator for effective use. There seems to be a gap between powered equipment with high capital as well as running cost and the traditional tools like a sickle which the small and marginal farmers seem to favour.

37.4 Discussion

The outcomes of this research have led to a clearer understanding of the gaps in existing solutions as well as areas which need more work so that specific focus areas for design intervention can be later identified. The overlays also aid in understanding the relationship between existing solutions and farm activities, which helps in identifying gaps like a lack of intermediate solution which bridges the gap between powered farm machinery and traditional animal-driven or handheld tools.

There is an urgent need for design and development of ergonomic, low cost, context-specific, locally manufactured tools and machines which should cater to the needs of the small-scale and marginal farmers without increasing the cost. The existing solutions on the market seem to be designed with a top-down approach which does not cater to these farmers' needs completely or have high running costs. These tools also affect technology diffusion and adoption by small-scale farmers. With respect to areas for further work, irrigation, transplanting and weeding seem to be the most urgent needs.

The visual mapping of activities and tools provides a way of observing and understanding relationships along with interdependencies between tools and activities as well as gaps in solutions available for some activities. These maps could aid in further research and study, which would ideally lead to the formation of a design framework. This framework would use essential factors identified by extensive user study and farmer participation to enable the development of solutions which are low cost, cater to user needs and are more susceptible to adoption and use of small-scale farmers. We are currently in the process of developing a framework as well as designing a tool on the bases of insights gained from work shown in the paper. We hope that the validation of the tool once field-tested would help in validating the findings presented in the paper.

37.5 Conclusion

The authors started with formal research through what is present in the published literature. Initially, it was decided to limit the scope of the study to rice farming and focus specifically on different stages and the tools used. A map and morphological representation of how rice farming activity is carried out through different stages were prepared. The amount of data from various sources was represented visually in two different layers. The overlay and the map could make a strong reference point for further studies as they allow easier understanding of activities in rice farming and provides an overview of available solutions for those activities. Also, we feel that the method used is a good example of how a designer can try and identify research or design potential in such domains.

However, the research is currently based on only one crop in one region of the state, and further research is planned to expand and refine the mind maps as more data about available tool alternatives, farm techniques and needs and wants of small and marginal farmers are added as overlays.

There is a need for further research and study which would ideally lead to a formation of a design framework which would use effective factors identified by extensive user study and farmer participation to enable the development of solutions which are low cost, cater to user needs and are more susceptible to adoption and use of small-scale farmers.

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Chapter 38
Design, Development and Experimental Evaluation of a Transfer Assistive Device for Paraplegic Individuals Using Biomechanical Analysis

Kelifa Seid Mahammad and Amarendra Kumar Das

Abstract The present study aimed at designing a simple, yet safe transfer assistive device for lower-limb impaired individuals in the context of a developing country. A novel design methodology was adopted by combining the product design process with the concepts of biomechanics, anthropometry and human dynamics in a human–machine environment. The first phase of this paper elucidates design conceptualization using biomechanics in a human–machine environment. The second phase investigates experimental validation of the manufactured prototype concerning the user's experience. Inertial parameters and design inputs were extracted from this setup that helped in the development of the 3D model. To evaluate the present device in terms of user's comfort of use and level of physical strain, subjects including 19 healthy students serving as "patients" have participated in a laboratory-simulated setting. Data was collected based on user's physiologic effort and rate of perceived exertion using heart rate monitoring device (Polar RS 400 heart taster) and Borg's scale, respectively. The data was analyzed statistically and revealed that the regression equation for predicting the RPE from HR showed 31.3% of the variance in RPE was predictable from the level of HR. The ANOVA significance also indicates that the model is statistically significant with ($p < 0.013$). Similarly, the estimated strain level has computed in terms of %HRR, and the physical strain averaged over the subjects who performed the task ($n = 19$) was expressed in terms of (mean $\pm$ SD) %HRR were ($16.21 \pm 7.64\%$) which was a relatively smaller strain level as compared to the previous research report.

38.1 Introduction

World health organization "WHO" estimates that over 650 million people live with disabilities worldwide or 1 in 10 of the world's population, of those, 80% live in low-income countries with inadequate access to health and rehabilitation services [1].

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A. Chakrabarti et al. (eds.), *Design for Tomorrow–Volume 3*,
Smart Innovation, Systems and Technologies 223,
https://doi.org/10.1007/978-981-16-0084-5_38

Similarly, in many low- and middle-income countries, only 5–15% of people who require assistive devices (ADs) and technologies have access to them, and among the investigated source of disabilities, common causes of disabilities are found to arise from injuries either at home, work or from violence and landmines [2]. Temporary or inexperience wheelchair users are often unaware of the fall risks and attempt to transfer themselves from wheelchair to bed/toilet and experience a dangerous fall due to improper or unassisted transfers, such types of fall also common even for most of the experienced users. According to the study made by occupational safety and health administration (OSHA) [3], stated that, the use of transfer devices or lifting equipment in healthcare center and at the home setting is indispensable to reduce exposure to manual lifting injuries by up to 95% for both healthcare workers and patients while improving the quality of patient care.

Exploring the level of physical strain during the activity of daily living (ADL) among the lower-limb impaired community is indispensable. Some investigations carried out on the evaluation of activity related tasks such as in physical exercises through the combination of heart rate (HR) and rate of perceived exertion (RPE) to determine the association between RPE scores and HR. But only few research studies have applied this method in evaluating the subject's physiological feelings during various activities [4–6]. It has been stated that the heart rate expressed as a percentage of the heart rate reserve (%HHR) provides a relative measure to estimate physical strain. HRR is the amount of cushion in heartbeats available for any activities [6]; to determine physical strain, heart rate was expressed as a percentage of the individual heart rate reserve (HRR). Among the above studies, the use of a percentage of heart rate reserve %HRR is shown as a good estimator of the strain level in lower physical activities, and they have been investigated on wheelchair user while performing their ADL tasks manually [5].

38.2 Design Methodology

The design methodologies adopted in this report was systemized into two phases, where the first phase elucidates the methods applied from design conceptualization up to analysis and product detailing, and it has been processed in a digital human modeling (DHM) workbench of Catia v5 using manikin as a human biomechanical model in a pre-defined posture. In this paper, DHM environment of the ergonomics design and analysis workbench was employed which comprises a human builder and measurements editor options to invoke the appropriate human models and to perform the anthropometric adjustments. Similarly, it consists of a human activity and posture analysis option which can help to render an appropriate comfort angle for the chosen posture. In this phase, a graphical and analytical method of determining the design parameters from inertial parameters was adopted in a human–machine context. Based on the extracted design parameters, product detailing and prototype development of the transfer assistive device was decided. The second phase was devoted on investigating the experimental validation of the manufactured prototype using subjective physiological measurement, and quantitative analysis was applied using SPSS to quantify the user's experience.

38.2.1 Product Ideation and Conceptualization

The initial concept ideation and mechanism synthesis are taken as one of the crucial stages for developing the new product or improving the existing one through a potential and innovative solution. The rationale for the conception of the proposed transfer assistive device (TAD) grew out of the currently existing issues such as increasing rate of lower-limb impairments and limitations of mobility or transfer aiding devices as well as the shortcomings observed in the literature review. Whole body forward pivoting and turning principles were chosen as a means of transferring from wheelchair to another seat and vice versa. The forward pivoting and turning principle require that the subject who is initially sitting on a wheelchair seat should bend slightly forward and displace to the front edge of the wheelchair seat; this method was proposed intentionally to allow for the center of mass of the subject move forward so as to create a smooth forward curvilinear motion. Thus, with the upper abdominal part supported by the saddle and both hands allowed to grip the handles, a forward pivoting/lifting and turning process will take place sequentially. Figure 38.1a shows the preliminary ideation of the preferred transfer method.

Figure 38.1b shows the main parts of the two general categories of candidate mechanisms in a line diagram (without actuators) such as four bar slider mechanism represented with line "OR" and "OQ" as first and second phase, respectively, and modified scissor mechanism represented with line "OPR" and "OPQ" as first and second phase, respectively. It was considered as the two candidate concepts that can accomplish the desired tasks but throughout this report, only the first mechanism has

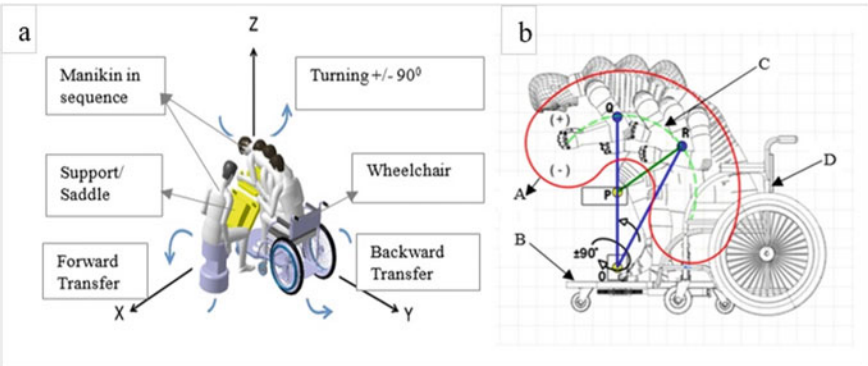

Fig. 38.1 **a** Three phases of transferring methods in the proposed concept ideation, **b** Proposed mechanism simulated in DHM environment (only sagittal plane is considered). [A. reach envelop, B. platform base, C. average trajectory curve and D. wheelchair]

been adopted as it was taken as the best concept. Point ‘Q’ and ‘R’ denote the location of the support/saddle, and the (+) and (–) signs indicate the two extreme positions for larger and smaller individuals, respectively. The transfer can be accomplished based on three phases such as forward transfer, turning by ±90° and finally back-transfer, and the mechanism synthesis and 3D model development of the proposed device have been processed based on the virtual motion planning by considering the digitized dynamic posture of the manikin simulated in DHM. Further, details related to mechanism synthesis, final concept selection and concept evaluation processes were accomplished in our previously published report [7].

38.2.2 Design and Analysis of the Transfer Mechanism Based on Biomechanics Concepts.

The location of the body center of mass (CM) is useful for a wide range of biomechanics analyses relevant to the design of seats, chairs, restraint systems and other products and environments intended for human use [8]. In order to compute the actuator specifications such as the load, it produces to raise/turn the users; it is necessary to substitute the manikin’s body dimensions with a known anthropometric data; similarly, the worst design scenario cases are also taken into consideration, since it gives an insight in determining the fit between human–machine and the maximum lifting limit of the device before failure. Although the proposed concept is designed to be adjustable to accommodate a wide range of population (5th to 95th percentile), but for the purpose of analysis the upper extreme, i.e., 95th percentile is chosen to better identify the maximum load needed by the actuator. Hence, the assumed manikin will be modified to match a 95th percentile anthropometric data of adult Indian male with height and weight of 1.78 m and 76 kg, respectively, as taken from Indian anthropometric database generated by Chakrabarti [9].

38.2.3 Computation of Center of Mass (CM) in the Context of a Human–Machine Environment

Previous researchers have presented empirical relationship that estimates the mass and the location of the center of mass of the various segments based on cadaver studies, geometric mathematical models and whole-body laser scan to estimate the location of CM of a whole body in a relaxed seated posture [10–13]. Almost all of the above studies have followed a similar fashion for determining the CM in a similar posture without the inclusion of the environment of the subject under consideration. In this paper, a novel way of determining the center of mass location graphically in a human–machine environment was adopted along with the prediction method of inertial data taken from the above studies. The sagittal plane view of the combined

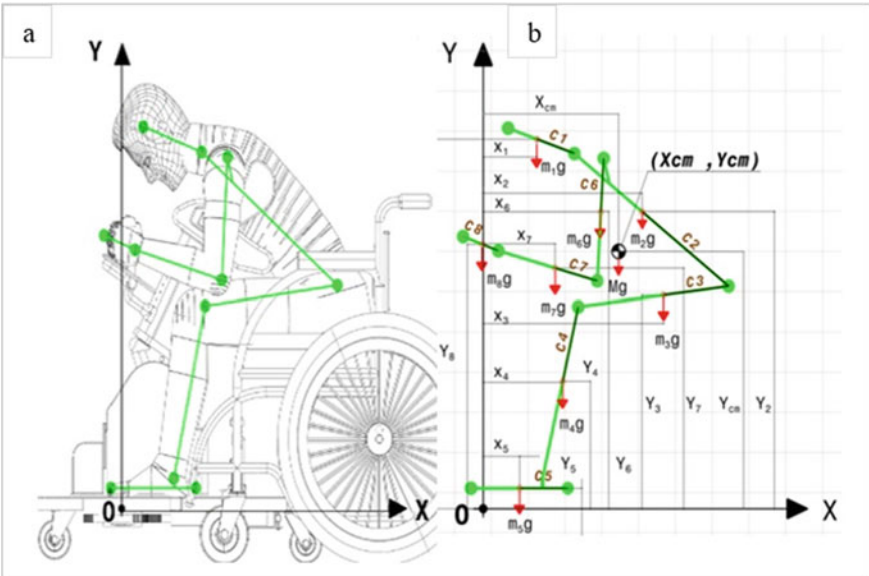

Fig. 38.2 **a** Modified manikin in a pre-defined posture, **b** stick diagram with the computed inertial parameters

subject transfers setup with the modified manikin which is exported from digital human modeling environment, and the link representation of the human model is shown in Fig. 38.2; each segment length is the computed values for the respective body segments. The downward arrows at the distance of the center of mass from proximal end of each segments indicated by (C1 to C8) is a point of application of gravitational force. The general equation for estimating the center of mass was adopted for the final calculation. The center of mass for the rotating part of the frame can be computed after defining its geometry as well as material properties of the frame which is used as an input for computing the same in CAD software such as Catia V5 which is adopted for current analysis.

Thus, the simulated result for the center of gravity or more commonly the center of mass of the frame is located near to the saddle as shown in Fig. 38.3a; the coordinates are ($X_{f,} = 204.12$ mm and $Y_f = 400.84$ mm) and denoted by Gf. Although the present analysis is undertaken with a human–machine context, a single or common center of mass is mandatory in order to handle or apply an equilibrium equation; thus, to determine the common center of mass between the frame Gf and the subject Gs, the following combined equation is used.

$$\left(X_{sf,} Y_{sf}\right) = \left[\frac{m_s x_s + m_f x_f}{m_s + m_f}, \frac{m_s y_s + m_f y_f}{m_s + m_f}\right] \tag{38.1}$$

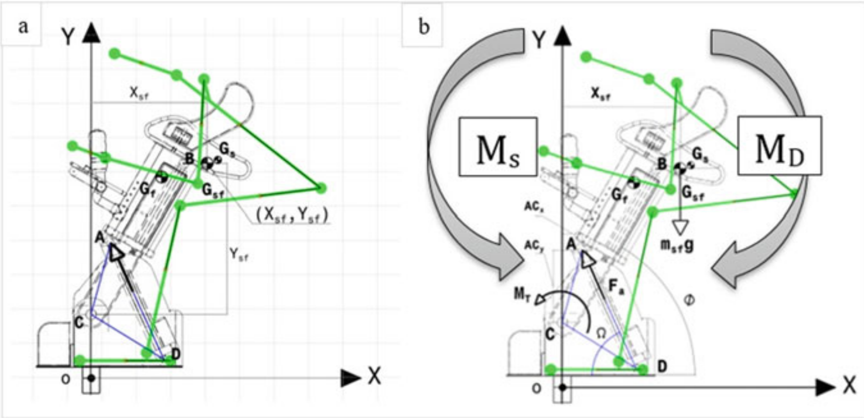

Fig. 38.3 **a** Center of mass of the frame Gf and **b** common center of mass G_{sf} coordinate as measured from the pivot of point c

where $X_{sf,} Y_{sf}$ are the common center of mass coordinates from pivot of point c; m_s, m_f are the masses of the subject and the frame, respectively; similarly, x_s, x_f y_s and y_f are centroidal distance from the center of mass of the subject and the frame with respect to X and Y axis, respectively. The common center of mass is located slightly below the center of mass of the subject Gs as shown in Fig. 38.3b and denoted as G_{sf}.

38.2.4 Design and Selection of Actuator for the Transfer Device in the Context of a Human–Machine Environment

Figure 38.3b comprises a geometrical parameters such as the actuator inclination angle Ω measured counter clockwise from horizontal and the main frame inclination angle Ø measured clockwise from horizontal. The worst case of transfer phase is considered for this analysis, which requires the maximum effort from the actuators, and this occurs during the initial phase of lifting the subject; thus, for the present subject—device interaction, it occurs when the main frame is at an angle of $Ø = 60$ and from the horizontal and when the actuator angle is at $\Omega = 65.51°$ from horizontal as shown in Fig. 38.3b. In order to estimate the maximum actuator force (Fa) needed for the worst-case scenario, analysis of stability equation will sound more reliable, and it was adopted to precisely compute the optimum actuator load Fa; the stability equation states that stabilizing moment MS ≥ MD destabilizing moment; thus, the actuator load Fa with respect to the combined mass of frame and subject (m_{sf}) can be estimated from equation of stability as:

$$F_a \geq \frac{m_{\mathrm{sf}} \times g \times X_{\mathrm{sf}}}{A_{\mathrm{CY}} \cos \Omega + A_{\mathrm{CX}} \sin \Omega} \tag{38.2}$$

The final decisions for locating the effective position of the actuator are one of the crucial design criteria in the process of a linear actuator design for patient lifting mechanism; therefore, based on the orientation of a load application coordinate point A (A_{CX}, A_{CY}), the corresponding force Fa which is expected from the actuator will change radically due to a change in the coordinate point (A) for the same subject in a given posture as discussed previously. Thus, using equation of stability from Eq. 38.2, the optimum location of actuator can be estimated for critically selected locations of the following four coordinate point A (A_{CX}, A_{CY}). These have been measured graphically and made to vary due to the change in actuator's orientation angle Ω such as for the four cases under consideration the coordinates A_{CX}, A_{CY}, and the actuator inclination angle Ω is taken as (0,0.0817 and 450), (0.0568, 0.208 and 65.510), (0.0853,0.147 and 65.510) and (0.211,0.282 and 900) for Case I, II, III and IV, respectively; the two cases (I and III) are made same angle but have different coordinate point due to variations in their actuator stroke length. Based on the measured quantities, the corresponding estimated results are plotted graphically in Fig. 38.4. All computed results of the actuator loads are able to perform the given task but due to some ergonomic aspects such as comfort and safety, the layout in case-IV cannot provide enough space for the user to freely perform the transfer activities although it provides a minimum lifting force; in addition to this, it needs a special actuator with a longer stroke of 130 mm to cover the required range. The layout in case-I is a very compact design, since it is made closer to the pivot point C, but due to a smaller moment arm of 58 mm, it requires an extremely high turning moment to lift the users; thus, it leads in the use of an expensive actuators. Similarly, the layout in case-III is also somewhat compact but it is difficult to have such a short stroke actuator of 46 mm with the specified load requirements.

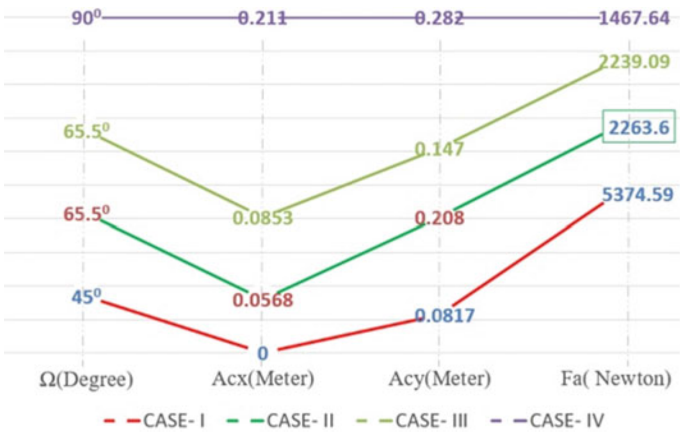

Fig. 38.4 Estimated actuator load (Fa) with respect to the three parameters

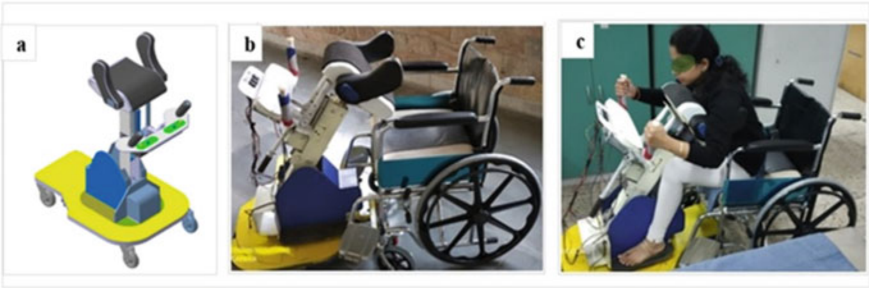

Fig. 38.5 **a** 3D model of TAD, **b** working prototype of TAD and a wheelchair in transfer set up mode and **c** subject during pre-testing

Therefore, the layout in case-II with values listed above is found to be the optimum range of the actuator force Fa based on the combined analysis of the inertial parameters found from biomechanics and stability equation in the human–machine interaction.

38.2.5 Design Features of the Proposed TAD

The present prototype was made to comprise three low-cost and simple linear actuators as a prime mover, which could be controlled easily using an ordinary double pole double throw (DPDT) switches either by the user or caregiver. The pre-testing of the completed prototype (TAD) was carried out with normal healthy volunteers with the maximum weight of 105 kg in addition to a pre-specified 95th percentile of Indian male adult which is estimated as 76 kg. The 3D model working prototype together with a standard wheelchair and a subject in a transfer mode for pre-testing session is shown in Fig. 38.5a–c, respectively.

38.3 Statistical Analysis for Estimating the Strain Level of a Subject During the Transfer Activities

38.3.1 Subjects and Data Collection

The study design in this experiment was a pilot study with healthy students serving as "patients" in a laboratory-simulated setting. The subjects comprising 19 healthy adults including fifty males and four females with mean ± SD of age, weight and height of (30.94 ± 6.3) year, (68.57 ± 11) kg and (170.31 ± 9.5) cm, respectively, were recruited from Indian Institute of Technology, Guwahati, IITG. Before proceeding the experiment, subjects are asked about their health conditions, demographic information and told about the protocol of the study by showing a demo task made by one of the study coordinators. The type of equipment used for data collection is as follows: light manual wheelchair, working prototype of TAD, sample bed/chair, heart rate monitoring device (Polar RS 400 heart taster). The heart rate monitoring device comprises a wristwatch and chest belt wirelessly connected to a Polar Pro 5 Software. The heart rate recording was made to start once the test subject wears the wristwatch, the chest belt and ready in a position of transfer, i.e., sitting on a wheelchair, as shown in Fig. 38.2. In the first phase, heart rate data was monitored from 19 healthy subjects who have completed the assigned task using Polar RS 400 heart monitors that sampled with a 5 s interval period. The average time required for the subject to transfer from wheelchair to bed was found around 55 s irrespective of the time lost during preparation. After completing the transfer, subjects are taken out of the wheelchair to properly share their feelings experienced during transfer in terms of perceived exertion on a BORG scale [14]. To estimate the strain level encountered during transfer and to evaluate the design features of the prototype, a questionnaire list containing BORG and Likert scale type questions was given for each subject. Statistical analyses were performed using SPSS version 20.0. The HR and RPE data collected during transfer activities from 19 test subjects are expressed in terms of mean ± SD which are given as (87.73 ± 8.4) and (13.05 ± 1.7) for heart rate and RPE, respectively. To precisely determine the predicted outcomes from the correlation of independent physiologic response HR and a dependent RPE, a linear regression model was performed. The normality of the two variables is checked using the normal P-P plot, and the regression line indicated that the two variables are positively correlated; the ANOVA significance also shows the model which is statistically significant with ($p < 0.013$).

38.4 Results

38.4.1 Statistical Results

A bivariate regression was conducted to examine how well the subject's rate of heartbeat while performing a transfer activity could predict the level of the rate of perceived exertion. A scatterplot showed that the relationship between the rate of heartbeat and rate of perceived exertion was positive and linear and did not reveal any bivariate outliers. The correlation between the rate of heartbeat and rate of perceived exertion was statistically significant $r\,(17) = 0.56, p < 0.013$. The regression equation for predicting the RPE from HR was ($y = 2.730 + 0.118x$). The r^2 for this equation was 0.313 which means that 31.3% of the variance in RPE was predictable from the level of HR, which shows moderately a good relationship.

Estimated Physical Strain Level. The value of heart rate monitored with a Polar RS 400 heart monitors was used to estimate the physical strain. Heart rate monitoring

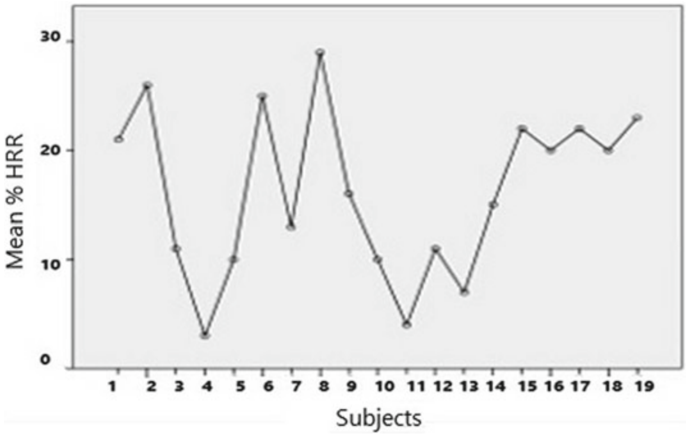

Fig. 38.6 Mean percentage of heart rate reserve (%HRR) computed from each subject during transfer tasks from wheelchair to bed/chair

was sampled with a 5 s interval period. The heart rate expressed as a percentage of the heart rate reserve (%HRR) which provides a relative measure to estimate physical strain. Therefore, heart rate was expressed as a percentage of the individual heart rate reserve (HRR) according to the NASA physical activity scale formula: which was given as Eq. (38.3),

$$\%\mathrm{HRR} = \frac{\mathrm{HR}_{\mathrm{AC}} - \mathrm{HR}_{R}}{\mathrm{HR}_{\max} - \mathrm{HR}_{R}} \times 100\% \tag{38.3}$$

where $\mathrm{HR}_{\mathrm{AC}}$, HR_{R} and $\mathrm{HR}_{\max}$ are the heart rate, heart rate at rest and maximum heart rate recorded by the Polar RS 400 heart taster during transfer activities, respectively; the overall computed mean %HRR values concerning the potential test subjects are shown in Fig. 38.6.

38.5 Discussion

The primary objectives of this research project were to develop an alternative design methodology in the field of product development related to assistive device that could help for designing a simple and yet safe, transfer assistive device that meets the requirements of a lower-limb impaired individuals living in lower-income developing countries, and to evaluate its comfort of use through physiologic measures of effort. Among the three interfacing parts (handle, saddle /chest support and the underarm support) between the user and the TAD, more attention was given for the underarm support also known as armpit support; because it is one of the interfacing part that overtakes majority of the loads during transfer activities; hence, it is evident that a well-designed underarm support would enhance the degree of the user interface, comfort of use, thereby reducing intensity of strain level. The two simple and novel designs incorporated in the present TAD are the unique features of underarm support and a lower turning drive system as shown in Fig. 38.7a and b, respectively. Firstly, it enabled the users to smoothly move toward the chest support; this was due to ergonomically designed underarm support having a curved shape to enable the sliding action between the subject's armpit and the upper portion of the underarm support. The sliding action of the underarm support allowed the reduction of the strain level; this was due to the curved shape of the underarm support that has the ability to generate a dynamic friction to overcome the inertia of the supported body at rest. Thus reducing the strenuous effect that might occur if a prolonged static contact between the subject's armpit and the upper portion of the underarm support exists. Secondly, the underarm support has helped users to safely and freely transfer their entire body without the need of handling the device's handle, especially for users who have limited or no strength to hold the handle for keeping stability while in transferring process.

Currently, many transfer devices that work based on "sitting forward pivot transfer" (SFPT) [15–18] have been developed, including a commercially available one which is slightly similar to our TAD. Still, they do not have underarm support that provides the above unique features during transfer activities. Hence, users who are using a transfer device without being supported by underarm are more susceptible to fatigue and sudden fall. Additionally, most of such devices require a substantial effort from the caregiver's side to help the users perform a transfer task. The unique feature of turning mechanism reveals the unconventional use of rack and pinion; in this design, the rack gear attached to the bottom of linear actuator was made to drive the pinion mounted on the main rotating shaft of the fame. This novel feature eliminated the need for auxiliary units such as gear reduction box which is obvious to impose additional costs, such as the initial design cost and the time taken during fabrication and assembly process; moreover, if such and similar auxiliary units are intended to be included in the system, it requires an additional space that might lead to a bulky final product. Previous studies related to transfer devices have used different

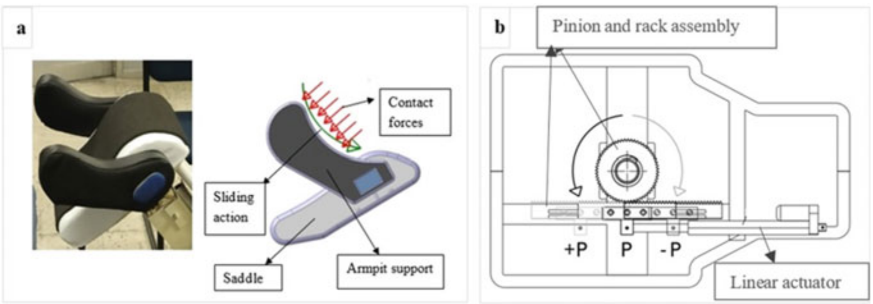

Fig. 38.7 **a** Armpit support mechanism. [Physical prototype (left) and CAD model (right)] and **b** lower turning drive system

turning mechanisms such as the use of omnidirectional wheels has been adopted in one study as a means of turning the user to specific locations [15]. Manually turning the device by caregivers or by the users itself and in another study, they have used an epicyclic gear as a reduction unit along with a rotary motor instead of using the linear actuators [16, 17].

The findings obtained during physiologic measurement revealed that the strain level averaged over the subjects who performed the task was expressed in terms of (mean $\pm$ SD) %HRR. The result (16.21 $\pm$ 7.64% HRR) was relatively smaller as compared to the previous study made by Janssen [5]. The previous studies' report was performed on wheelchair users who are physically fit in the upper half and are able to transfer independently; the activities were based on the selected ADL task; such as, manually transferring from wheelchair to bed (35.1 $\pm$ 10.5% HRR). This result could be an evidence that our device TAD helped to minimize the amount of strain level that might be created during unassisted transfer or without the use of a transfer device. The present equipment could be an ideal transfer device for lower-limb impaired individuals in terms of safety, design simplicity and minimum design cost, especially who are living in low-income developing country. The limitation of the present study was that it was carried out in laboratory simulated settings using students as a patient. Thus, further studies are required to investigate the research under real patient transfer conditions.

38.6 Conclusion

The present study primarily has investigated how the high level of compatibility between the 3D conceptual model and the final product requirement which is suitable for the end users could be achieved proactively through the adoption of the new design methodology. Similarly, the use of innovative ideas in a human–machine environment at the beginning of the design process had successfully optimized the overall design process in terms of choosing an appropriate and cost-effective component that could fit and work in a compact space without extra auxiliary unit. The transfer assistive device (TAD) developed in this study had also contributed a unique feature such as the armpit support. It acts to dynamically reduce the contact force due to the curvature profile of the underarm support and also helps as a double safety support to prevent a sudden fall that might occur due to unconscious release of the device handle, which is the frequent cases of fall in most transfer assistive devices. Currently, a subsequent study is going on to conduct further experiments with a real patient and their caregivers at a healthcare setting and finally to conclude its effectiveness and applicability in low-income developing country.

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Chapter 39
Effect of Different Root Canal Filling Materials in Endo-perio Lesions: Design and Computational Analysis

Anupam Purwar and Pragya

Abstract Dental problems are mostly multi-factorial in nature and thus difficult to diagnose and treat. A tooth infection which leads to degeneration of pulp and subsequent loss of tooth vitality is called an endodontic lesion, whereas a disease affecting the supporting structures of tooth such as bone/ligament is known as periodontal lesion. When an infection is identified with both endodontic and periodontal involvement, it is termed as endo-perio lesion. Endo-perio lesion (EP) is a complex disease entity which involves the tooth structure as well as the supporting periodontium. This study was conducted with an aim to assess the effect of different root canal filling materials on different classes of endo-perio lesions (Simon's Classification, 1972) using computational modelling, thus enabling the clinician in making an informed decision for treatment planning of endo-perio lesions. In present work, mandibular molar human tooth with lesion (damage to tooth/surrounding tissue) has been precisely modelled in consultation with a clinician (Dentist). Then, four different finite element models representing one healthy tooth and root canal treated tooth with endo-perio lesion (one filled with gutta-percha, one filled with MTA, one filled with biodentine) were designed. Next, finite element models were validated with experimental data for a normal tooth under a defined (300 N) masticatory load. Biodentine as filler has not been investigated so far, for its performance in a simulated study while considering all the individual parts of tooth and their properties. However, biodentine was suggested as an alternative to mineral trioxide aggregate (MTA) and has better regenerative capacity due to its bioactive nature. In this perspective, our study provides clinical inputs to dentists regarding use of biodentine as filler. Such cross-disciplinary work involving a design engineer and a clinician also demonstrates the importance of collaborative research for getting meaningful design insights in biomedical sciences. The insights from this finite element-based investigation are being used currently for therapeutic purpose by clinicians.

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A. Chakrabarti et al. (eds.), *Design for Tomorrow–Volume 3*,
Smart Innovation, Systems and Technologies 223,
https://doi.org/10.1007/978-981-16-0084-5_39

39.1 Introduction

Dental problems are mostly multi-factorial in nature and thus difficult to diagnose and treat. Another fact which makes these problems complex is that it is difficult to contain the disease in a particular part of the dental unit. If not diagnosed and treated at an initial stage, the disease progresses and spreads to oral structures other than the native site of infection in most of the cases. The tooth, the pulp (part of the tooth in the centre which is made up of living connective tissue, blood vessels and nerves) within it and the specialized tissues that both surround and support the tooth (periodontium) should be viewed as one biologic unit.

The relationship between the periodontium and the pulp was first discovered by Simring and Goldberg in 1964 [1]. The periodontium and pulp have embryonic, anatomic and functional interrelationship. Ectomesenchymal cells proliferate to form the dental papilla and follicle, which are the precursors of the periodontium and the pulp, respectively. This link in embryonic development gives rise to anatomical connections, which remain throughout life. As a result of this predetermined interrelationship of these structures, they influence each other during health, function and disease.

Endodontic-periodontal lesions (EP) are complex disease entities which involves the pulp of tooth structure (endodontic) as well as the supporting periodontium (periodontal). These lesions present challenges to the clinician as far as diagnosis and prognosis of the involved teeth are concerned. The interrelationship between periodontal and endodontic diseases has aroused much speculation, confusion and controversy. Etiologic factors such as bacteria, fungi and viruses as well as various contributing factors such as trauma, root resorptions, perforations and dental malformations play an important role in the development and progression of such lesions [2]. The periodontal-endodontic lesion develops by extension of either periodontal destruction combining with an existing periapical lesion or an endodontic lesion combining with an existing periodontal lesion. From the diagnostic point of view, it is important to realize that as long as the pulp remains vital, although inflamed or scarred, it is unlikely to produce irritants that are sufficient to cause pronounced breakdown of the periodontium [3]. Thus, a close relationship exists between disease of the dental pulp and periodontal disease, and it expresses itself in several ways. The most commonly used classification was given by Simon, Glick and Frank as follows: (1) primary endodontic, (2) primary periodontal, (3) primary periodontal secondary endodontic, lesion (4) primary endodontic secondary periodontal and (5) true combined lesion [4].

Treatment and prognosis of endodontic-periodontal diseases vary and depend on the cause and the correct diagnosis of each specific condition. Many studies in the literature indicate that combined periodontal and endodontic therapy is essential for successful healing of a periodontal-endodontic lesion. It has been said that either endodontic or periodontics treatment alone would not lead to a satisfactory prognosis, if both disease entities are present and that both must be considered together [5]. However, the decision of which aspect to treat first is made over which lesion came first and which caused or perpetuated the clinical problem. It is generally agreed that pulpal disease could initiate or perpetuate periodontal disease; the opposite theory is controversial [3]. Hence, for all the four classes of EP lesion except for primary periodontal lesion, the primary treatment modality suggested is endodontic therapy (treatment of the dental pulp) followed by periodontal surgery. Endodontic therapy consists of root canal therapy which is instituted immediately, and the cleaned and shaped root canal is filled with different root canal filling materials such as calcium hydroxide paste, gutta-percha, mineral trioxide aggregate (MTA) and biodentine. Assessment of the best root canal filling material in terms of stress caused by it in the apical area in each of the four classes of EP lesions is nearly impossible to do clinically. In this perspective, we have carried out this investigation to assess the effect of different root canal filling materials viz. gutta-percha, mineral trioxide aggregate (MTA) and Biodentine in endo-perio lesion using computational modelling, thus enabling the clinician in making a better and more informed decision to deliver treatment for endo-perio lesions.

39.2 Computational Modelling

39.2.1 Geometric Model

In the present work, mandibular molar human tooth with lesion has been precisely modelled through consultation with clinician spanning over 4 months to model every possible detail of tooth including various layers viz. enamel, dentin, cementum, root canal pulp and the surrounding cortical bone. The geometry used for the tooth model is based on average measurement of molar tooth and is in confirmation with the model from Wheeler et al. This model has been designated as the control, and one more model has been created from it simulating endo-perio lesion (Class: true combined lesion as classified by Simon et al.) [2] model. This was done by creating a periapical defect of radius 0.5 mm at the periapical area and creating a periodontal defect of 1 mm parallel to the root surface from the apex of the tooth, fusing with the periapical lesion till the coronal end of the cortical bone. Based on these models, four FEA models of endo-perio lesion were created, representing an unfilled tooth, a tooth filled with gutta-percha, a tooth filled with MTA and a tooth filled with biodentine. Autodesk inventor has been used rigorously to create a 3D reconstruction based on average of measurement of molars, as shown in Fig. 39.1. Post creation of tooth CAD model, geometric cleaning has been carried out to remove dangling edges and vertices for creation of a better-quality mesh. During the geometric cleaning, precautions have been taken to prevent the loss of critical geometric details of human tooth. The assembly of tooth and mandibular bone was carried out in ANSYS Workbench by assembling tooth component with respect to mandible and proper Boolean operations.

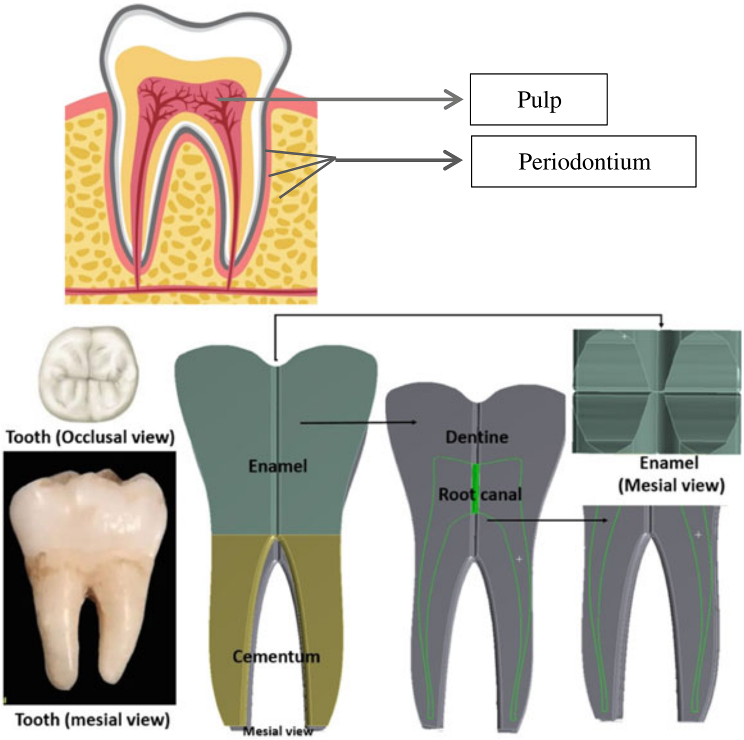

Fig. 39.1 Pictorial representation of pulp and periodontium and CAD model of tooth and different views

39.2.2 Finite Element Model

In the present work, mandibular molar human tooth with lesion has been precisely modelled in consultation with a clinician. Then, four different finite element models representing EP lesions with selection of four different filler materials have been developed. After the geometric modelling, the tooth along with surrounding cortical bone has been meshed using ANSYS using 10 node tetrahedral elements (SOLID187). The contact of tooth components and the surrounding the bony region was meshed finer (element size 0.1 mm) than the tooth (element size 0.5 mm) and rest of the mandible (element size dependent on curvature from 0.1 mm to 3 mm), as shown in Fig. 39.2. The material properties (i.e. density, Young's modulus and Poisson's ratio) to tooth and surrounding bone have been assigned in ANSYS based on the material of each tooth layer. Materials used in the study have been assumed to be homogenous and isotropic. Corresponding elastic properties, such as Young's modulus (E) and Poisson's ratio, were determined from the literature and summarized in Table 39.1. Because the authors could not find any FEA study simulating

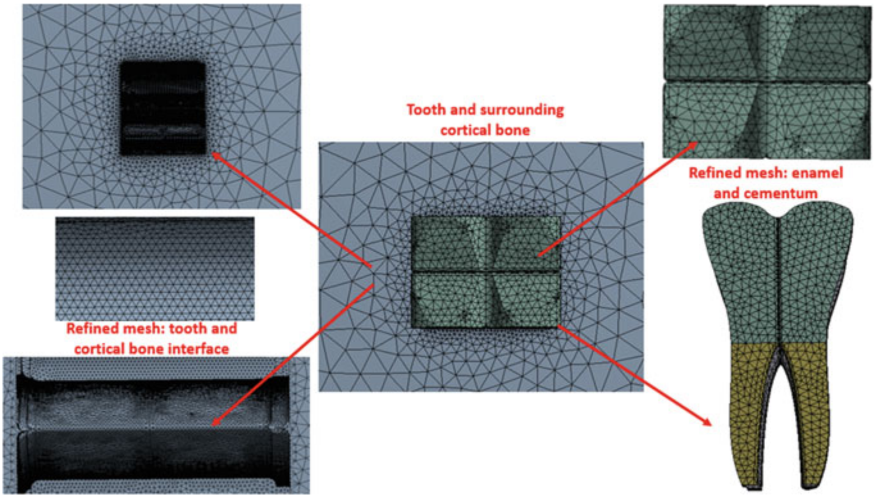

Fig. 39.2 Refined mesh of tooth and magnified view of mesh near bone-tooth interface

Table 39.1 Properties of different tissues of tooth and surrounding area

Material	Young's modulus (GPa)	Poisson's ratio	Density (kg/m^3)
Dentin	18.6	0.31	2700
Enamel	41	0.31	2800
Pulp	0.003	0.45	1077
Cementum	2.4	0.3	2100
Cortical bone	13.7	0.3	1850
Cancellous bone	1.37	0.26	1080

EP lesions and considering the structure of periapical lesions and bone defects, the lesions have been considered as having the same elastic modulus as pulp tissue.

39.2.3 Boundary Conditions and Assumptions

Next, the finite element models were validated with experimental data for a normal tooth under a defined (300 N) masticatory load. To calculate stress distributions, a 300-N static load was applied to the contact area at the buccal cusp of the crown. Results are presented considering von Mises criteria. To better visualize mechanical phenomena in the models, calculated numeric data were transformed into colour graphics. Sections obtained from the 3D models were used to present the stress distributions, and the colour scale was limited between 0 and 3 + MPa. Exterior nodes of the models' root structures were fixed in all directions as the boundary condition.

39.3 Results

The stress values in different regions of tooth have been estimated through FE-modelling. In particular, stress in three different regions apical third, middle third and coronal third has been estimated. Apical third represents lower 1/3rd of the root (away from the tooth crown) and bone surrounding it; middle third represents the middle 1/3rd of the root and bone surrounding it; coronal third represents upper 1/3rd of the root (towards the tooth crown) and bone surrounding it.

Table 39.2 denotes the value of stress at three sites on the root and three sites on the surrounding cortical bone. The stress is observed to be maximum at apical and coronal third on the root surface and on the cortical bone. The same is depicted in the FEA model of healthy tooth and alveolar bone (Fig. 39.3).

After filling root canal of tooth with biodentine, it is found that the stress level is significantly less at the apical and middle third of the infected root when compared to the middle third of the root, whereas the minimum stress in cortical bone was found at the apical third (Table 39.3).

On filling the root canal with gutta-percha, the stress on the root is found to be minimum at the coronal third, followed by apical third, followed by middle third of the root. On the cortical bone, stress is observed to be almost similar at all the three sites with marginally higher stress values at the middle third of the cortical bone surrounding root structure (Table 39.4).

The stress is noticed to be having the least value at coronal third of the tooth when root canal was filled with MTA with almost similar values at middle third and apical third. At cortical bone, the stress values are lowest at apical third and almost same at middle and coronal third (Table 39.5).

The use of biodentine shows least amount of stress in apical region of root, whereas teeth restored with MTA shows similar stress as the ones restored with biodentine in coronal and middle third (Table 39.6). Least stress at all three sites are observed on utilization of biodentine with significantly less stress at the apical third of the surrounding cortical bone (Table 39.7).

Table 39.2 Stress distribution in normal tooth without defect

Tooth area (MPa)	Tooth root	Surrounding cortical bone
Apical third	7.8	6.3
Middle third	2.4	1.4
Coronal third	8.4	5.7

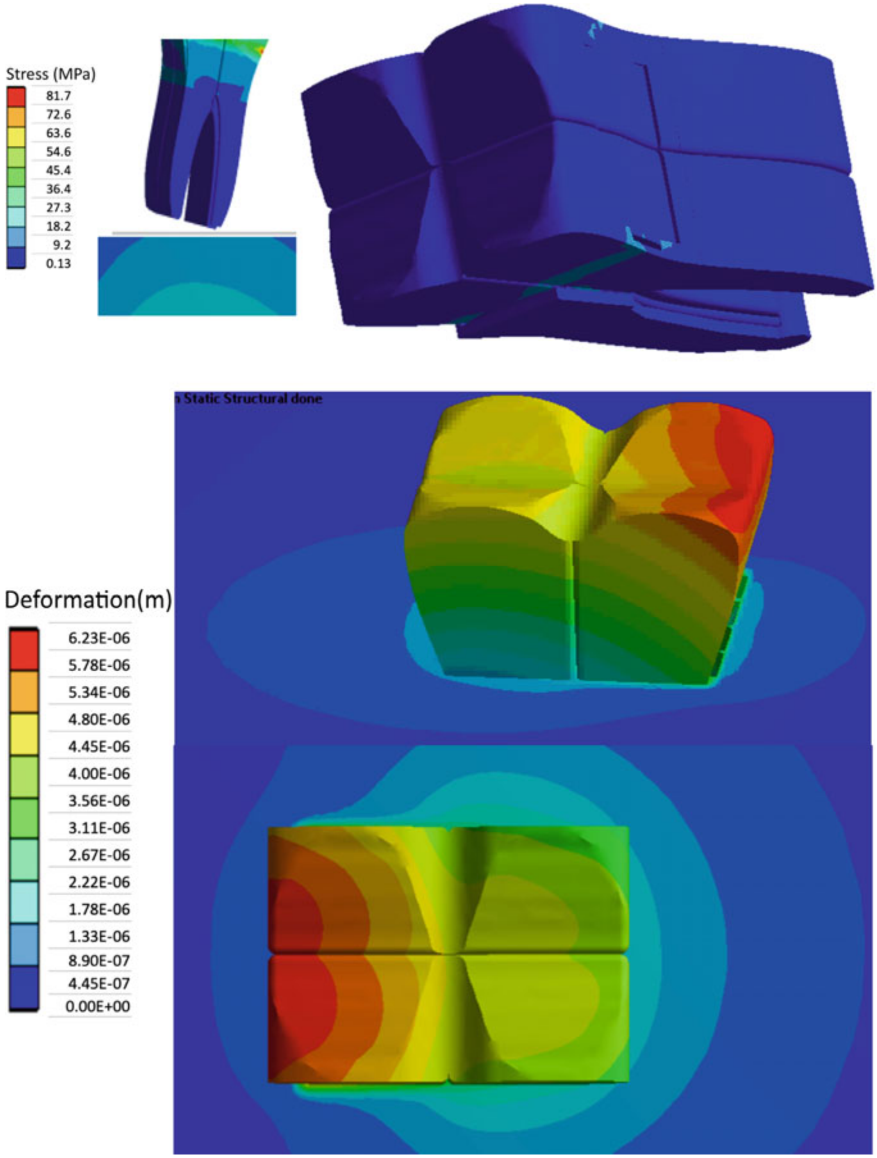

Fig. 39.3 Stress and deformation distribution on tooth and surrounding bone in normal tooth

Table 39.3 Stress distribution in root canal filled with biodentine

Max. stress (MPa)	Tooth root	Cortical bone
Apical third	0.1	1.0
Middle third	0.8	2.3
Coronal third	0.1	2.5

Table 39.4 Stress distribution in root canal filled with gutta-percha

Max. stress (MPa)	Tooth root	Cortical bone
Apical third	0.6	2.1
Middle third	1.5	2.8
Coronal third	0.3	2.5

Table 39.5 Stress distribution in root canal filled with MTA

Max. stress (MPa)	Tooth root	Cortical bone
Apical third	0.7	1.5
Middle third	0.8	2.3
Coronal third	0.1	2.7

Table 39.6 Comparison of stress distribution on tooth root on application of force after filling the root canal with different filler materials

Max. stress (MPa)	Gutta-percha	Biodentine	MTA
Apical third	0.6	0.1	0.7
Middle third	1.5	0.8	0.8
Coronal third	0.3	0.1	0.1
Compressive strength (MPa)	6.9–8.9 11.7–20 (UTS)	78–85	58–65

Table 39.7 Comparison of stress distribution on surrounding cortical bone on application of force after filling the root canal with different filler materials

Max. stress (MPa)	Gutta-percha	Biodentine	MTA
Apical third	2.1	1.0	1.5
Middle third	2.8	2.3	2.3
Coronal third	2.5	2.5	2.7

39.4 Discussion

Highly refined structured mesh with high fidelity second-order elements has been generated [6–11]. ANSYS has been used to perform structural analysis [8, 9]. The defect created for FEA analysis simulated true combined lesion (Class of endo-perio lesion). This class of endo-perio lesion shows endodontic as well as periodontal involvement of the tooth. The different filler material utilized in the study is biodentine, MTA and gutta-percha. Biodentine is new bioactive cement which in terms of performance resembles the widely used mineral trioxide with enhanced regenerative properties. It has dentine like mechanical properties, which may be considered a suitable material for clinical indications of dentin-pulp complex regeneration such as pulp capping [12]. Mineral trioxide (MTA) is a restorative material which prevents microleakage, is biocompatible and promotes regeneration of the original tissues when placed in contact with dental pulp or perradicular structure [13]. Gutta-percha is one of the oldest root canal filling material but it has been found to demonstrate a few microscopic inadequacies such as: irregularities in form and condensation, inadequate sealer dispersion, lack of demonstration of canal variations, lack of correlation with radiographs and roughness/pitting [14]. It was observed that stress reduced on the root and bone surface post root canal treatment. Also stress at the middle third of the root was consistently higher when compared to apical third and coronal third in filled root. This is in stark contrast to clinical studies which reported significant decrease in fracture strength with restoration [15]. However, filling of the root did not affect stress distribution. This study proves the highest efficacy of biodentine compared to MTA and gutta-percha in treatment of endo-perio lesion, followed by MTA and gutta-percha. This was in accordance with a study which concluded that biodentine composition resulted in enhanced chemical properties relative to MTA [12, 16].

39.5 Conclusion

The study concludes that biodentine when compared to gutta-percha and MTA exerts least stress on root surface and cortical bone surrounding the tooth on applying a force of 300 N. In clinical scenario, this can be possibly construed as, less stress on root of a root canal treated tooth infected with endo-perio lesion using biodentine on mastication. Lesser stress for prolonged period of time can decrease instances of tooth fracture of a root canal treated tooth. Further, clinical studies with long-term follow up shall be conducted to assess any difference in longevity of tooth due to fracture when biodentine is used as root canal filling material in endo-perio lesions. If it is so, the salvageability of a root canal treated tooth can be better in long term with the use of biodentine as root canal filler material. From the rigorous FE-analysis, it is plausible to suggest that:

1. Filling root canal with filler material reduces the stress at root and surrounding bone and with biodentine as filler due to better dissipation of compressive forces by applied filler.
2. Maximum stress in a filled tooth is consistently found to be at the middle third of the root.
3. Biodentine can be declared the better root canal filler material in endo-perio lesions as it showed least stress on root as well as the cortical bone post-treatment, especially in the apical region compared to gutta-percha and MTA.

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Chapter 40
Design of a Maternal Healthcare Monitoring Device for Pregnant Women

Deepika Gopalakrishnan, Pramoddini Warale, and Rahul Bhaumik

Abstract Around 800 maternal deaths occur every day from preventable causes related to pregnancy and childbirth. A majority of these deaths are caused due to pregnancy-related complications and occur in low-resource settings. To improve the current situation of maternal healthcare in rural areas, this paper proposes an IoT-based solution that monitors the vital signs of a pregnant woman and her foetus. At a socio-systemic level, the solution ensures communication of the vital data across relevant stakeholders (e.g. healthcare professionals, family members and others), thereby ensuring timely intervention in case of abnormalities. Several unmet needs and pain points of pregnant women were identified across the antenatal, intra-partum and post-partum stages of pregnancy from surveys, interviews and the literature, based on which a list of requirements was formulated. Ideas were generated against the finalized design brief, and preliminary evaluation was conducted to filter the ideas. Concepts were then explored from the set of viable ideas using different design methods like relational mapping, bundling and mash-ups. The proposed design seeks to reduce morbidity and prevent maternal deaths through the facilitation of timely medical intervention, by connecting various stakeholders involved at the time of pregnancy.

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A. Chakrabarti et al. (eds.), *Design for Tomorrow–Volume 3*,
Smart Innovation, Systems and Technologies 223,
https://doi.org/10.1007/978-981-16-0084-5_40

40.1 Introduction

40.1.1 Background

Despite progress made by countries in maternal health care and a decline in mortality rates over the last two decades, there were around 295,500 maternal deaths in 2017 [1]. India accounts for 12% of maternal deaths in the world as of 2017 [2]. This large number of deaths indicates that there are several underlying challenges in maternal healthcare. Poverty, distance from the healthcare centre, lack of information, cultural practices and inadequate services are a few factors that restrict women from receiving or seeking the required antenatal, intra-partum or post-partum care [3]. Since only a half of the women in low-resource settings receive adequate health care, this paper focuses on tackling problems in this context.

40.1.2 Literature Review Related to Gaps in Maternal Healthcare

The literature review was conducted in this regard to understand the problems faced by pregnant women and assess the existing solutions for the same. Around 18 challenges across the antenatal, intra-partum and post-partum phases of pregnancy were identified and grouped under three main themes: (a) to provide better moral, emotional and physical support for the pregnant woman, (b) to enhance access to quality care and (c) to provide adequate pregnancy-related information to the pregnant woman and her family. Table 40.1 highlights eight of these maternal healthcare challenges prevalent in low-resource settings. A critical view of the existing design interventions that aim to solve some of these problems is also provided in Table 40.1.

The literature study reveals that tackling individual challenges in isolation might not lead to a holistic solution since most of the mentioned problems are interrelated. Hence, there is a need for a solution at a systemic level that bridges the existing gaps in the domain of maternal health care.

40.2 Methodologies

A field study and a survey were carried out to understand the ground reality in a developing country (India) and empathize with the pregnant women and other stakeholders like midwives and obstetricians. For the field study, three hospitals in Karnataka were visited—(a) a Taluk hospital located in the outskirts of Bengaluru, catering to the needs of underprivileged women in rural areas, (b) a charitable hospital and (c) a corporate hospital in the city of Bengaluru. Expert interviews were conducted with

Table 40.1 Literature review of challenges and interventions in maternal health care

Maternal health challenges	Existing gaps and needs identified	Existing interventions	Shortcomings
Theme I: Providing moral, physical and emotional support to pregnant women			
Prevalence of stress in pregnant women: Several pregnant women experience increased anxiety levels about pregnancy and development of their child which leads to preeclampsia, prolonged labour, primary post-partum haemorrhage and clinical foetal distress [4]. Research relates antenatal maternal stress to emotional, behavioural and cognitive problems in the child [4]	There is a lack of access to information regarding anxiety, especially in pregnant women. Hence, providing access to information and effective communication to the patients can reduce stress amongst pregnant women [5]	Childbirth education classes intend to familiarize parents about the stresses of pregnancy and the procedure of delivery with a proven positive impact on the overall experience of the pregnancy period [6] 'Better Beginnings' is a service design tool under the 'Better Outcomes in Labour Difficulties', BOLD project initiated by WHO [7]. It focuses on frequent engagement with the healthcare facilities, improving the experience of a pregnant woman and her preparedness for childbirth	
Teenage pregnancy: Adolescent pregnancy has serious social and medical implications for maternal and child health [8]. It can lead to adverse pregnancy-related complications and neonatal outcomes [9]	Studies show that pregnant teenagers, whose reproductive systems are not yet fully developed, are often malnourished and anaemic [8]. They also experience a heightened level of emotional and psychological stress [10]	ARMMAN is an India-based non-profit organization committed to improving the well-being of pregnant women, newborn infants and children in the first five years of their life [11]	There are no initiatives specifically catering to the cases of teenage pregnancy
Inconvenient/uncomfortable obstetric beds: Obstetric beds confine the woman to a resting position on their backs. While this is required for high-risk women, it is not a requirement in most situations [12]	Studies show that women giving birth in comfortable, upright positions were less likely to develop epidural analgesia and experienced less pain. An upright posture eliminates the need for forceps and ventouse [12, 13]	'Birth upright' is a product that helps a woman give birth in an upright position [14]	It is expensive, leading to lower adoption in low-resource settings. This suggests a need for a cost-effective and easily adoptable product

(continued)

Table 40.1 (continued)

Maternal health challenges	Existing gaps and needs identified	Existing interventions	Shortcomings
Mistreatment in the form of physical or verbal abuse during childbirth [15, 16]	This not only violates the fundamental rights of women, but also acts as a barrier to avail intrapartum services [17]	There are personal safety devices that women can use to send a distress message when subjected to physical or sexual assault	These solutions are not designed for use specific to the context of maternal health care
Theme II: Enhancing accessibility to quality health care			
Pregnancy among the differently abled: The probability of complications is higher amongst the differently abled women depending on the nature and severity of the underlying condition [18]	There is a gap in understanding the linkages between disability and its possible effects on pregnancy. There are accessibility issues in post-partum nursing units which make self-care and recovery difficult [18]	There are information guide books and prenatal classes for differently abled women	While there are devices available to aid the differently abled after childbirth, there is a dearth in aids to help during pregnancy [19]
Lack of information for emergency care: This leads to failure in rapid emergency care to manage maternal complications. Hence, there have been deaths due to preventable causes despite being under supervision in a healthcare facility [20]	There is a lack of compliance to evidence-based clinical interventions and practices, as well as poor documentation and information database	Maternal Early Warning Score is an important bedside screening tool that enables tracking of vital parameters and when a threshold is reached, triggers assessment by a healthcare professional [21]	There is a need for remote monitoring of the vital parameters to enable timely intervention

(continued)

Table 40.1 (continued)

Maternal health challenges	Existing gaps and needs identified	Existing interventions	Shortcomings
Theme III: Providing adequate pregnancy-related information/tools to the pregnant woman and her family:			
False labour contractions: Even for the most informed women, it is difficult to rightly identify the onset of labour [22]. This results in women approaching the medical facilities multiple times despite experiencing false labour	Tocodynamometers that are used to monitor uterine contractions are expensive, bulky, not portable and inconvenient to use, due to which they are not widely used in low-resource settings [23]	Koala Toco [24] and Bloomlife [25] are products that are portable, lightweight and are convenient to use	Existing solutions are expensive. Hence, there is a need for a low-cost and reusable device to detect false labour contractions
Emergency childbirth: Unplanned out-of-hospital births can have negative consequences on maternal and neonatal health [26, 27]	It is important to share information with women and their families for the early recognition of danger signs [28]. There is also a need to strengthen the communication between the healthcare provider and the woman	e-Health applications on smartphone-based devices are available, to strengthen communication links between health professionals and pregnant women [29]	

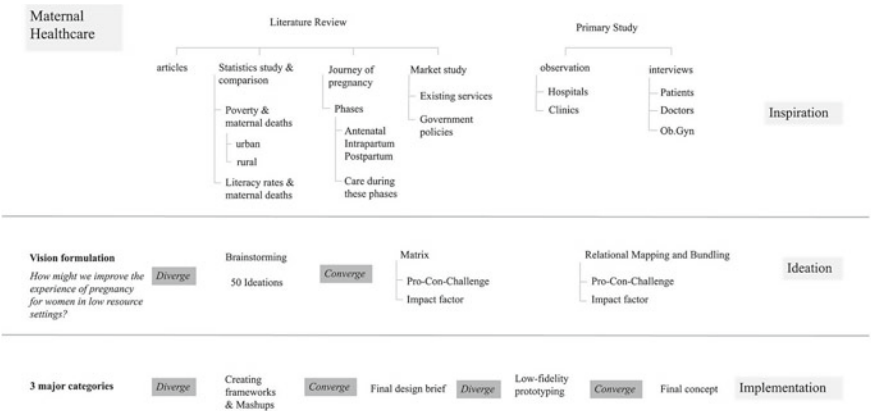

Fig. 40.1 Design process flowchart

four obstetricians and two midwives, apart from personal interviews with three pregnant women in these hospitals. Further, a survey was conducted with ten women who recounted their pregnancy experience. Following the literature review and the primary study, the design vision was formulated. Based on the identified needs and gaps, ideas were generated using techniques like ‘brainstorming’ and ‘synectics’ [30, 31]. The advantages, disadvantages and the uniqueness of each idea were listed. Additionally, each idea was rated based on its feasibility and impact along the scale of 1–5 (1 = lowest, 5 = highest). This evaluation helped in eliminating ideas with a comparatively low-impact and low-feasibility ratings.

The retained ideas were then sorted and bundled. Concrete concepts were created using methods like ‘idea bundling’, ‘relational mapping’ and ‘mash-ups’ [30].

Figure 40.1 shows the outline of the design process and the methods followed to arrive at the final design concept.

40.3 Results and Discussion

40.3.1 Primary Study Insights

Insights from Doctors and Midwives at the Taluk Hospital

Most pregnant women from rural areas are between the ages of 18–20 years. Unfortunately, they are unaware of the implications of pregnancy, and most of them are anaemic throughout the gestation period. Pregnant teenagers tend to be more stressed and uncooperative during the childbirth process. They feel uncomfortable and do not allow anyone to touch them during the intrapartum stage, making it difficult for a vaginal delivery. The specialist doctors such as gynaecologists and obstetricians are not available at all hours. In the case of abnormalities, pregnant women are referred to a hospital in the city. However, the travel duration can prove to be a critical or fatal period for the pregnant woman and her foetus.

Insights from An Obstetrician at a Private Hospital

Doctors and nurses are comfortable with the tools that they have been using for years and do not find the necessity for using better-designed tools.

Insights from Pregnant Women and Mothers

Throughout the pregnancy, women feel quite stressed and worried about their health and their baby's health. They also feel stressed especially during the third trimester regarding arriving at the hospital on time for the intrapartum stage, owing to the possible delays caused due to traffic in the city. Several women complained of the obstetric beds being uncomfortable because they were not equipped with handrails and bars that could provide grip and physical support at the time of delivery. They also expressed the discomfort and awkwardness caused while breastfeeding the baby in public spaces.

40.3.2 Design Vision

The insights from surveys and interviews led to identification of the scope for the project and helped shape the design vision. The vision of this project is to improve the experience of the antenatal, intra-partum and post-partum phases of pregnancy for women in low-resource settings and to also enhance the quality of maternal health care at a larger scale (country level).

40.3.3 Idea Generation

Ideas were generated across the three themes as mentioned in the introduction (Figs. 40.2 and 40.3). The final design concept was selected after screening the concepts on the following criteria: improves the experience of pregnant women, provides support to the pregnant women and has potential to improve the quality of maternal healthcare systems.

40.3.4 Design Brief

The finalized brief is to design a device that acts as a stress-relieving aid and monitors the vital parameters of a pregnant woman at an individual level, while connecting the healthcare stakeholders with the pregnant woman at a systemic level.

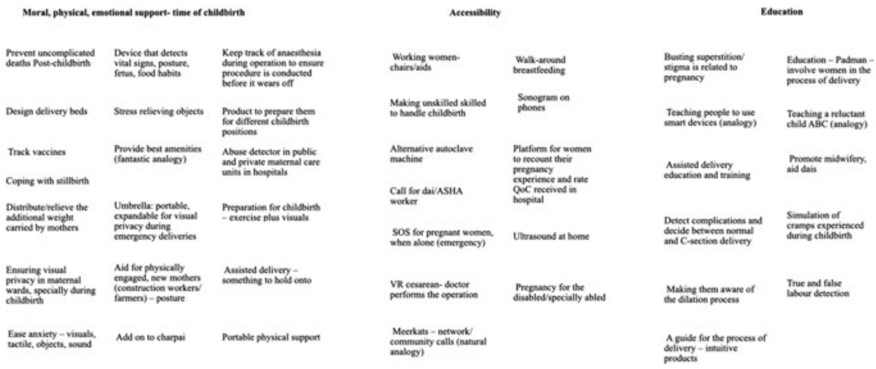

Fig. 40.2 Brainstormed ideas

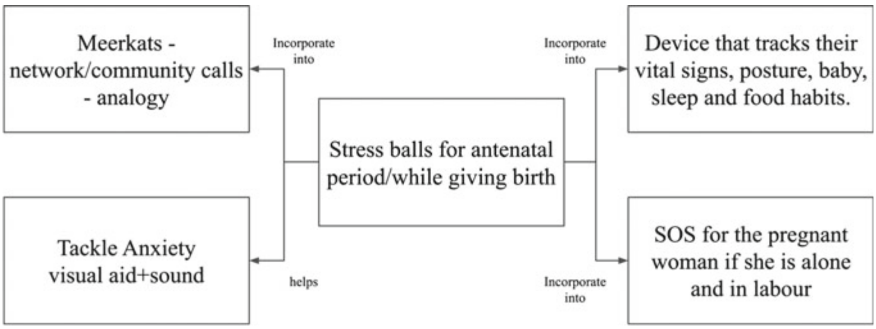

Fig. 40.3 Mash-ups

40.3.5 Proposed Intervention

'Matru' is proposed as a system which connects various stakeholders including the pregnant women, doctors, midwives, the government and local NGOs, enabling them with data regarding the vital parameters of pregnant women and facilitating actions towards improving the quality of maternal health care on various levels. The data is collected through 'Shanth', a portable IoT device for remote monitoring of the vital parameters of the pregnant woman and her foetus. 'Shanth' is used by pregnant women throughout the stages of pregnancy in domestic settings at a personal level.

Table 40.2 shows the relation between the stakeholders and the transfer of relevant information between them.

Table 40.2 Stakeholder activity mapping

1° Stakeholder	Input (from 1° to 2° stakeholder)	2° stakeholder	Output (from 2 stakeholder)	Inference
Pregnant woman	Vitals	Doctors	– Values-record of the pregnant woman's medical history of the specific vitals	– Help provide better treatment, primary data for other related data
Pregnant woman	Vitals	Mid wives	– Values-record of pregnant woman's medical history of the specific vitals	– Observe fluctuations and help keep track of foetal development
Pregnant woman	Vitals	PHCs	– Values-record of pregnant woman's medical history of the specific vitals	– Help provide better treatment, easy-to-find information of a specific patient – Make data banks and infer from it
PHCs, analysts	Inference of data	NGOs	– Inference of the data collected over time – Identify areas where awareness and care is to be provided	– Observe fluctuations and help keep track of foetal development
Our company	Vitals	Data analysts	– Values- record of pregnant woman's medical history of the specific vitals – Values of a large audience whose medical record is hard to obtain	– Annual data collection of large percentage of the population – Provide inferences of the development of medicine in these sectors – Provide inference on where there is lacking
Pregnant woman	Vitals	Government	– Inference of the data collected over time – Identify areas where development is required	– Make relevant policies to help develop these sectors – Provide better medical facilities and aid to pregnant women in the country – Ensure advancements in the countries medical systems

Product Description

'Shanth' is a handheld stress-relieving device that measures the vital parameters of a pregnant woman and her foetus during the antenatal period. The product is primarily made with silicone and has two sections: the stress reliever, which is compressible and the electronic component housing, which is rigid and inflexible. The electronic components include sensors that monitor the heart rate and body temperature of the pregnant woman and heart rate of the foetus. It also includes red and green LED light indicators that get activated based on the level of the measured values. The user can position the device at the relevant points on her body, such as the forehead to measure her body temperature, the index finger to measure her heart rate and the abdomen to measure the heart rate of her foetus. The maternal early warning score serves as a tool for predictive analysis for maternal morbidity [21]. Shanth uses this index to alert the user when the vital parameters go above or below the normal. If the vital parameters are normal, it is indicated by the green LED. In case the measured values are above or below the normal range, the user is alerted by the red LED, urging her to go to the healthcare centre for a checkup. The device also includes a Wi-Fi module that enables wireless, real-time communication of the data collected by the device to a mobile application which can be accessed by the doctor and other relevant stakeholders. The doctor's app has detailed information regarding the parameters, facilitating timely diagnosis and intervention. If the pregnant woman has access to a smartphone, she could also view the data collected on a similar app that has a minimal interface, retaining only the relevant information to reduce cognitive load. The image below shows screenshots of two interfaces of the mobile application (Fig. 40.4).

As mentioned in Table 40.1, stress and anxiety contribute to complications like hypertension and post-partum haemorrhage which are the leading causes of maternal deaths (14% and 18%, respectively) [32]. The flexible part of the device allows the user to compress and manipulate it with their fingers, providing temporary stress relief (see Fig. 40.5). Additionally, monitoring their vital parameters equips them with information regarding their health, reassuring them if their vitals are normal. In case of any abnormalities, it notifies both the user and the healthcare worker, enabling timely intervention. The device being Wi-Fi enabled, regularly updates the pregnant

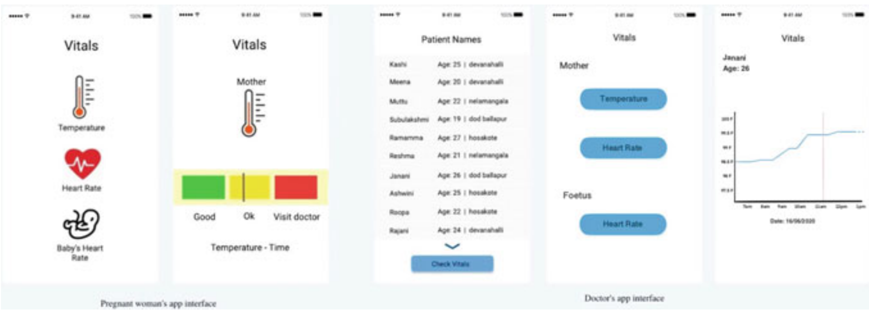

Fig. 40.4 Pregnant woman and the doctor's app interface

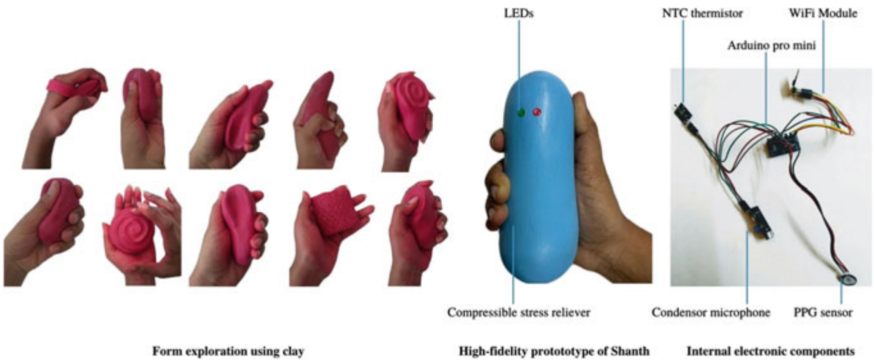

Fig. 40.5 Low and high-fidelity prototypes of Shanth

woman's vital parameters on the healthcare worker's app, forming a preliminary medical record. As highlighted under theme 2 in Table 40.1, the vital parameters database would also aid the healthcare workers in making crucial decisions during emergencies.

Prototyping

Forms were explored using clay to understand the human factors behind the handling of the product. The texture and feel of the product were first simulated by creating a low fidelity mock-up using readily available objects like latex balloons (filled with grains or liquids). The high-fidelity prototype was then made using silicone, casted in a 3D printed mould. Electronic components were housed in a 3D printed Polylactic Acid (PLA) casing, which was in turn integrated in the silicone body.

Electronic components were procured based on the desired functionality and cost constraints. Later, the components were assembled as per the product architecture (see Fig. 40.5), and the measured values were tested. However, the prototype is yet to be tested with the users.

Cost Structure

The cost of the electronic components as mentioned in Table 40.2 is approximately 950 INR (≈13 USD). The approximate cost for the silicone embodiment is 800 INR (≈11 USD). The total cost of the prototype is approximately 3000 INR (≈41 USD) including the cost of materials and fabrication. Once put to mass production, the cost of the device would reduce as compared to the initial prototype (Table 40.3).

Distribution Model

The device would be rented free-of-cost to the registered pregnant women in the semi-urban and rural areas by the ASHA workers and primary healthcare centres for the antenatal, intra-partum and post-partum stages of pregnancy. Funding and financial assistance from governmental bodies and non-governmental organizations is crucial for widespread adoption of the product in the low-resource settings. Rental

Table 40.3 Electronic components

Components	Model number	Function of component	Function in the proposed device	Cost per unit (in INR and USD)
PPG sensor	REES52	Measures heart rate by tracking the fluctuation in volume of blood flow using a low intensity light	Measures heart rate of the mother by tracking the fluctuation in volume of blood flow using a low intensity light at her finger tip	195 INR ($\approx$ 3 USD)
Condenser microphone LM 471 operational amplifier	LM386 (amplifier)	Captures a wide range of frequency using a capacitor which changes pressure variations to electrical signals	Measures the foetal heart rate (number of heart beats per minute)	180 INR ($\approx$ 2.5 USD)
NTC Thermistor sensor	KY-013	Indicates change in temperature (with change in resistance)	Measures the pregnant woman's body temperature	50 INR ($\approx$ 1 USD)
WiFi module	ESP8266	Gives a microcontroller the access to Wi-Fi network and can be integrated with sensors	Communicates the measured values through WiFi to the mobile application	150 INR ($\approx$ 2 USD)
Arduino pro mini	ATMEGA 328p	Microcontroller used for connecting sensors and actuators where space is a constraint	Connects the PPG sensor, condenser microphone LM 471, NTC Thermistor sensor, WiFi module and LEDs	200 INR ($\approx$ 3 USD)
LEDs	Red and green	Emits light when current is passed through it	Green LED is triggered if the parameters are within the normal range while the red LED is triggered if there are abnormalities	2 INR ($\approx$ 0.03 USD)
(a) 3.7 V lithium ion battery and (b) Recharge module	(b) TP4056	(a) power supply and (b) recharge the battery	(a) Powers the device and (b) recharges it	170 INR ($\approx$ 2.5 USD)

versions of the device would have an added GPS module for tracking the location of the device during the use phase. In between rental cycles, a quality check would be conducted to ensure that the device is functional. There are around 23,391 primary healthcare centres in India and around 145,894 sub-centres through which the product can reach pregnant women [33]. The ASHA workers would also play a crucial role in ensuring women even in the most remote regions which have access to and benefit from Shanth.

40.4 Conclusion

An attempt has been made in this paper to identify the gaps in maternal health care, opening avenues of exploration for designers and researchers looking to address challenges in this domain. The outlined design process involving methods like 'brainstorming', 'relational mapping' and others were followed to arrive at a promising solution. The proposed system-level intervention, 'Matru' is accessible to people across various socio-economic backgrounds and connects relevant stakeholders in the domain of maternal healthcare. The system enables better psychological well-being of the pregnant women through the proposed personalized device 'Shanth' by making them aware of their health information. Also, the system would aid in timely diagnosis of pregnant women and improved decision making for the healthcare professionals.

As the future scope of the project, the prototype would be tested across several potential users to assess the effectiveness of the solution. Moreover, the real-time data pertaining to the vital parameters collected from user testing as well as the self-reported user health data would be analysed to develop an alert system for unforeseen emergency situations in pregnancy. Such data collected from pregnant women across different regions (urban and rural) of the country would be instrumental in creating a database that can provide additional documentation of maternal health data to aid in policy making. The proposed systemic model connecting various stakeholders along with the low-cost IoT-based health monitoring device would likely impact the healthcare sector in a constructive way.

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Chapter 41
Approach for Industrial Design and Evaluation of Product-Integrated Solar Photovoltaic (PIPV) Products

Pranav Satpute, Ravi Mokashi Punekar, and Avinash Shende

Abstract The term product-integrated photovoltaics (PIPV) are used for the products which includes integrated solar PV panels to provide electricity for the function of product. As PV panel is driving whole function of product, it becomes critical component which dictates overall design of it. In current scenario, most of the easily available solar panels in market are rigid in nature with varying sizes and ratings. Also, there is an involvement of electronic system including charge controller circuit and batteries. It affects form exploration process while conceptualisation of product. Objective of this study is to understand the involved barriers in design process of PIPV products and to extract a design approach for them. To understand design process and evaluate one concept of PIPV product, it is prototyped and tested with users in actual scenario. Paper compiles the observations gathered from the journey of PIPV product from ideation phase to realisation phase, and it concludes with framing of step-by-step approach for designing of new PIPV products. Evolution of product based of predefined parameters contributes guideline loop to reiterate PIPV product concept for its improvement.

41.1 Introduction

For the entire world, solar could be the largest source of electricity by year 2050 [1], and solar PV power will be the major contributor of total solar power production. It has potential to provide solutions to the longstanding energy problems being faced by the developing countries like India. Distributed (off grid) solar generation is the

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A. Chakrabarti et al. (eds.), *Design for Tomorrow–Volume 3*,
Smart Innovation, Systems and Technologies 223,
https://doi.org/10.1007/978-981-16-0084-5_41

opposite of 'centralized generation', wherein the electricity is generated at 'central power plants' that are sometimes located hundreds of miles away from 'load centre', where the customers are located. Centralized generation leads 25% energy loss in transmission [2], and hence, distributed solar energy is an option to prevent this loss. India has enormous potential market for distributed solar energy and ranks first among top twenty potential markets of world [3]. Also, it can fulfil energy demand of rural areas of India, where there is no or limited access of electricity grid. Off-grid applications of photovoltaic technology bring product-integrated photovoltaics (PIPV) in the picture. Although, various possible applications of PIPV envisage but there are very few products designed and available in the market due to underexplored. This scenario implicates that there is a need of intervention of multi-disciplinary experts including industrial designers in this field. A PIPV product comprises PV panels, circuits, batteries and other components, where PV panel is directly dominating/dictates the overall form of the product. Available literature and research say that lack of information on compatible size versus energy of PV panel leads to non-feasible ideas that act as a barrier for conceptualization of ideas at early stage of design process. This issue needs to be rectified while considering design process of PIPV products. The research started with a pilot survey of PIPV market of India to explore various commercialized applications. It is observed that most of the PIPV products are available for lighting purpose, and very few new applications are commercialized in Indian market. Less penetration of PIPV in rural market is fairly evident. Based on the fact of huge population resides in rural India, where accessibility to the electricity is still a major challenge, the initial study was planned to begin with the field studies in villages, where conceptual design intervention in PIPV has been envisage through involving industrial designers for creative session organized as a part of this research.

41.2 Industrial Design of PIPV Products for Rural India: Two Aspects for Consideration

The heading contains two pillars for consideration which are industrial design aspects of PIPV products, and another one is the suitability of that product in rural context as shown in Fig. 41.1.

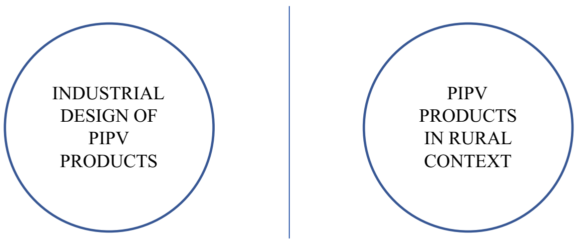


Fig. 41.1 Two aspects to consider while thinking design of PIPV products for rural use

This study is divided into two parts: first part defines the approach to design solar PV system required for product design, and second part elaborates the possible methods for the evaluation PIPV products to decide its suitability for rural use.

41.3 Ideation to Realization of PIPV Concept for Rural Scenario

To know the process of development of PIPV product from ideation to realization, a design exercise is conducted with industrial designers by providing them a brief which was used in earlier studies, where design concept was generated in raw form. In this phase of study, the same design brief is used to design and develop PIPV product involving industrial designer and technology experts who are active in development of products for rural context. Initially, the path was defined from the process of design which included various phases like concept design, concept development, embodiment design and detail design. Below is the design brief provided to the industrial designer involved in this study.

41.3.1 Design Brief—Design Solar PV Powered air Blower for Firewood Cookstove for the Scenario of Rural Domestic Kitchen

In earlier studies, the scenario of rural kitchen was shown to the designers in the form of visual of actual firewood cooking then the group of designers produced multiple concepts which further analysed for feasibility. Being feasible, the concept of PV powered air blower was considered to observe from the phase of ideation to realization as shown in Fig. 41.2.

Few questions from designer side were considered to form the path for development of the concept. While proceeding with the idea generation, few questions arise which are:

- What is the context of use and who are the target users?
- What function product needs to fulfil?
- What are the components (electronic) required to fulfil the function of product?
- What are the specifications of PV panel?
- Size of components is essential to explore other design parameters like form, material, etc.

From these questions, the technology experts who are actively involved in developing PV powered products for rural use are identified. From their expertise, the path of electronic systems including selection of PV panel involved is defined. The

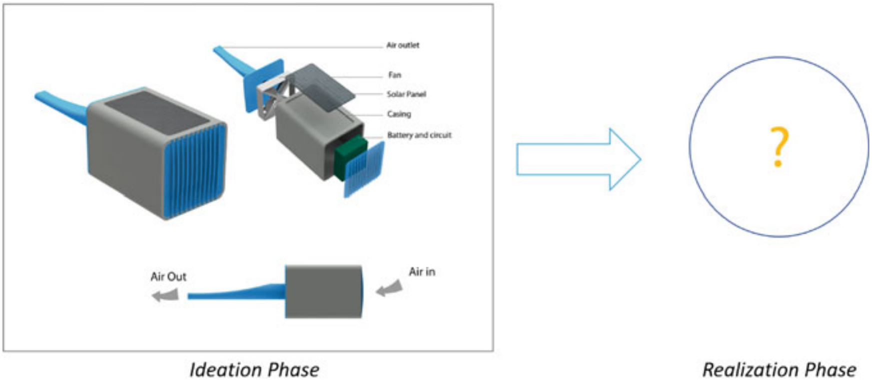
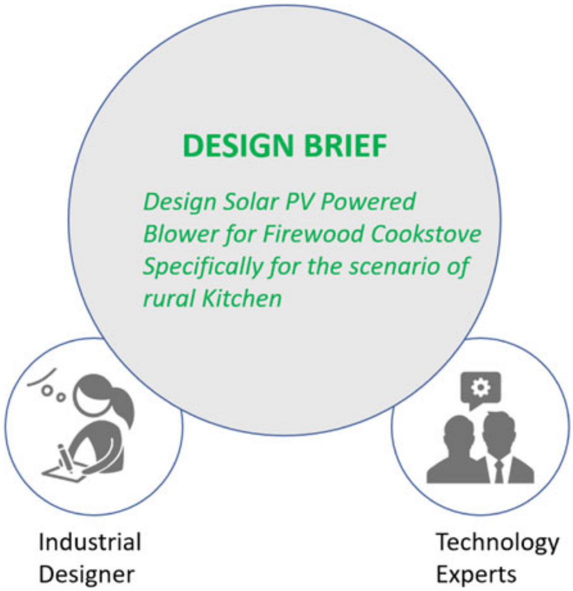


Fig. 41.2 Initial concept of PIPV air blower

data/instruction extracted from both the participants as industrial designer and technology experts were shared to progress on development stages of PIPV product. Very first the database of various sizes of PV panels is built with the help of identified technology experts.

Figure 41.3 shows the schematic of proposed approach to involve industrial designers and technology experts in formulated design brief.

Fig. 41.3 Formulation of design brief



41.3.2 Design Requirements and Electronic System Design

To fulfil the function of air blowing, high-speed DC fan was procured. To suit the specifications of fan, various size of PV panels are tested with different sunlight conditions as shown in Fig. 41.4. And an optimum suitable panel was selected after selection of functional component and suitable solar PV panel. Below are the steps noted with the iteration from technology experts.

Development Phase	Input Information	External Support
Concept Generation	1. Problem Definition/Design Brief 2. Context of use 3. Target users 4. Limiting parameters like cost, material 5. Form Exploration	1. Field requirements
Detail Design	1. Functional requirement 2. Component specifications 3. Component dimensions 4. Electronics elements	1. Component Specifications 2. Electronics Elements
Development	1. Material Selection 2. Manufacturing process 3. Manufacturing and Assembly	1. Manufacturing possibilities
Testing	-	

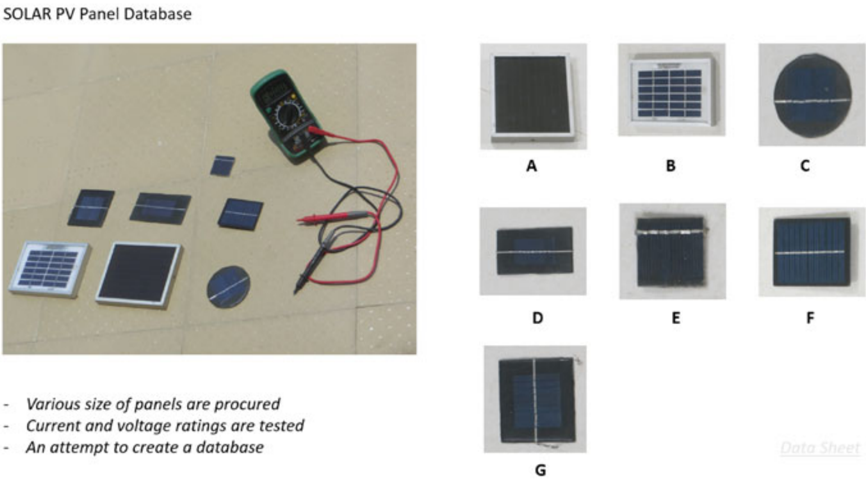


Fig. 41.4 Design requirements and formation of PV panel database

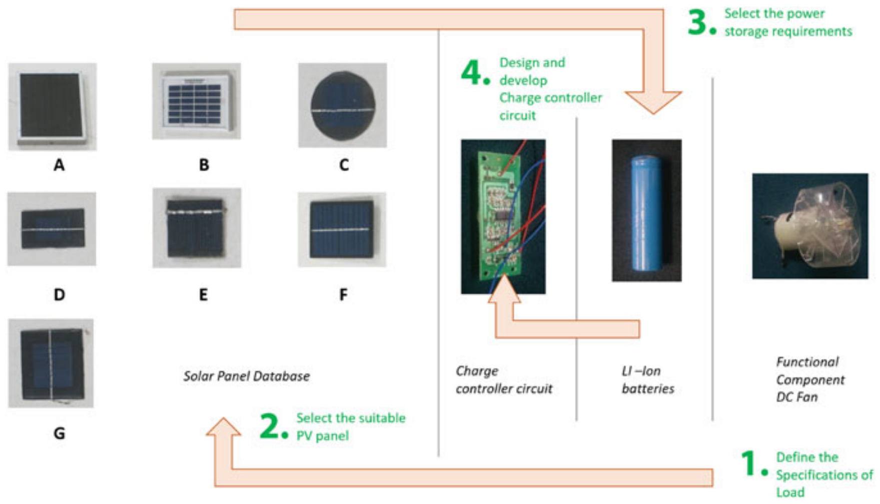


Fig. 41.5 Steps of PIPV electronic system design

1. First step is to define the function and component required to fulfil desired function. In the brief provided, the functional requirement was to blow the air. In first step, high-rpm DC fan was selected.
2. According to the specifications of DC motor, the suitable size of PV panel was selected from the created database.
3. Third step includes the selection of appropriate power storage by selecting the batteries. Load requirement and time of operation decide the number of batteries required for the operation of product.
4. Next step includes the design and development of charge controller circuit. It is the major part of any solar PV electronic system. Charge controller system regulates the charging cycle of battery and the supply of sufficient power to the load as per requirement.

Steps described above in Fig. 41.5 come under electronic system design. These details are found important to start with the form exploration for the designer. Once the dimensions of all the components are fixed, the data is given to the industrial designer instead exploring the form on sketching designer preferred to model the provided components on CAD to get actual visualization and iteration of arrangement of various elements. Below are the steps recorded from the CAD.

41.3.3 Form Exploration and Concept Design

CAD gives freedom for designer to arrange the components in required manner. After basic arrangement of components, designer tried iterative sketches to improve on the form of product. It started with the modelling of panel followed by modelling of functional components like battery, fan, etc., then exploration of product body form and in last fine tuning of the form as shown in Fig. 41.6. Designer considered various issues of usability, aesthetics and functionality of product while exploring the form. Figure 41.7 shows the concept presentation by designer; product is named as JHONKA as it is the word for breeze in Hindi.

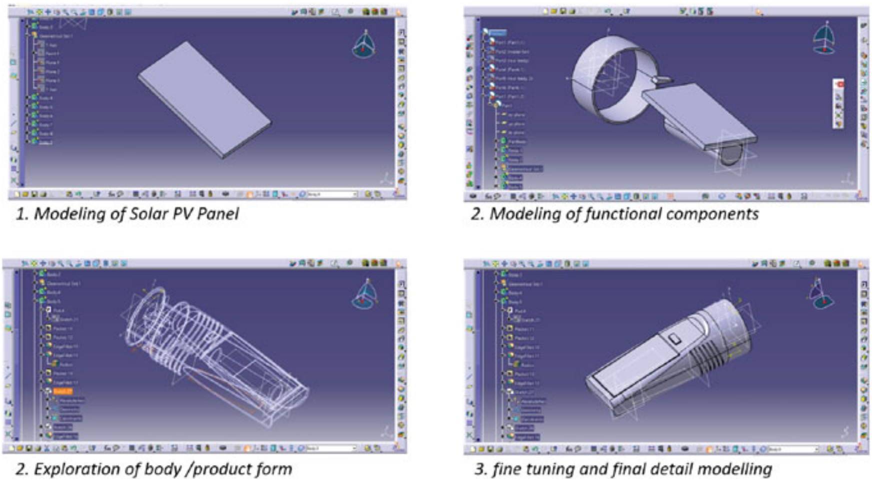


Fig. 41.6 CAD Exploration steps of PIPV air blower design

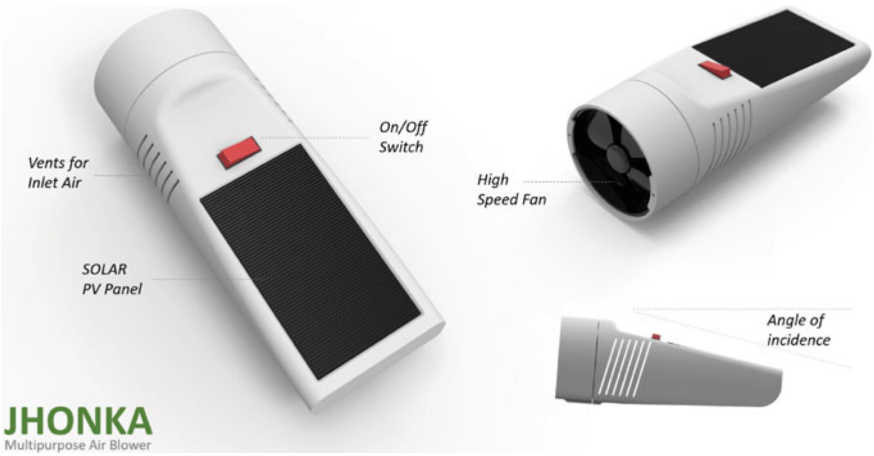


Fig. 41.7 Final concept of Jhonka—air blower for firewood cookstoves

Fig. 41.8 Manufacturing and assembly of concept prototype

41.3.4 Method of Study

Hundred PIPV product are identified from various platforms including online marketing, retail shops from Guwahati and Pune city. Information about Innovations and attempts to innovate is gathered from 'Techpedia' an online platform provided by National Innovation foundation and various individual designers working in this sector.

41.3.5 Concept Execution

After electronic system design and from exploration of product, concept was executed with available manufacturing resources. As it was a prototype, 3D printing was selected to manufacture the body of product. This was a low-cost alternative for conventional plastic manufacturing processes. Whole electronic system was designed and developed with the technology experts viz. Protek Instrument Pvt. Ltd. based in Pune. Figure 41.8 shows few steps of development of product.

Images clockwise from left: 1. product body 3D print and component inspection, 2. component assembly with product body, 3. final soldering and fixing of electronic system and 4. final working prototype of the product. This prototype is tested for its working. Prototype of JHONKA was able to provide 1 h of working with 5 h of charging. Charging time was higher as two Li-ion batteries are used to suit the rating of high-speed fan. Product was then tested in actual environment with target users.

41.3.6 Testing with Users

Developed prototype was tested with users who are involved with use of firewood for cooking activity. Nearby villages of Nashik district of Maharashtra state are visited. Proto was handed over to two families from different villages to observe

Fig. 41.9 Testing of prototype in actual scenario with target users

their perception and asses the prototype to know the design bottlenecks. Figure 41.9 shows the product with its user and in related environment.

After receiving the feedback from the users, few points were observed which are mentioned below:

- Product was designed and developed as an air blower for the use with firewood cooking; it is observed that users used it with the other activities which need the same kind of function. Users used this product with water heater which works on heat produced with firewood burning.
- It is found that the product performance was not as per expectations as it was taking more time for charging and delivering low amount of air comparatively.
- Product was provided only with the function of air blowing. After use for certain time, users expected to get few more function along with it like torch light, FM radio, mobile charging, etc.
- Product was then analysed using spider web assessment model to know the lagging factors into it. Certain factors are identified from this exercise which is important to consider while designing new PIPV product for rural scenario.

Figure 41.10 shows the spider web analysis representation of product.

From the spider web analysis, it is observed that the product lags in the aspects of repairability, durability also it poses comparatively low affinity, affordability and functionality. Product repairability was an issue as users were not sure about the maintenance and from where they can repair the product if any issue occurs. As product was manufactured using 3D printing of PLA material, the durability of product was in doubt. Users gave feedback that they expect multi-functional product in this price range that is why the affordability and functionality was in doubt. However, product was found acceptable, desirable and useable for the users.

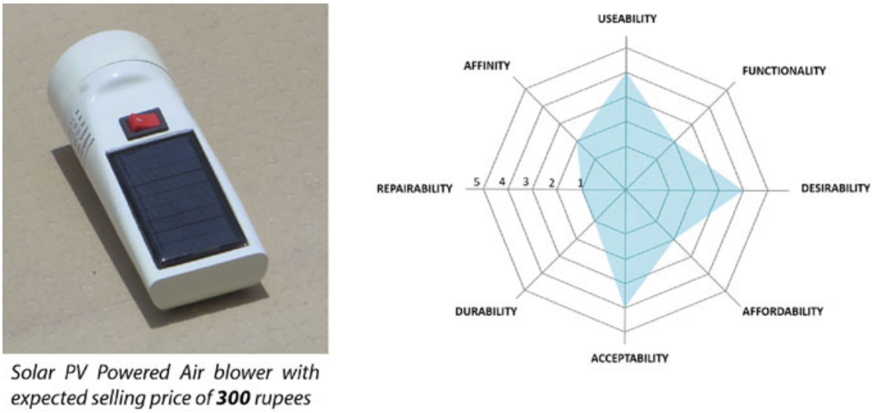


Fig. 41.10 Spider web assessment of developed PIPV concept on the basis of user feedback

41.4 Conclusion

Here, product passed through three phases of concept generation, execution and testing. During these studies, it is realized that three stakeholders are associated with these three phases. These stakeholders are designers, technology enablers and users as shown in Fig. 41.11.

In this model, there should be active feedback system between these identified phases and respective stakeholders for successful PIPV product design for rural scenario as shown in Fig. 41.12. Here, product users are the problem owners. These problems are solved by designers to create required solutions through PIPV product designs. While designing those concepts as there is involvement of electronic systems including PV panels. There is the role of technology experts to provide required electronics systems for further design explorations by industrial designers. This system

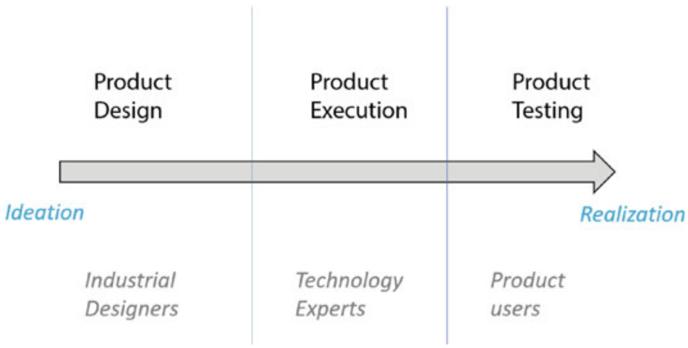


Fig. 41.11 Phases of PIPV product development and associated stakeholders

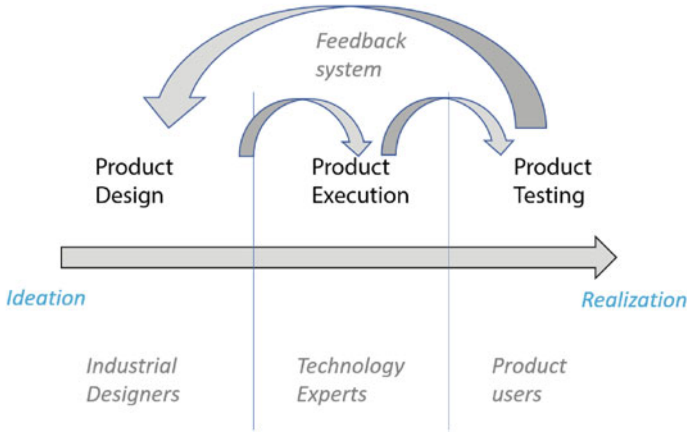


Fig. 41.12 Active feedback system between different phases of PIPV product development

will help in reducing lead time of product to market and will increase the rate of success with target users.

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Chapter 42
Design and Development of Low-Cost Unplugged Activities for Teaching Computational Thinking at K-5 Level

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Abstract Children of this era are considered as 'digital natives' as they are born and live in a world integrated with digital technologies. As a user of digital technology, they are expected to be aware of the fundamentals of computational thinking and logic to use it as a creative tool. Though there are many efforts to introduce computational thinking at the K-5 level globally, many children are still not exposed in India to the tools and techniques of the computational thinking, and many of those who are exposed are apprehensive of learning how to code. The major reasons observed in India are: (1) lack of exposure to the computer in many areas, (2) lack of ludic value in the process of teaching computational thinking, (3) cost of the toys and games available in the market are still beyond the capacity of many people and (4) design of the toys and games without considering zone of proximal development. To address these issues, a set of unplugged activities has been designed and developed using blended prototyping approach and the 5/10 method of game design as a framework. This paper illustrates the effort into a comparative analysis of the existing products, user study, state of the art review, design and testing to validate the design of low-cost unplugged activities for teaching computational thinking at the K-5 level.

42.1 Introduction

Computational thinking is a set of problem-solving skills that involves expressing solutions to various problems, in ways that a computer can execute [1]. It provides a powerful base for studying computing but has applications beyond computing itself.

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A. Chakrabarti et al. (eds.), *Design for Tomorrow–Volume 3*,
Smart Innovation, Systems and Technologies 223,
https://doi.org/10.1007/978-981-16-0084-5_42

Many quantitative and data-centric problems can be solved using computational thinking as a foundation to recognize aspects of computation around us and applying tools from computing to understand and reason.

The main aspects of computational thinking are [2],

- Computational concepts, which are the concepts that students employ when they code: sequences, loops, events, parallelism, conditionals, operators and data.
- Computational practices, which are problem-solving practices that occur in the process of coding: experimenting and iterating, testing and debugging, reusing and mixing and abstracting and modularization.
- Computational perspectives, which are the students' understandings of themselves, their relationships with others and the digital world around them: expressing, connecting and questioning.

There have been many efforts to introduce computational thinking at the K-5 level globally [3, 4]. Primary school is an ideal time to introduce computational thinking as this is the age where children enter the concrete operational stage of cognitive development, according to Piaget's theory of cognitive development [5]. The concrete operational stage is characterized by the development of logical thinking and problem-solving skills, which correlate with the skills and abilities we are trying to develop. Introducing computational thinking at this stage will make formal computer science education easier and also develop logical thinking and problem-solving skills, such as creative expression, hypothetical thinking, lateral thinking and persistence.

Unplugged activities, that translate concepts into everyday objects and actions that the learners are familiar with, are very effective. Unplugged activities have the advantage of not requiring costly equipment or skill to operate. This advantage of viability and accessibility is valid only if the activity has educational potential, as an effective method to learning. Unplugged activities also rely on interactions between pupils and their spatial surroundings, which encourages social interaction. Tangible interactions reduce the cognitive load experienced during using a machine and engage episodic and semantic memory.

This approach to computational thinking educational builds upon previous methods and products, by focusing on development of skills and implicit learning, rather than presenting direct concepts packaged as a game. This allows for a far more holistic learning experience and ensures that the learners master fundamental concepts and skills, rather than simple approaching educational concepts directly.

42.2 Issues with Computer Science Education

Computer science education in schools, currently focuses more on information and communication technologies, rather than teaching CS concepts like algorithms, data structures, etc. [6] Moreover, there is a focus on theory and concepts, rather than real-world applications. Despite efforts, computer science education is not accessible to a majority of K-12 students. This is mainly due to: (1) lack of infrastructure, (2) lack of understanding of the importance of CS, (3) unqualified teachers and (4) CS courses as optional in the curricula. Hence, there is a need to improve awareness about CS and teach students the basics of computation in an easy and accessible manner.

Based on previous research towards computational thinking resources [7], a board game was chosen to be the most effective medium to engage children at the same time effectively presenting various concepts. The board game [8] includes the basic concepts of computational thinking and presents that in an abstract and stimulating manner. A board game is advantageous as it allows for effective usage in classrooms, keeps the children engaged, and can be made accessible at a low cost. Game-based learning aims to achieve some learning objectives, by providing an element of addiction that makes the pupils learn to face the challenges presented to them [9].

42.3 Market Study

Popular games, toys and educational platforms towards computational thinking were researched and studied, for various age groups and mediums. The products were judged based on their unique features, mode of instruction and replay value and focus on educational concepts.

Name	Age group	Price	Features	Educational concepts
Sphero	8–14 years	INR 8000	Programmable robot, supporting app, real-time feedback	Fundamental concepts, real world applications, programming logic
Code and go robot mouse	4+ years	INR 3000	Programmable robot via tiles, follows instruction on a maze to find cheese	Sequencing, algorithms, real-world applications
Robot turtles	4–15 years	INR 1500	Control a turtle on a grid, suing action cards, to collect gems	Sequencing, algorithms, loops, debugging
Qwirkle	6 months +	INR 2000	Lay tiles according to matching colours or patterns to form lines	Critical thinking, strategy, pattern recognition
Scratch	10–14 years	Free	Blocks-based programming, interactive interface, classroom teaching aid	Fundamental concepts, syntax, algorithms

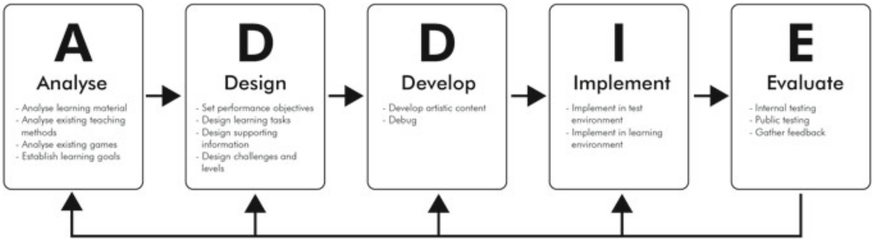

Fig. 42.1 5/10 method

42.4 Methodology

The 5/10 method has been used as a framework for designing the game [10]. The 5/10 method combines the five steps of the ADDIE model with Merriënboers ten steps to complex learning in a way aimed specifically at educational game design (Fig. 42.1). Combining these two methods ensures that the game has clear learning goals and methods to achieve them.

The method focuses of instructional system design, and not the artistic side of development, such as visual and audio design. While they are important, they are a separate scope of research and development.

The most important phase is the design phase, where all the details are finalized for the end product. The ten steps ensure that the game has clear learning goals and provides the learner with the right information at the right time.

42.5 Game Design

The design direction decided upon for the game was:

- Tangible, non-electronic products.
- Focus on algorithm over syntax.
- Development of spatial ability and awareness [11].
- Multiplayer game, encouraging players to interact.
- Focus on fundamental computational thinking concepts.
- Game based on strategy over luck.

42.5.1 Analyse

Learning material and existing teaching methods were studied as illustrated in previous sections, following which learning goals were established. The primary goal of the game is to teach learners about computational thinking concepts in an implicit manner. The aim is not to directly present concepts, but to use aspects of the concepts in the game mechanics, such that the learner learns how to apply these concepts while playing.

Game mechanics of popular games were studied to analyse what makes a game fun and re-playable. The game should be fairly simple and straightforward, with easy to grasp rules and game mechanics. This allows for play to start quickly without getting lost in too many rules and restrictions. The players are also free to discover strategies and techniques as they continue to play. Hence, they are constantly evaluating and analysing the gameplay. The games also offer a social setting, where the players interact with each other, either to simply tease and chatter, or to team up and strategize.

42.5.2 Design

Game mechanics from existing games and teaching methods from various educational platforms were used as a base to develop game concepts. The final concept of the game has multiple players, controlling knights, trying to capture a dragon, controlled by one player, loose on the board (Fig. 42.2). The players lay down hexagonal tiles, with paths on them to move around the board (Fig. 42.3). They can make use of already played tiles to extend their path. The dragon is captured when one of

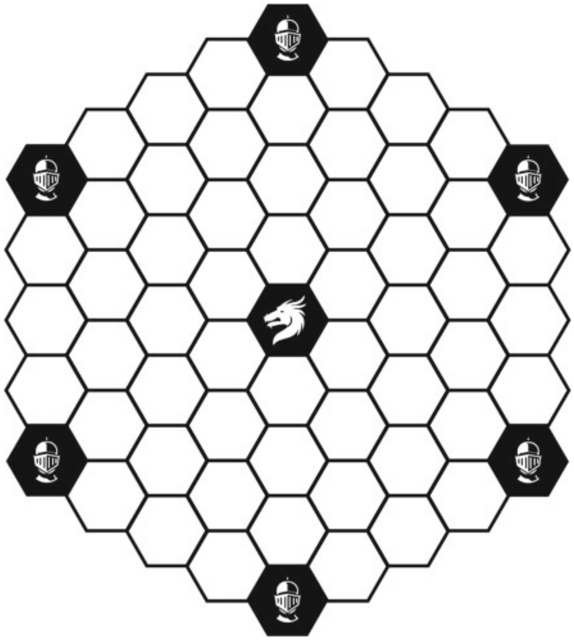

Fig. 42.2 Game board layout

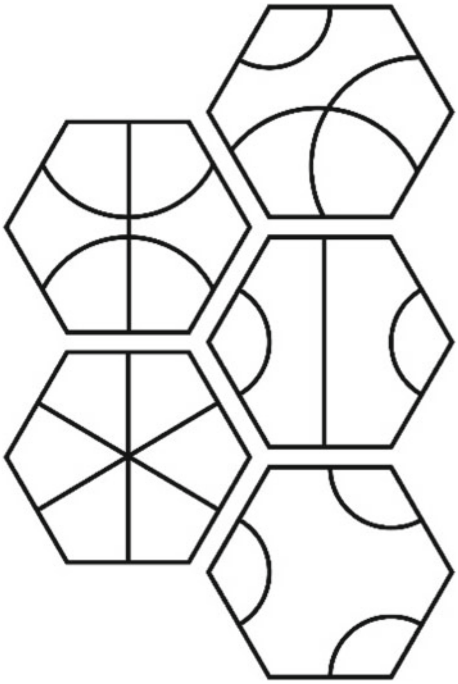

Fig. 42.3 Path tile patterns

the knight's lands on the space occupied by the dragon's marker. A knight is eliminated if the dragon lands on a space occupied by the knight, or they go off the edge of the board.

The players work together as a team, to evaluate real-time conditions and decide the next move. The game opens up opportunities for various defensive and offensive strategies for both the dragon and the knights. The objective for the knights is to intercept their path with the dragon, capturing it, while at the same time avoiding being eliminated either by the dragon, or by going off the board. The knights can work either individually or as a team to capture the dragon. The dragon's objective is to elude capture either till all the knights are eliminated, or the board is filled, and no more plates are possible.

42.5.2.1 Strategies

An array of defensive and offensive strategies is possible for both the dragon and knights. A defensive strategy for the dragon would be to avoid the knights for as long as possible, until the board is fairly full. At this point, the knights will have trouble easily navigating the boards trapping the knights on the one side. The offensive strategy for the dragon would be to actively seek out knights and eliminate them. However, this can backfire as there is a risk of being captured by the knights.

The knights can actively seek out to corner and capture the dragon. This is most effective when the knights are working as a team, rather than alone. The knights cannot afford to be completely passive in their gameplay, as the dragon wins if all the tiles are placed. Hence, they have to pursue the dragon if they are to win. This encourages the players to attack and allows a more interesting and active gameplay.

42.5.3 Develop

Once the gameplay was finalized, the graphic elements and deliverables of the game were made (Figs. 42.4 and 42.5). The theme is an important aspect of the game design, as it is what will grasp the attention of children and engage them in the game. A lot of themes were explored. Some of these are detectives trying to catch a thief, spaceships orbiting a planet and explorers search for treasure. A small verbal survey was conducted amongst primary school students and their teachers. It was learned that children in the target age group of 8–10 relate the best to larger than life adventures, which allow their imagination to run free. They also do not need to be provided with a lot of detail or factual elements and can imagine and fill in a lot of details.

Hence, the theme of dragons and knights on a quest was chosen (Fig. 42.6). The theme is familiar to children due to popular medieval pop culture shows, movies,

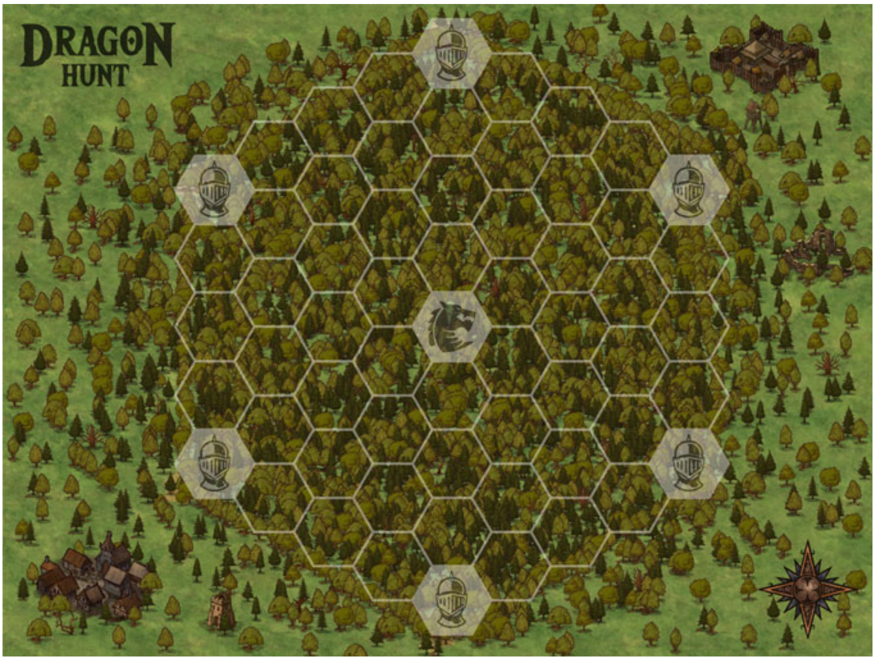

Fig. 42.4 Game board design

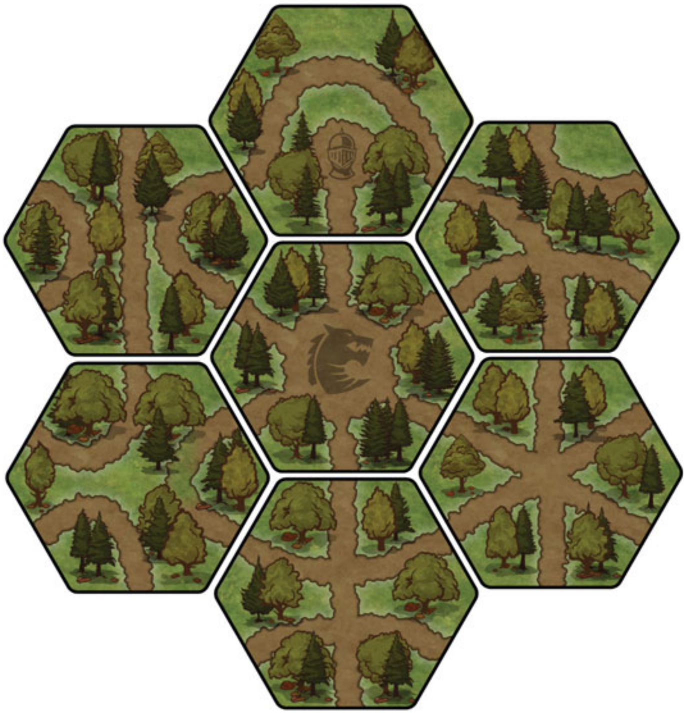

Fig. 42.5 Path tile designs

Fig. 42.6 Game box design

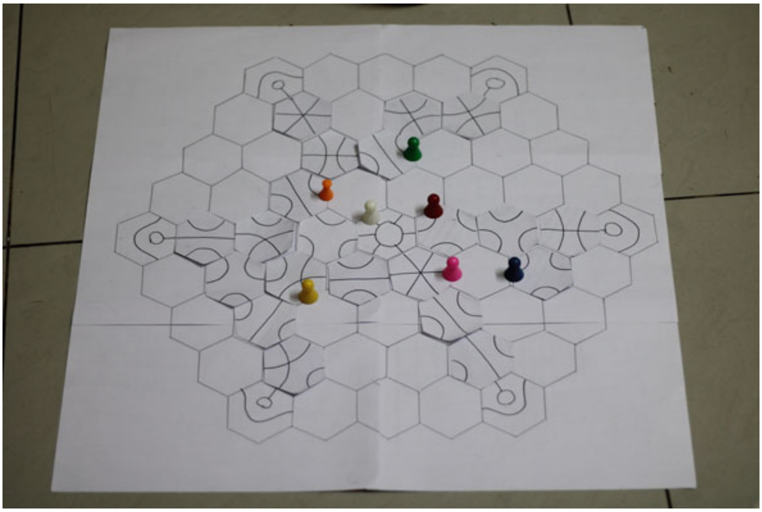

Fig. 42.7 Paper prototype

literature and games. The theme of the game can easily be changed, with minor modifications to the game mechanics to make it more appealing to an older audience.

42.5.4 Implement

A paper prototype was made to test the game (Figs. 42.7 and 42.8). The game was evaluated with various combinations of rules and set-ups. Various gameplay elements, such as strategies, game mechanics, the flow of the game and interaction between players were observed.

42.5.5 Evaluate

Pilot testing was carried out for the game, with a limited test group of five members within the age group 10–17. Further, extensive testing was not possible due to social distancing guidelines in place. Further testing will determine the long-term skills developed due to repeated. Usability testing was done using observation evaluation method [12]. The effectiveness, efficiency and satisfaction of the game were evaluated. The test group was observed while playing the game and asked a set of questions after to understand how their thought process worked during play and how they had interpreted the concepts presented.

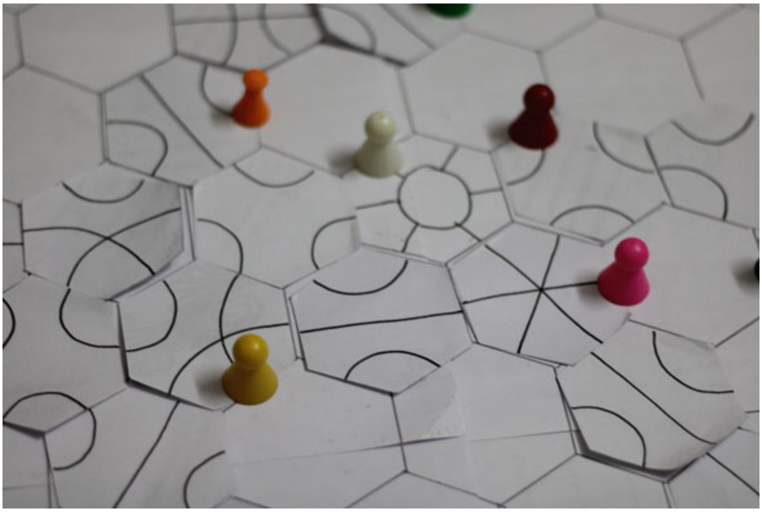

Fig. 42.8 Close-up of markers and tiles

The game can be played between 2 and 7 players. Each game lasts between 20 and 30 min. Observations from usability testing are:

- The game is very visually oriented, with players having to connect paths on the game board.
- There are also a variety of strategies possible. The knights can either work together to corner and eliminate the dragon or play individually, trying to capture the dragon on their own.
- There is a lot of interaction and teamwork between the players.
- The addition of knights and dragons to the gameplay makes children feel as though on a fantasy adventure and helps engage them more into the game.

The game effectively represents computational thinking concepts. As the players analyse patterns on the board and think how to best strategize and play their next turn, they employ concepts of decomposition, abstract thinking and pattern recognition.

The paths on the board represent algorithms which the players follow. Each player is mapping out a path or algorithm for them to follow to achieve objectives of the game. As the game progresses, each player focuses on tasks which are a priority to them, getting to a better position on trapping another player. This is the concept of abstraction, deciding what details to highlight and what details to ignore. The players also break down their thinking process into small objectives and steps, which is decomposition or breaking down a problem into smaller parts.

All these thinking processes happen efficiently and intuitively by the players during the game. This encourages implicit learning, where the learner subconsciously experiences and learns to use these skills. Implicit learning is the learning of complex information in an incidental manner, without awareness of what has been learned. It is a passive process and people acquire knowledge through exposure. There are many advantages to implicit learning, compared to explicit learning, where the user makes a conscious effort to learn the subject matter. Implicit learning offers better retention of concepts, it is independent of age and intelligence, and it is very efficient in that the learning takes place outside of conscious awareness and requires few attentional resources.

42.6 Future Scope and Conclusion

Learning computing is essential in today's digital world, if people are to switch from being consumers to creative contributors. Introducing computational thinking at an early age is especially important to allow critical and logical thinking skills to develop. Play and games are a very effective medium for implicit learning, as it is low threat, high feedback and high fun. Learners are not pressured to learn, as in classrooms and exams, as there can be heavy consequences when a mistake is made, such as failure in an exam or embarrassment.

This game is an improvement over existing toys and games towards computational thinking education, as it focuses more on implicit learning, and developing skills in the learner, rather than presenting them with direct concepts to learn via the game, as done in games such as robot turtles. The game is also more straight forward, with simpler, easier to follow rules, so that the learner can focus on strategies and skills rather than remembering the rule book. Implicit learning has far less lethal consequences and allows the learner to learn quickly from his mistakes and can therefore pick up concepts more clearly and with an open mind. This is a far from holistic approach to learning, then simply packaging educational concepts in a game format.

The game has clear learning goals, and it is interesting to see how learners interpret the rules and develop strategies on their own. As this was only preliminary research, the results were satisfactory; however, for more concrete research, it will be required to expand testing and feedback, with a greater number of children and a formal evaluation of the concepts presented.

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Chapter 43
Design and Development of Attachment for Ceiling Broom

Shohel Gardia, Abhishek Gupta, Swastik Subham Sith, and Swadha Krishn

Abstract In India, ceiling broomsticks are available and used for dust and cobwebs cleaning, but people in India utilize the grass broomsticks for both floor and ceilings. It is observed that there are many ergonomic- and health-related problems associated while cleaning ceilings even with particular application-oriented products. Problem statement involves fall of dust on the person cleaning ceiling especially in eyes and nose which is very hazardous and also results in cleaning of the residual dust again. Considering the feasibility factor, an innovative broom is designed with a hopper for collecting fallen dust and dirt. After several trials, products have been driven through CFM (color-finish-material) whose aftermath is a transparent sheet for better visibility and viewing angle. In addition, target users are not only restricted to the domestic users but also enfolds all the applications which demand hygiene, e.g., medical centers.

43.1 Introduction

The word "broom" [1] derives from the name of certain thorny shrubs used for sweeping. Flat brooms, made of broom corn and broom vice, were invented in the nineteenth century. A smaller whisk broom or brush is mostly called a duster. [1] In 1797, Levi Dickenson, a farmer in Hadley, Massachusetts, made a broom made of tassels of sorghum, a type of grain grown for the seeds [2].

Cooking at that time was mostly done in a large open space where ashes, dust, and dirt were a dominant factor of life. Wood was taken inside the home to heat and cook. Dirt, debris, and ash were left behind. The homemade brooms swept clean, but their lifespan was short. Unrefined brooms were subservient and fragmented easily. Their crude nature made sweep even more difficult.

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A. Chakrabarti et al. (eds.), *Design for Tomorrow–Volume 3*,
Smart Innovation, Systems and Technologies 223,
https://doi.org/10.1007/978-981-16-0084-5_43

Broom [2] In 1810, the foot treadle broom machine was invented. This machine played an integral part in the Industrial Revolution. Shaker presented a new design of the round broom in the mid 1820's. Design removed the woven stems up the handle, and wire was introduced to bind the broom and handle. Using a vice, flat brooms were made by sewing linen twines and strands. By about 1830, the United States was producing enough brooms [3]. Increasing demand of brooms was incorporated by large factories. Broom making equipment and technology developed in the United States can be found throughout the world [4].

A broom is a cleaning tool consisting of usually stiff fibers (often made of materials such as plastic, hair, or corn husks) attached to, and roughly parallel to, a cylindrical handle, the broomstick. It is thus a variety of brush with a long handle [5]. It is commonly used in combination with a dustpan [6].

They are made from a variety of materials, both manmade and natural. Manmade bristles are generally of extruded plastic and metal handles [7]. Natural-material brooms may be constructed of a variety of materials, including brush, but generally include stiff grasses such as broomcorn or sotol fiber [7]. Brooms from broomcorn are in market for at least 200 years and considered superior brooms, but plastic brooms are replacing them over the time.

Broom is useful in many purposes specially cleaning ceiling of houses, hospitals, bus stands, auditorium, etc. In modern days, both inside and outside cleaning are becoming an important role in our life [8]. Few ceiling cleaners are available.

Cleaning is essential need of this generation. In houses and hospitals for cleaning ceiling, regularly different techniques are used. The reasons for ceiling cleaning are:

- Dirty ceiling leads to poor indoor air quality, which can cause airborne sickness to people [9]. Beautification of the ceiling.
- Dust, dirt, grease, and other materials keep accumulated in ceilings of space. Any vibrations or breeze cause the roof to shake and release the dust and dirt.
- Removal of allergens and dusts.
- When dust get built up on high surfaces, it can create an explosive dust cloud causing fire hazards, and these dust particle results in catalyst for fire hazards.
- Accumulated dust can enter the ventilation and obstruct the working of HVAC system.
- Continuous accumulation of dust and dirt can cause breeding of mold, bacteria, viruses, etc., on the ceiling. It can cause odors and even rot the surface.

43.2 Literature Survey on Different Design of Brooms

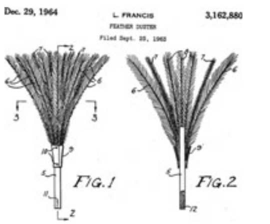
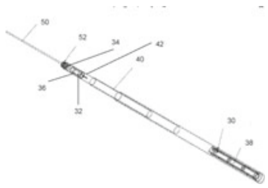
Some designs which are solving the problem up to a certain extent are found with different design, aspects, and specifications. Some found solutions are listed below:

- Feather duster, 1963—US Patent (patent number—US3162880A) [10]. The patent consist of a bunch of feathers in arrangement such that soft feather will remove certain kinds of dust and stiff feather will remove other particles.

- Cobweb cleaner, 2017—US Patent (patent number - US20170325655A1) [11]. It comprises of a flexible handle, an elongated rod axially extending from an end of the handle, and a motor fitted in the handle, and cobweb is collected around the rod.
- Ceiling dust cleaning device, 2011—China patent (patent number CN103126631A) [12]. The invention consists of hairbrush connected to telescopic handle with an ash cover, housed in lanyard. Ash cover creates hindrance and persists limited volume.
- Novel broom, 2010—China patent (patent number CN201939279U) [13] the device consist of three section of broom. Cavity is provided for dust collection, and sections were detachable. Once, totally detached device was very tough to re-attach, and also size of cavity was also small that made eyes prone to flying dust and dirt.
- Ceiling sweeper, 2013-China patent (patent number CN203107009U) [14], device consists of a hollow pipe and rocker in the bottom to be used by the user and user can sweep the ceiling. Due to heavy weight of the device, it was not useful in every scenario.
- Roof ceiling cleaning device, 2009-China patent (patent number CN101987004A) [15], invention provides a device for cleaning ceiling. With use of a telescopic handle lever, a hopper was arranged at the front of device. Hopper could be sleeved with a garbage bag. Bag attachment is one of the few drawbacks of the invention (Table 43.1).

Since all these designs were not completely solving the purpose, a study was proposed. Designs with these features were selected to study that collectively comprises all the features of the above-mentioned designs.

Table 43.1 Similar Technologies

Product	 Feather duster, US3162880A	 Cobweb cleaner, US20170325655A1	Novel broom, China patent (patent number CN201939279U)
Features	• Combination of assorted feathers • Lightweight • High reachability	• Telescopic stick • Sturdy structure • Ease of use	• Good grip for better efficiency • Cavity for dust collection • Lightweight
Drawback	No prevention from falling dust	No prevention from falling dust	Cavity cannot be detached

43.3 Problem Identification

During cleaning operation of ceilings, human body is susceptible to dirt and dust particle causing several health problems. Also, fallen particles on the floor result in extra efforts of cleaning.

43.4 Objective

1. To develop a broom attachment that can enable user to view while dusting.
2. To provide the hygiene safety.
3. To reduce allergies caused by dust and other small particles getting into nose or eyes.
4. To prevent double cleaning.
5. To develop an attachment that fit utmost standard brooms with minimum
6. hassle.
7. To develop a broom with minimum cost and to prevent recurrent cleaning.

43.5 Design Consideration

While designing the concept, we would have to deal with some defined problems to make the product viable and easy to use. Our design works around the following considerations:

- Universal attachment which could be fastened with any ceiling broom.
- Cheap and worthy.
- Should consider visibility for ease of use.
- Utmost efficient in collection of falling dust.
- The attachment should create a minimum hindrance while cleaning.
- The design should be a minimalistic approach for easy operation and maintenance.

43.6 Conceptualization

It all started with a design structure welded with the broom, to collect dust. With time, it was noted that visibility was also a factor for cleaning efficiency and hygiene. Initial designs concept was collapsible brush with dust holder as a trigger to open and close broom, dust holder was shaped as a cup and bristles were all shaped in broom and motion of dust holder in upward and downward direction release and contract bristles for use. Elimination of concept was because of the high intent of material for bristle. Other concept was based on retractable hand fan—where concept suggested blade expansion would convert broomstick to umbrella, but elimination of concept

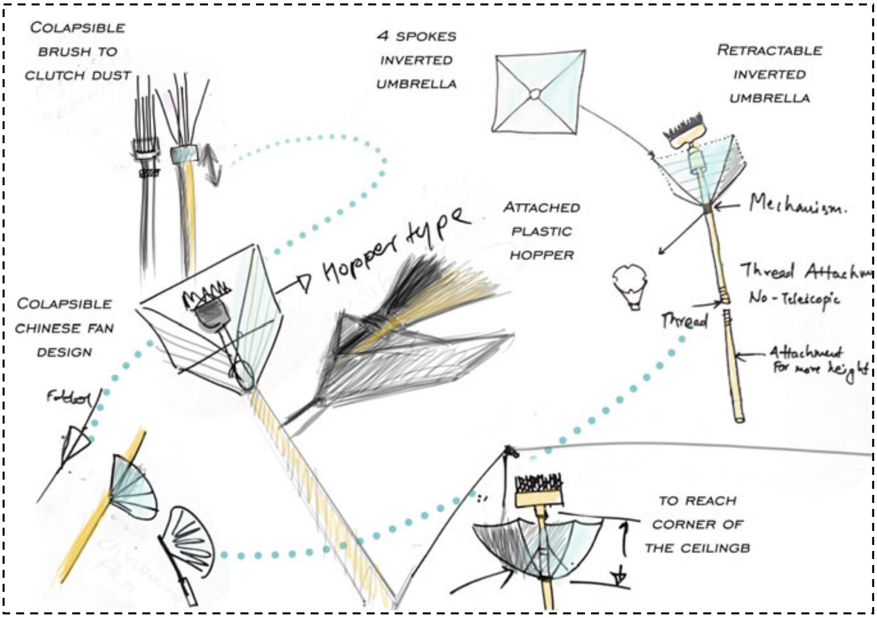


Fig. 43.1 Conceptualization sketches of design consideration

was caused by limitations of visibility and feasibility of design and cost. Another concept suggested a solid and fixed hopper but due to fixture and solid hopper weight of the broom was increased dramatically which led to strain and inconvenience in use. In addition to different concepts of design, approach of research was also different combinations of broom type and existing concepts with standard and most common size for ease to attachment with utmost broom. Final concept was spoken with connecting rod with pivot point in approx. center of connecting rod and covering whole setup with transparent plastic film (Fig. 43.1).

43.7 Construction

The attachment was consisting of the four main elements which are upper frame, lower frame, tightening screw, transparent plastic sheet, and connecting plates. The upper and lower frames were connected with connecting plate, and only upper frame was free to move in upward and downward directions. The transparent plastic covers the whole frame involving all the components and was attached to plates with washers, nuts, and bolts. Mechanism was very similar to umbrella in inverted formation. Tightening screws were for adjustment and was a pass through design in upper frame. There were two different size of plates used plate A = 450 mm and plate B = 300 mm. Plate A was used in couples and was attached to lower frame, whereas

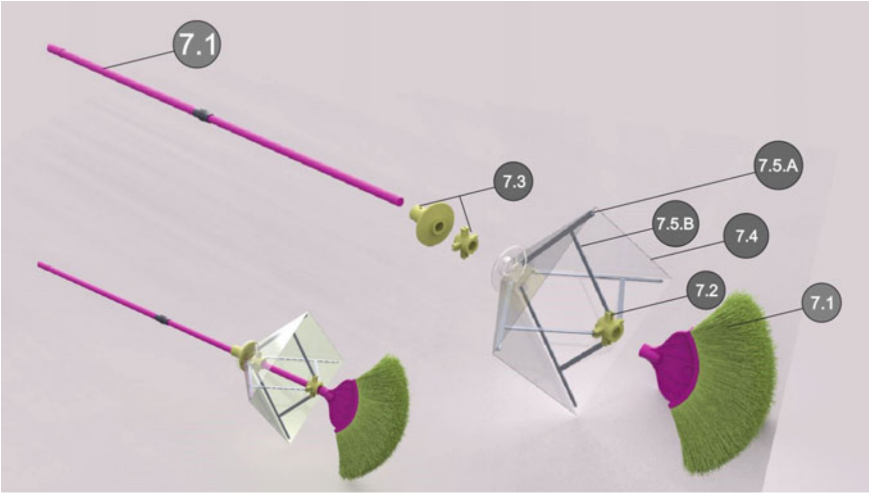


Fig. 43.2 **CAD** model and exploded view

plate B was connected with plate A at middle and is fixed with upper frame. All the plastic parts were developed using 3D printers, plates used were of mild steel with 2 mm thick, and transparent plastic sheet is 0.15 mm PVC (Fig. 43.2).

43.7.1 Broom

Broom was extendable from middle. This was most common type of broom used in household and other minor purpose. So this broom was selected. Body of the broom was of thin steel pipe. Bristles of plastic and since broom was for ceiling it was preferred to be flat and wide for larger area of sweep. Cost of the broom is Rs. 150/-.

Specification

Broom (length = 2 m, diameter = 20 mm, 0.190 kg)

43.7.2 Upper Frame

Upper frame was the structure that holds the whole frame of the broom and moving parts in alignment. Later was fixed on the rod of the broom at 10 mm below the brush head of the broom. Margin was given for ease of detachment of the brushes. Upper frame and lower frame were both made with help of 3D printer with software–Flashforge Creator Pro using PLA material with material infill of 65% with hexagonal pattern.

Table 43.2 Comparison of different developed designs for optimization of prototype

Design type	3–Spoke design	4–Spoke design	6–Spoke design
Image			
Approx. weight-g	12.56	14.95	17.25
Material—[infill]	PLA—[Hexagonal]	PLA—[Hexagonal]	PLA—[Hexagonal]
Volume liters	19.34	23.12	26.98
Advantages	Lighter in weight. Easy in design and manufacturing	Moderate in weight. symmetry in design	Overall heavy built and complex design and manufacturing.
Disadvantages	Life of the design is less than other two because of increased stresses due to lesser member in extrusion	Most optimized design, symmetric as well as moderate life span	Weight of frame is heavy that leads to strain in upper body. Resulting in decreased efficiency

Specification

Upper frame (Material = PLA, Weight = 14.95 g, Density = 1.04 g/cm^3)

Since, four-spoke design is most optimized among all three concepts. Hence, same was selected for final design and development (Table 43.2).

43.7.3 Lower Frame

Lower frame was the sliding component of the device with improvised design to minimize friction which had a larger diameter than upper frame. It is identical with upper frame with larger diameter and a hole of 8 mm for tightening screw for adjustment of the position of same.

Specification

Lower frame (Material = PLA, Weight = 35.07 g, Density = 1.04 g/cm^3)

43.7.4 Plastic Sheet

For the device, transparent plastic sheet PVC 0.3 mm was used instead of fabric of inverted umbrella. Transparency of the sheet helps increase efficiency of cleaning.

There were other thin sheets, but the 0.3 mm was the most optimized as it can bear the holes for nut and bolt as well light in weight.

Specification

Plastic sheet (Material = PVC, Thickness = 0.3 mm, Area = 8000 cm^2)

43.7.5 Connecting Frame

Connecting rods used in this device were of two different lengths, i.e., A = 450 mm and B = 300 mm with hole diameter of 6 mm. Rod A was connecting with lower frame, and it provide the outer structure as well as connecting holes for plastic sheet on which nuts and bolts were loosely fastened for movement of rods with holes as pivot. There were holes in rod A which were at 35 mm part and provide the adjustment for rod B, whereas rod B was connected with upper frame and connected with rod A with same fastening.

Specification

Connecting frame (Material = CI, Lengths = 450 mm (A)/300 mm (B), Thickness = 2 mm)

43.8 Working

Device consists of majorly five components, and working is easy and does not require much of skills. Weight of the whole device is 1.465 kg and is telescopic making the device more compact. Device can be set to any height in between 1 m and 2 m as per requirement then can be locked in the position. After that, lower frame which is sliding component of the device is pushed upward resulting in rod A and rod B to rotate in the pivot points which in turn expands the connecting frame away from the center axis. Since, device is covered with plastic film whole device replicates the appearance of an inverted umbrella. After fixing, the position of lower frame position can be tightened by screw. After the purpose achieved, whole device can be tilted for removal of dust and dirt, either by tilting or by moping the inner surface or even by removing the plastic sheet.

Folding of the device can be same as the unfolding. Device must be unscrewed first from lower frame to lower the position of the same. Since, all nuts and bolts are loosely fitted, they are free to rotate in the pivot points and are prefixed in folding position, weight of the attachments drive it to initial position, and after that broom can be folded back by losing it from the center and can be stored (Fig. 43.3).

Fig. 43.3 Prototype demonstration

43.9 Discussion

It is an easy and retractable attachment designed and developed especially with a see through feature to clean the dust and cobwebs on ceilings, without getting affected by falling dust which maintains hygiene and safety. Device can be used in both industrial as well as domestic space.

Advantages: Since double sweeping was reduced, a lot of time was saved. Both cleaning and polishing operation could be done at same time. Power consumption was nil. Maintenance of attachment was simple and required no skill to attach and detach.

Disadvantages: Application of broom was limited to ceiling only. Mechanization was not used in attachment. Due to attachment, body of whole system was quite heavy and requires extra strength than using a conventional ceiling broom. Self-cleaning is missing in the device. Proper cleaning and dusting of the plastic film is required for a proper visibility.

Applications: Best suited for domestic cleaning. Hospitals and medical center's for utmost hygiene.

43.10 Conclusion

Use of broom had been significant from decades. It has been observed that design was not suitable in some instances, and modifications done were not sufficient in designs. This research also explored some of the existing problems, and device was able to solve few problems and still requires few modifications to attain all objective.

High impact-resistant materials like nylon or acetal co-polymer can be used in mass production.

A motor could be mounted with spherical brush in near future to make the device more efficient.

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Chapter 44
Glame—Glass Holding Plate Accessory

Abhishek Gupta, Akash Kaushik, and Vishwa Goswami

Abstract Performed a problem-solving exercise for the agony of holding a beverage glass while having a meal in a buffet. This is contemplated as a considerable matter. Even after thorough market research, there is no single foolproof product or concept obtained, except for some product-oriented accessories. Many feasible concepts were designed and prototyped in consideration with CFM (color-finish-material) and utilitarian form. Trials and feedback were recorded to explore a worthwhile concept. The selected concept is a detachable device with three-point gravity-locking system attributed by the claw that can hold any size of glass without any hassle and tends to remain stable during any movement due to gimbal. The final design is analyzed with distinct materials for optimum holding efficiency. Trials were performed successfully with an adopted set of beverage glasses and cups.

44.1 Introduction

There are times when people gather and have food while standing, called buffet meal. If only, considering the buffets at a very auspicious day which is Indian weddings, it already sums up to 10 million meals, i.e., 10 million weddings as per BBC India [1]. Wedding day contemplates as a major day which results in maxi- mum invitations as a token of love and regards. With such high numbers, buffet becomes more of a meal while standing, either have to hold the glass in one hand and need to put it on the plate for eating which is daunting and sometimes risky too, as one has to balance it the whole time, also anyone might impinge with someone that causes the glass to disbalance or topple which might spoil the food on the plate or can stain costly dresses. Buffet meals are considered to be partial without beverages, whether the gathering is acute or large, a complete meal or just snacks beverages are always

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A. Chakrabarti et al. (eds.), *Design for Tomorrow–Volume 3*,
Smart Innovation, Systems and Technologies 223,
https://doi.org/10.1007/978-981-16-0084-5_44

accompanied. From just a half cup of tea to a full flute of hard drinks, as already mentioned, beverages are crucial for every meal in India. Still, no one gives it a thorough thought on these hardships, undergone by people but get accustomed to that.

44.2 Literature Review

Some designs which are solving the problem up to a certain extent are found with different design, aspects, and specifications. Some found solutions are described below:

1. Combination buffet plate and cup holder, a United States patent (Patent number US5803305A) [2].
2. Cup holder for a plate, a United States patent (Patent number US20080142528A1) [3].
3. Party plate, a United States patent (Patent number USD774360S1) [4].
4. Party plate, a United States patent (Patent number USD453891S1) [5].
5. Adjustable cup holder, a United States patent (Patent number US8757573B1) [6].
6. Buffet plate with integrated cup holder [7].
7. Plate with holder for the wine glass, a United States patent (Patent number US20050218144A1) [8] (Table 44.1).

Since all these designs are not completely solving the purpose, a study was proposed. Designs with these features were selected to study that collectively comprises all the features of the above-mentioned designs.

44.2.1 Design Considerations

While designing the concept, it is a requirement to deal with some defined problems to make the product viable and easy to use. The present design works around the following considerations:

1. Attachment should be reusable and easy to clean.
2. The attachment must be self-adapting which can incorporate almost all types of glasses and cups. A range is determined by analyzing the typical Indian meal. It starts with a very acute cup of tea with a capacity of 80 ml, a glass of water, a thermoformed cup and enfolds the largest juice glass of 350 ml.
3. The accessory should be universal, so as to mount on distinct sizes from 7 to 13 in. of dishware plates.
4. It should be easy to mount and unmount.
6. The accessory must create a Minimum hindrance in the plate well cavity.

Table 44.1 Market research

 **Fig. 1.1** Wine flute holder [9]	 **Fig. 1.2** Cocktail buffet plate [10]	 **Fig. 1.3** Table glass holder clip [11]	 **Fig. 1.4** Stemware plate clips [10]
• Unibody design • Easy to attach with plates	• Inbuilt with the plate • No need to carry an attachment	• Easy to clamp • Can be used for cylindrical glass as well as with conical glass	• Suitable with dimensionally varied plates • Unibody design • Can be used with of different thickness
– Not suitable for holding cups, perfectly cylindrical glasses, etc. – Cannot be used with the plate of different thickness – With the change of lip or rim angle, the axis of the glass with the horizontal surface will also change and limit its functionality – Consumes the space in the plate	– Consumes the space in the plate – Only suitable for the flute glasses – Cups or the other disposable glasses cannot be fit- ted – Picking and placing the glass is little bit tedious as glass has to be dragged first then has to be lifted	– Seizes its functionality as change the lip or rim angle of the plate changes – Cannot be used with cups or coffee mugs – Only useful with the de- fined thickness of the plate	– Cannot hold the normal glasses and cups – Only suitable for some standard flute glasses – Less-dimensional adaptability for different shape of glasses

• Advantages
– Disadvantages

Fig. 44.1 Both hands are occupied while eating

Fig. 44.2 Beverage glasses and cups range

7. The design should follow the minimalistic approach for easy operation.
8. The device needs to be feathery to be able to hold it for a while, it should not be an auxiliary weight.
9. It also demands to be stable the whole time in order not to spill anything (Figs. 44.1 and 44.2).

44.2.2 Concept Journey

The initial design encompasses a basic structure welded with a basket, which can hold beverage glasses. Gradually with a demand for stability, the gimbal mechanism is introduced, and the attributed three-point claw firm locking system brings trust and confidence. The process has gone through ample material options for manufacturing and ends up with structural strengthening design with the plastic itself. It is important to accommodate all types of glass and cups, which it does with an adjustable base (Fig. 44.3; Table 44.2).

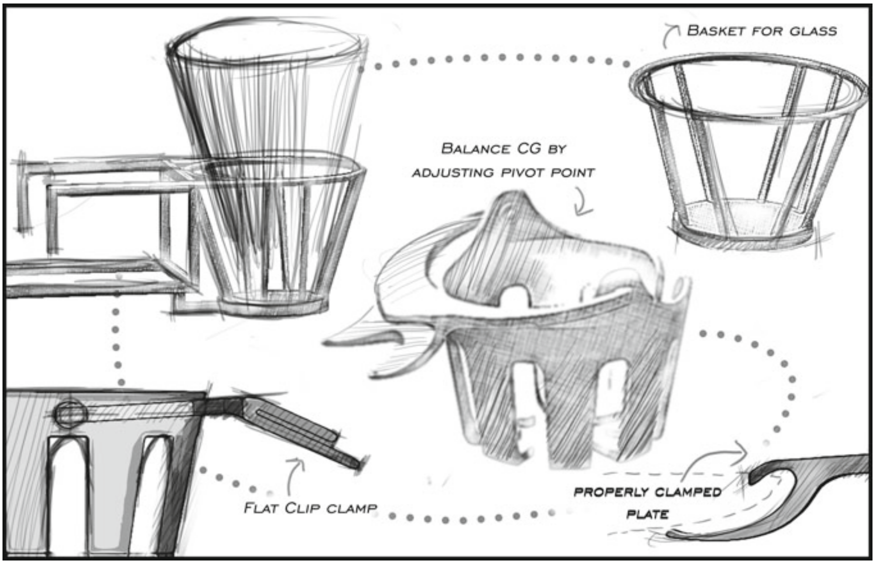


Fig. 44.3 Concept development sketches

This journey was started in order to cover all the facets of the design considerations, and concept 4 was found most compatible with all aspects of the design consideration; hence, the journey comes to an end with the selection of the concept 4.

44.2.3 Design and Calculations

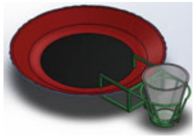
Design enfolds sturdy cad modeling for assurance and confidence. Finished manufacturing includes compressed injection molding with a polycarbonate plastic material ensuring reliability (Fig. 44.4).

Parts

1. Basket
2. Clamp

1. **Basket**—A self-adjusting designer bottom to accommodate a range of drinking glasses and cups. Bi-laterally placed slit is to settle up the handle of any type of cup. The main basket is with height 57 mm developed with reference to the smallest glass that we considered in our range, which is a paper teacup with a height of 64 mm. Thus, even the shortest cup is significantly accessible. Importantly, the pivot point should be higher than the center of gravity in order to maintain equilibrium. The tallest glass considered is juice glass with a height of 110 mm. Considering the CG for the tallest glass, which is 65 mm from the bottom as calculated we need to shift the pivot 10 mm higher to maintain equilibrium (Fig. 44.5).

Table 44.2 Concepts comparison

 **Fig. 2.1** Concept-1	 **Fig. 2.2** Concept-2(metal)	 **Fig. 2.3** Concept-3	 **Fig. 2.4** Concept-4
• Simple four-point locking design • Easy to attach and detach • Able to hold glasses and cups as well • Lightweight (25.3 g) • Material used is ABS PC • It can bear a weight of 220 g	• Metal used for strength and rigidity • Used material is annealed carbon steel (SS) PC (food grade material) • It is almost seven times heavier than ABS PC 186.26 g	• Hinder less on plate well cavity • Basket of the attachment can hold any shape of a glass • Gimbal is introduced • Weight of attachment s about 30–44 g • It can bear a maximum set of about 250 g	• Hinders less than the concept 2 • Can be mounted on any shape of plate lip and rim angle • Lifted pivot points to balance CG • Weight of the attachment is about 30.48 g • It can bear a maximum weight of about 420 g
– Consume at least 1/4 footprint of the plate – Consumes the bottom space of plate as well hence create hindrance while holding the plate – Can bear a maximum weight of only 220 g	– It has a heavyweight compared to all other designs and to hold it on a of plate requires more force by user due to its momentum – Cannot accommodate different variety of glasses and cups	– This attachment was not able to hold the cups and flute glasses – Clamp design is not fit for many plates design – Pivot points are lower than the CG of glass which leads to malfunctioning of gimbal mechanism and ultimately tumbling of glass	– Only suitable for range adopted considering Indian meal

• Description
– Drawbacks

Fig. 44.4 Glame

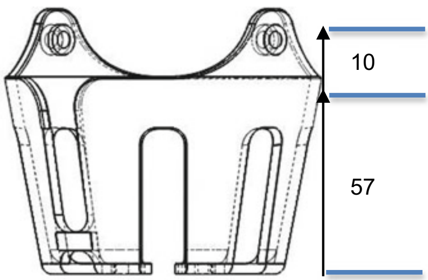


Fig. 44.5 Front view of a line diagram of basket depicts pivot point from base

Its open-ended base provides a spring action that allows a number of different shapes and sizes to fit into it. Also due to the spring action, it provides a good grip to the glass and cup which helps in stabilizing the glass or cup, so the drink will not spill out of the glass or the cup.

In Fig. 44.6, point 'O' is the hinge point where basket and clamp are attached and due to contact, there is a frictional force that acts opposite to the angular velocity. Point 'C' is the center of gravity (COG) of the basket and the glass which is filled with some liquid.

If any slight force is applied to the basket or glass, the COG will shift at an angle 'θ' from its mean position.

Here: F_G = Force of gravity, F_A = force of gravity along the line of action, F_P = force of gravity perpendicular to the line of action, and F_t = Tension force.

So hereby the trigonometry, we can say:

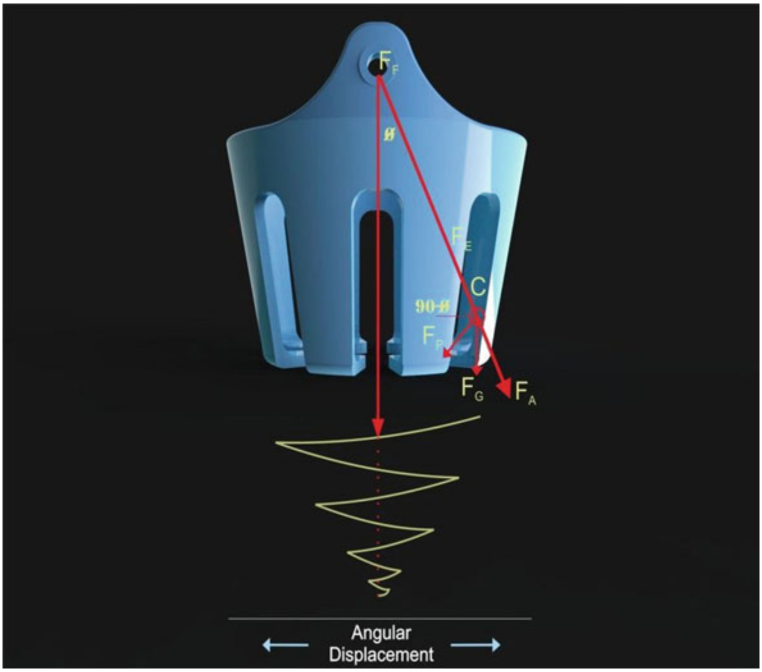


Fig. 44.6 Angular displacement curve

Sin $\theta = F_{\mathrm{P}}/F_{\mathrm{G}} \Rightarrow F_{\mathrm{P}} = F_{\mathrm{G}}$ Sin θ and $F_{\mathrm{A}} = F_{\mathrm{t}}$ (here, F_{A} will not contribute to the angular acceleration).

$F_{\mathrm{G}} = mg \Rightarrow F_{\mathrm{P}} = mg \times$ Sin θ (where m = mass of basket and the glass filled with water and g = gravitational constant).

Since at the hinge point 'O', a constant frictional force is acting against the angular velocity and will lead to generating a negative angular acceleration until the velocity goes to '0'. And as shown in the diagram, the whole attachment will achieve a stable position after some point of time which is required.

Clamp—Properly hinged meta-centric pivots for sturdy action. However, a three-point claw clamp bothers less on the eating plate. Clamp consists of the driven dimensions by basket.

Material selection range consists of ABS PC (copolymer), PP (homopolymer) and PVC. The copolymer of ABS (acrylonitrile butadiene styrene) and PC (polycarbonate) material offers a good balance of impact, heat, chemical, and abrasion resistance, dimensional stability, tensile strength, surface hardness, and rigidity (Fig. 44.7).

Figure 44.8 shows the displacement through structural analysis at maximum load impact with PC ABS copolymer. It successfully sustains the load of the largest glass with a capacity of 340 ml with load of 3.3 N. The maximum deformation spotted is around 1.6 mm at the pivots which is innocuous.

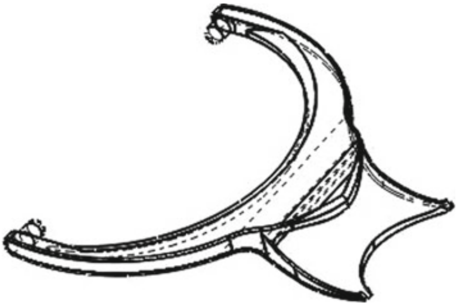


Fig. 44.7 Line diagram of clamp

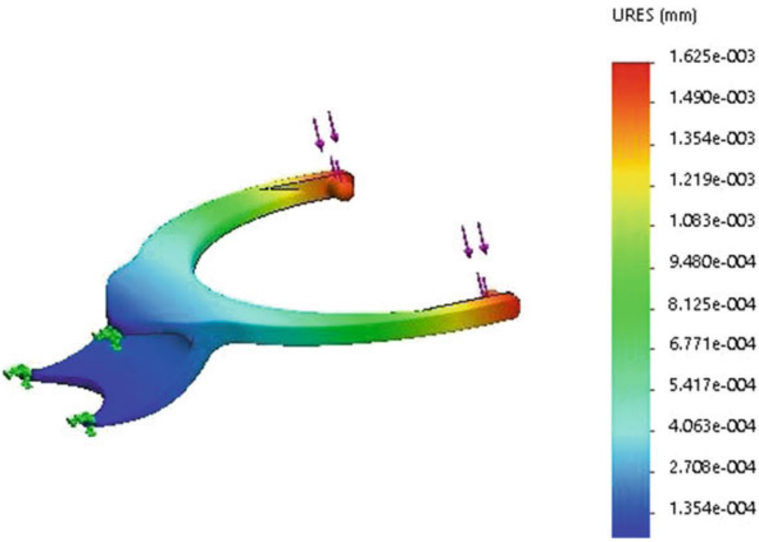
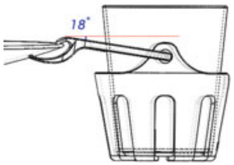
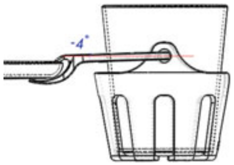
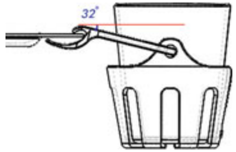


Fig. 44.8 Structural analysis of the clamp

44.2.4 Interaction with Plates

Distinct Lip and Rim Plate Designs

This experiment depicts an interaction between the Glame and plates with common lip and rim designs. It is imminent to see how every time Glame accommodates the glass vertically stable. The design of pivot hinges at meta-centric height allows the basket to perform gimbal effect in order to adjust the center of gravity.

		
Smooth plate with a decent cavity. Here, the Glame is declined at 18° to maintain stability	Plate with curved lips to create a cavity. Here, the Glame is inclined at −4° to maintain stability	Plate with an extended collar. Here, the Glame is declines at 32° to maintain stability

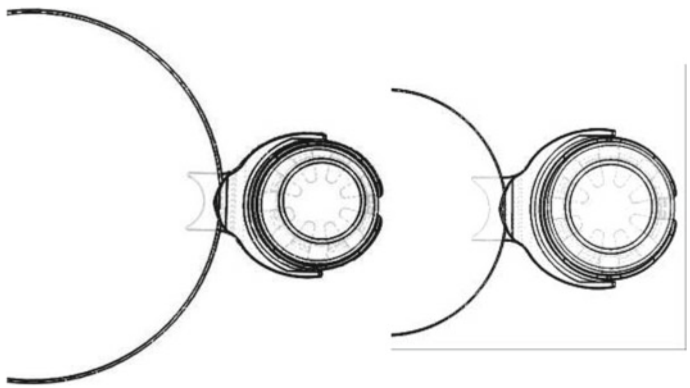


Fig. 44.9 Glame coupled with both small and large dia. plates

44.2.5 Distinct Diameters

Dishware plates are segregated in mainly 2 sizes, i.e., food plate which is big and dessert plate which is small. The experiment shows how Glame interacts with the plates of different sizes. Large or small, Glame braces both the plates impeccably. The claw lock is designed in such a way that it barely hinders the good area of the food plate (Fig. 44.9).

In the left, food plate generally ranges from 11 to 13 in. in diameter. Glame clamps the plate perfectly in spite of utilizing very little area on the front. In the right, dessert plate generally ranges from 7 to 9 in. in diameter. The thickness of the claw lock is so absolute that it braces both the size of plates without any imbalance.

44.2.6 Glame (in-Use and Multi-utilities)

A pictorial glance of "Glame" in-use. It conveys the confidence to clasp single-handedly. Also, it does not hinder the dishware well which furnishes the sense of hygiene while consuming food. Also, Glame clearly proclaims the characteristics of multi-applications. This single device can uphold the beverages for distinct occasions, including cups with handles and flutes for wine. Upside down slit on the basket makes it possible to accommodate cups with handles. Moreover, we can use two or more glasses in a single plate if a variety of drinks are available (Fig. 44.10).

Fig. 44.10 Multi-utilities

44.3 Conclusion

Nowadays, predominantly buffets are offered on many occasions, and most of the attendees feel the need for such accessories. Efforts have been built resolving the problem with a unique, compact, rugged, and detachable holder that can be used with any kind of washable plate and a huge variety of glasses. Glame's feathery built not only makes it easy to handle but also provides more space for food items on the plate. Self-adjusting basket and gimbal effect makes Glame omnipresent and a needful product. After exploring the various existing concepts and keeping in mind all the design considerations, few designs were calibrated that may resolve related problems. This helps to come up with unique designs that withstand optimal design consideration. Compared to the other options available in the market, this attachment is cheaper and more efficient variety of shapes of glasses and cups with less space consumption in the plate. Design can solve the problem effectively without hindering other parameters.

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Chapter 45
Design and Development of Mini Ginger Planter Suitable for Hilly Region Agriculture

Thaneswer Patel, K. N. Dewangan, B. S. K. Chhetry, Sarju Thokchom, and Bishorjit Ningthoujam

Abstract Most of the states of the northeast region of India are known for the ginger cultivation. However, Meghalaya, Arunachal Pradesh, and Mizoram are the leading ginger producing states in the region. It is one of the most known emerging cash crops with business and marketing potentiality. The agro-climatic condition of northeast India is highly suitable for the cultivation of various types of horticulture fruits and spices. Due to the lack of suitable ginger planting machines, usually manual method for ginger cultivation is predominant in the region. Therefore, a power-operated mini ginger planter was designed and developed, considering the requirements like lightweight, economical, portable suitable for the northeast region of India. The ginger planter consists of a chain and bucket type of metering mechanism. Semi-circular bucket-type metering mechanism was fabricated and tested for performance at a forward speed of 0.75 km/h. For the testing of performance, collected and analysed the various performance data like seed missing (%), bucket filling (%), physical damage (%), theoretical field capacity (ha/h), actual field capacity (ha/h), field efficiency (%), depth of plantation (cm), and seed spacing (cm).

45.1 Introduction

India is a leading producer of ginger in the world and exports to more than 50 countries, accounting for more than 70% of world production. Ginger is grown both in irrigated and rain-fed areas of India, and India is known as the 'land of spices' in the world. Ginger thrives best in well-drained soil like sandy loam, clay loam, red loam, or lateritic loam, and a pH of 6.0 to 6.5 rich in humus is ideal. Ginger grows

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A. Chakrabarti et al. (eds.), *Design for Tomorrow–Volume 3*,
Smart Innovation, Systems and Technologies 223,
https://doi.org/10.1007/978-981-16-0084-5_45

well in a warm and humid climate. It is cultivated up to 2000 m above mean sea-level and thrives well in partial shade, but elevation between 300 and 900 m above MSL is best for cultivation. However, being an exhausting crop, it is not desirable to grow ginger in the same soil year after year. The crop grows well in a temperature range of 19–28 °C and a humidity of 70–90%. Moderate rainfall at the time of sowing till the gingers sprout, fairly heavy, and well-distributed showers during the growing period and dry weather with a temperature of 28°–35 °C is optimum requirements for its successful cultivation. The traditional method of ginger cultivation is labour, required 200–250 man-h per hectare [1]. The total production of ginger in India from 1991 to 2015 is 1.76 to 6.5 lakh MT [2].

Ginger is also the main cash crop in the North-Eastern Region (NER) of India, accounting for 49% of India's ginger cultivated area and 72% of India's ginger production. NER of India is one of the highest productivity areas in the world, accounting for 5.8 t/ha as against the national average of 3.7 t/ha, considering as an organic ginger hub [3]. The cultivated area under ginger is 33.2 thousand ha which gives total production of 191 thousand tons at an average yield of 5.8 t/ha [4]. Among the northeastern states, Meghalaya is a major producer and second-largest producer of ginger in the country with a total share of 19.59% after Kerala contributing 23.08% to the total country production [4]. There has been an increase in the area under the cultivation of ginger in Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, and Tripura from 1999 to 2015. The production in this region also had been increased from 37.32 to 48.56 MT from 1991 to 2015 [2].

Due to adverse topographical conditions, most of the farmers living in NER still following traditional methods for ginger cultivation. Further, 80% of the farmers are poor, illiterate, and under small and marginal categories [5]. Traditional methods of cultivation take a long time and create more physical exertion to workers [6]. Workers generally employed traditional methods of harvesting because it is eco-friendly, less expensive, and utilizing local resource knowledge and labour, still facing some of the constraints in terms of production, labour availability, labour drudgery, and economic return. Delay in planting due to labour shortages and rain adversely affects the yield and production of ginger [1]. Therefore, there is a great need for the development of need-based power-operated mini ginger planter for hill agriculture which is of utmost importance. Because of this, a study was conducted to develop a suitable metering device for planting ginger on the small-scale farm. The main hindrance to foster agricultural growth in the NER of India lacks in support of proper technology and mechanization. In NER, traditional tools used for ginger cultivation include a spade, dao, khurpi, hoe, etc. [7]. In traditional methods, the farmers had to dig the soil for sowing ginger which is tiresome and also led to several WMSDs due to continuous awkward body posture. Traditional methods of ginger cultivation are time-consuming, labour-intensive, low productivity, and not efficient from the view of farmer's heath and economic return. The main purpose of this research topic is to overcome the drudgery associated with the farmer. If the mechanical planter replaces the traditional method, there would be a reduction in the necessity of surplus labour requirement and health-associated problems.

45.2 Methodology

The laboratory testing of the machine was done at a farm machinery laboratory in the agricultural engineering department, North Eastern Regional Institute of Science and Technology (NERIST), Arunachal Pradesh. The research focused on the design, development, and testing of self-propelled mini ginger planter suitable for the hilly region of northeast India, where the use of the large size of machinery is not feasible.

45.2.1 Design of Seed Metering Mechanism

Ginger is irregular in shape and planted by cutting the portion randomly with buds of varying lengths from 20 to 30 mm. The length of ginger used for plantation is 2.5 to 30 mm in length, the thickness of 19.23 mm with a standard deviation of ±1.94 mm [1], and width was taken to be the maximum length of the ginger seed. For picking the irregular shape, the chain and bucket metering mechanism was used for the planter, as shown in Fig. 45.1. The overall length and width of the cup were kept at 45 mm. The depth was decided as 22 mm to avoid the chances of coming two seeds at a time during operation.

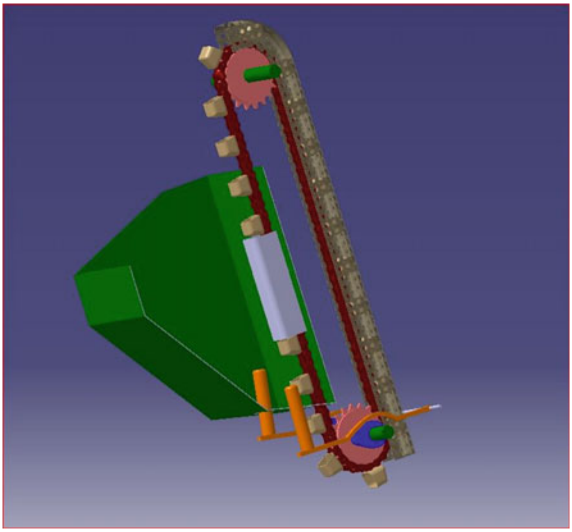

Fig. 45.1 Semi-circular bucket-type metering mechanism attached with a chain

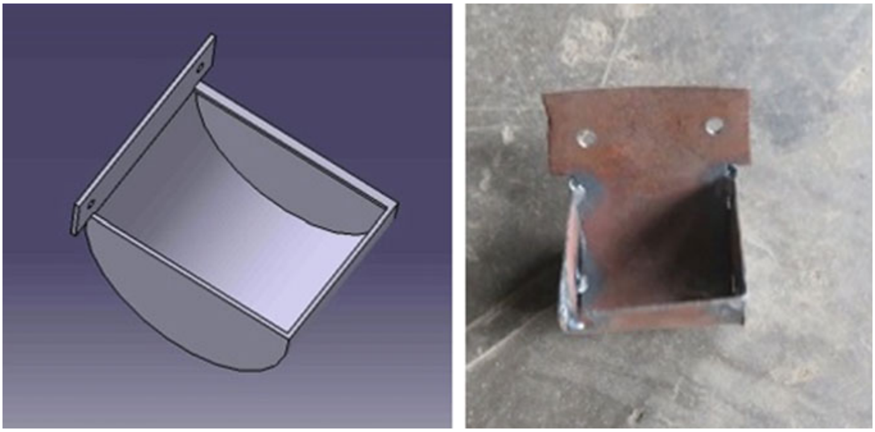

Fig. 45.2 Semi-circular shape of a bucket for ginger seed metering unit

45.2.2 Metering Mechanism

As the bucket passes through the hopper filled with ginger seed, the bucket picks up the seed from the hopper. The bucket inverts as they pass around the top sprocket, and the seeds pass through the discharged tube. The whole pathway is enclosed with a rubber material to avoid damage of seed until it gets delivered in the furrow opener through the discharged tube. The number of the bucket on the seed metering device depends on the desired seed spacing, ground wheel diameter, and gear ratio. The spacing between gingers was considered 250 mm. The power of the metering mechanism was obtained from the furrow wheel using suitable gears.

45.2.3 Design of Circular Metering Bucket

The semi-circular seed metering cup with chain and sprocket mechanism was fabricated. The length of the chain was 1420 mm and sprocket with 15 teeth on the metering mechanism and 11 teeth on the furrow wheel to form a gear train mechanism. Further, a rod operated by a cam attached to the shaft of the metering mechanism was used as an agitator for a smooth flow of ginger seed. The semi-circular bucket of dimension 35 $\times$ 45 $\times$ 24 mm was fabricated (Fig. 45.2).

45.2.4 Design and Fabrication of Ginger Planter

The design of a power-operated mini ginger planter was conceptualized and fabricated. The developed machine was attached with a power tiller which is a walk-behind

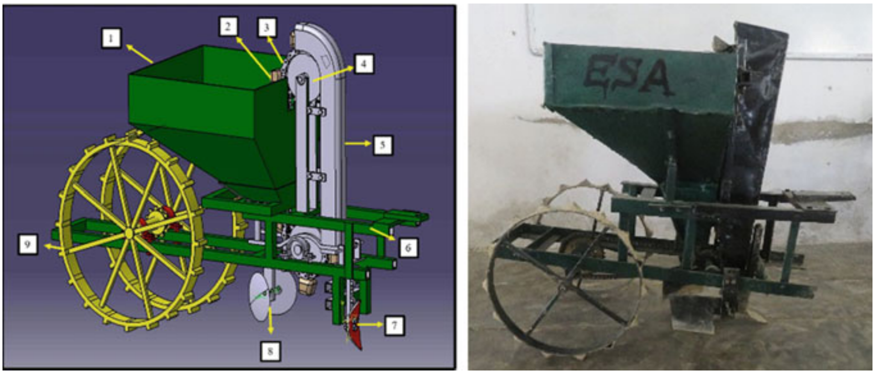

Fig. 45.3 Various components of the developed ginger plant

type. The design constitutes hopper (1), metering bucket (2), chain (3), sprocket (4), metering device covering unit (5) frame (6), furrow opener (7), furrow covering device (8), and furrow wheel (9).

The developed planter consists of two furrow wheel and a horizontal frame that supports all other components. The various components of the ginger planter were shown in Fig. 45.3.

45.2.5 Performance Evaluation of Ginger Planter

The ginger planter was tested in the laboratory and the field conditions. In the laboratory testing, evaluated parameters like a seed to seed spacing and depth of furrow opened. However, in the field testing evaluated various parameters like mean seed missing (%), mean bucket filling (%), percentage of physical damage (%), theoretical field capacity (ha/h), actual field capacity (ha/h), field efficiency (%), depth of plantation (cm), and seed spacing (cm).

45.3 Results and Discussion

45.3.1 Laboratory Testing of Ginger Planter

The developed ginger planter was tested in the laboratory for performance evaluation. There was no physical damage to the seeds due to the seed metering mechanism. The performance evaluation also showed that missing seed percentage increased with a reduction in the depth of ginger in the hopper. Laboratory evaluation of the ginger

Fig. 45.4 Laboratory performance evaluation of developed power-operated mini ginger planter

Table 45.1 Laboratory performance evaluation of the developed ginger planter

SI. No.	Parameters	Value
1	Turning radius (mm)	1100
2	Mean seed missing (%)	17.74
3	Actual field capacity (ha/h)	0.07
4	Mean seed spacing (mm)	250
5	Average cup filling (%)	111
6	Depth of furrow opened (mm)	150 mm

planter is shown in Fig. 45.4. Laboratory performance evaluation of the developed ginger planter is shown in Table 45.1.

45.3.2 Field Testing of Ginger Planter

Performance evaluation of the developed power-operated mini ginger planter was done at Lakhana Bari village, Assam in the farmer's field, as shown in Fig. 45.5. The performance of the ginger planter was evaluated at the forward speed of 0.75 km/h. The results obtained in performance evaluation are shown in Table 45.2. The results showed that the depth of plantation and seed spacing was not dependent on the operating speed. The missing of seeds increased and the filling of bucket decreased with an increase in the speed of operation. As the seeds missing increased, the filling of the bucket decreased.

Fig. 45.5 Field performance evaluation of developed power-operated mini ginger planter

Table 45.2 Field performance results of developed power-operated mini ginger planter

SI. No.	Parameter	Values
1	Treatment before plantation	No
2	Manures applied	No
3	Type of soil	Clay loam soil
4	Row to row spacing (cm)	40
5	Size of ginger (cm)	3
Independent parameter		
6	Speed of operation (km/h)	0.78
Dependent parameter		
7	Percentage of physical damage (%)	0
8	Theoretical field capacity (ha/h)	0.078
9	Actual field capacity (ha/h)	0.074
10	Field efficiency (%)	94.8
11	Depth of plantation (cm)	5
12	Seed spacing (cm)	25
13	Speed of operation (km/h)	0.78
14	Mean seed missing (%)	1.00
15	Mean bucket filling (%)	134.08

45.4 Conclusion

The use of large and heavy machinery is very limited in the northeastern region of India due to small fragmented landholding and topographical constraints. Therefore, ginger planting work is still carried out in the northeast region of India using the manual method. However, it required more time and physical exertion of the workers, hence developed single-row self-propelled mini ginger planter to reduce the time of planting and human efforts. Ginger planter performance was tested under laboratory and field conditions. The outcome of the results showed satisfactorily within the acceptable range. The developed single-row ginger planter would be most suitable for small and marginal farmers.

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Chapter 46
Development of Al–Cu Metal Matrix Composite Using Powder Metallurgy Technique

Subham Kundu and Subhas Chandra Mondal

Abstract Aluminium is a lightweight soft metal with moderate electrical conductivity. It is commonly used in aerospace, automotive industries as well as in day-to-day life. Several researchers and practitioners had worked to increase the strength of aluminium alloy by mixing some alloying elements such as Cu, Mg and Si with aluminium. The alloys are mainly prepared by stir casting and powder metallurgy techniques. Very few research works are carried out to increase the electrical conductivity of the aluminium alloy. In this paper, powder metallurgy technique is applied to prepare aluminium metal matrix composite with 10, 20 and 30% of copper weight percentage. Powder metallurgy technique is taken for proper dispersion of copper powder using ball milling process. SEM image shows the dispersion of copper with Al powder. Copper acted as binder to increase hardness when tested by Rockwell hardness tester. Densities of all three composites are measured. The significant amount of electrical conductivity is increased by increasing copper percentage. Lowest electrical resistivity is achieved for Al-30% Cu composite and highest for Al-10% Cu composite.

46.1 Introduction

Aluminium is a lightweight, soft material hugely used in aerospace, automobile, defence industries to day-to-day life [1]. Several research works have been carried out to fabricate metal matrix composite (MMC) of aluminium (Al) by adding different reinforcement materials such as silicon carbide (SiC), alumina (Al_2O_3), zirconia (ZrO_2), carbon, graphite in fibre, particulate or whisker form by applying different fabrication method like spray deposition, powder metallurgy, stir, squeeze and compo

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A. Chakrabarti et al. (eds.), *Design for Tomorrow–Volume 3*,
Smart Innovation, Systems and Technologies 223,
https://doi.org/10.1007/978-981-16-0084-5_46

casting [2]. Mainly mechanical and tribological properties are investigated on developed metal matrix composite such as aluminium–zinc MMC using squeeze casting method [3], aluminium-graphite composite by pellet method [4], copper-coated carbon fibre reinforced Al MMC by cementation or electroless deposition technique [5] and cast aluminium composite containing copper-coated mica particles developed using copper sulphate solution [6]. The effect of copper reinforcement in pure Al matrix is investigated in few numbers of literature. The researchers followed the path of liquid state fabrication technique such as stir casting to develop Al–Cu MMC and studied mechanical properties and micro-structure of the composite. Al–Cu composite with 5, 10 and 15% copper weight percentage by adding EC grade copper chunks in IE grade molten aluminium at 720 °C was developed by stir casting method [7]. The developed composite material has 80% better hardness than same composition Al–Cu alloy. The Al–Cu composite showed decrease in stress strain value by 13% and 15%, respectively, when prepared by stir casting technique [8]. Copper powder has poor wettability in liquid aluminium. Powder metallurgy has an advantage over stir casting to get uniform distribution of copper particles in Al matrix. Powder metallurgy is a technique to fabricate intricate shape of material with good surface finish and dimensional accuracy. It is used in many industries to produce small electronics goods, mechanical components, bearings, etc. Powder metallurgy mainly consists of three steps as follows: mixing of metal powders with binder, compacting and sintering. The purpose of the present work is to develop Al–Cu metal matrix composites with different weight percentages of copper following solid state fabrication method powder metallurgy and using few alternative techniques.

Researchers observed that reinforcement of aluminium alloy AA6061 with fly ash (FA) increased the micro-hardness of the composite [9]. Density of the metal matrix composite increased with increase in copper content by 2%, 4% and 6%, respectively, with aluminium through powder metallurgy technique when formability of Al–Cu composite was studied [10]. Though aluminium and copper both are good electrical conductor, the study on electrical property of powder metallurgy processed Al–Cu composite is neglected. In this research, work micro-structure of the developed Al–Cu composite is studied by SEM, and density, hardness and electrical property are analysed for the composite. This powder metallurgy processed Al–Cu MMC can be used to make components in electrical and electronic industry because of its good electrical and mechanical property.

46.2 Development

Weight of aluminium powder (extra pure powder of 98% purity supplied by LOBA Chemie) and copper powder (ultra fine powder of 99.8% purity manufactured by diamond tool metal powder) is measured with a KERRO Digital precision weighing machine with 0.001 g accuracy inside a glass box to avoid turbulent air pressure which may cause fluctuation of weight in the display. Powders are taken in certain weight percentage (wt%) to prepare three numbers of samples. The powders are properly mixed within a steel container using a centre lathe, compacted using a compression testing machine (CTM) and sintered inside a muffle furnace.

46.2.1 Mixing of Al and Cu Powders

For preparing Al-10% Cu sample, 2 g of aluminium powder and 18 g of copper powder are taken in a steel container of diameter 88 mm and length 120 mm. 40 numbers of stainless steel balls of diameter 6 mm are taken in the container. After filling the container with 20 g of powder and steel balls, the lid of the container is sealed with layers of transparent polypropylene-based pressure sensitive sellotape or glued cellophane to make it air tight. Proper care is taken to resist the leakage of powder or opening of the container lid due to centrifugal force generated during rotation. Instead of laboratory ball mill [11], an alternative method of mixing is obtained by using a centre lathe. The laboratory ball milling is a low energy milling process which required higher duration of time for mixing. The effect of relatively high energy milling on mixing for lesser duration of time is observed by rotating the container in centre lathe. The distribution of Cu particles within Al matrix changes the micro-structural formation of developed composite which has an important role on electrical resistivity of powder metallurgy composite [12]. Mixing is done by rotating the container filled with ball and powder. The airtight closed container is fixed in the 3 jaw chuck. The rpm of the lathe is fixed at 240 rpm and rotated clockwise for 30 min and then anticlockwise for another 30 min for dispersion of copper powder in aluminium powder. After 1 h of rotation, the container is taken out of the chuck, steel balls are separated and mixed powder is weighted again. An error of 0.010 g weight before and after mixing is observed at that time.

46.2.2 Compacting

The mixed powder of aluminium with 10% of copper is filled in the hollow cylinder of a high speed steel (HSS) die as shown in Fig. 46.1. The inner diameter of the die is 16 mm and outer diameter of the die is 50 mm. The height of die and punch is of 55 mm and 61 mm, respectively. The pin seats on the base to stop displacement of die and base. Then the die is placed on the base. After filling the die with powder, compaction is done with the help of punch. Seat of die which is made of aluminium is used to extract the cold compacted sample from die.

Depending upon the compaction pressure and volume of powder, cylindrical shape sample of height 16 mm and diameter 16 mm is prepared. Instead of table top hydraulic press commonly used in powder metallurgy laboratory, a compression testing machine (CTM) is used for axial compaction. The die filled with powder is placed on the base of the machine lower press. The punch is placed perpendicularly to the base along the centre axis of the die, giving pressure on the filled powder. On

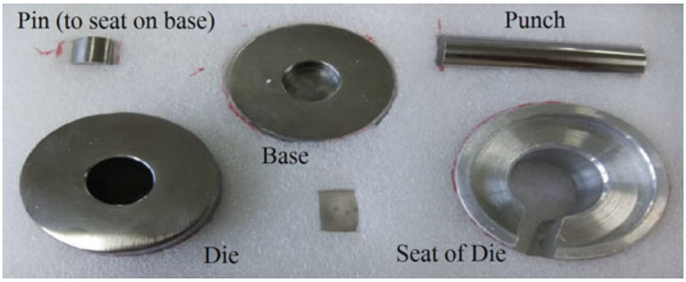


Fig. 46.1 HSS die and punch set

the top of the punch, the upper press of the machine is placed manually by rotating the wheel. After providing the initial pressure manually, the compressive pressure is increased hydraulically by reciprocating the lever using a piston lever arrangement. 6.5 ton of pressure is applied on the die, stayed for 10 min and the load withdrawn. No binder is used separately as copper acts as a binder and creates strong interfacial bond with Al with bimetallic layers of CuAl, Cu_3Al, Cu_4Al_3 and $CuAl_2$ [13]. The powder is compacted due to the applied pressure. Green compact is prepared within the die. Then the die is placed on a hollow, lightweight base and the punch is pressed downward manually by the upper press of the machine. The applied pressure slides away the green compacted powder sample from the die.

46.2.3 Sintering

The green compacted sample is then taken for sintering. It is handled cautiously as the green compact is prone to break. Tube furnace [11], spark plasma sintering machine [14], muffle furnace [10] can be used for sintering. The sintering is done lower than melting temperature within a muffle furnace fitted with energy regulator, insulation blanket and thermocouple. The adjustable working temperature of the furnace is 900 °C and maximum temperature is 1000 °C. The green compacted sample is heated up to 500 °C gradually from atmospheric temperature within muffle furnace for 45 min and stayed inside the furnace for 3 h to reach atmospheric temperature again. The inter-metallic bonding creates due to fusion and sintered sample is taken out of the furnace. This method is followed thrice for preparing three samples of different amount of copper and aluminium powder as shown in Fig. 46.2.

46.3 Property Analysis

Electrical conductivity of three samples is measured by Kelvin four wire resistance measurement methods [15]. According to Ohm's law, the resistance (R) is the ratio

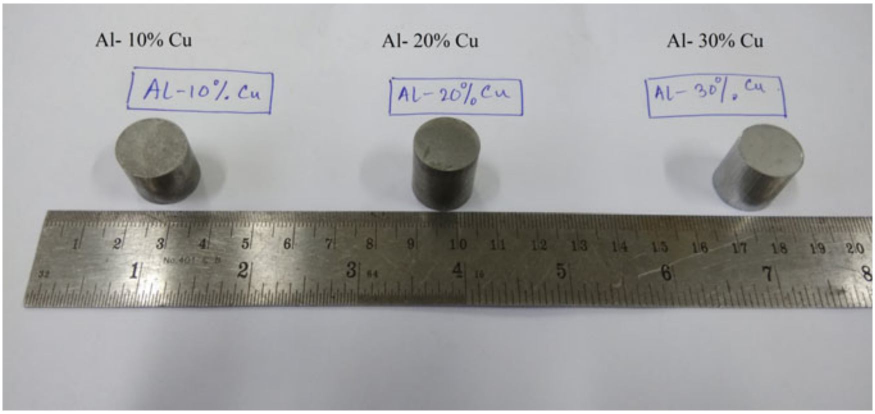


Fig. 46.2 Three powder metallurgy specimens

of voltage (V) and current (I). Resistance (R) is related to resistivity (ρ) by $R = (\rho L/A)$, where A is the area of the specimen. Electrical conductivity (σ) is inverse of the electrical resistivity (ρ). Using the above mentioned method, electrical resistivity achieved of the following specimens is shown in Table 46.1.

Hardness of three samples is tested by "Rockwell hardness tester", supplied by "Saroj hardness testers", model RAS/RAB-1 using 1/16″ (1.588 mm) diameter steel ball and 100 kgf of load. B Scale and Red dial of the tester are checked for Rockwell hardness number. Density of three specimens is measured using Archimedes principle. Hardness and density achieved are shown in Table 46.2.

Table 46.1 Electrical resistivity of specimens

Specimen	Electrical resistivity (ρ) in Ohm-metre (Ωm)
Al-10% Cu	2.312
Al-20% Cu	0.955
Al-30% Cu	0.00021

Table 46.2 Hardness and density of specimens

Specimen	Hardness (HRC)	Density (g/cc)
Al-10% Cu	95	2.6879
Al-20% Cu	96	2.7977
Al-30% Cu	96	3.1709

46.4 Results and Discussion

It has been observed that electrical resistivity decreased with increase in copper content. As electrical conductivity is inverse of electrical resistivity, Al-30% Cu has highest electrical conductivity, whereas Al-10% Cu has lowest electrical conductivity. The electrical conductivity of copper is more than aluminium. The decrease in electrical resistivity with the increase in wt% of Cu is almost linear within the scope of this study. Copper content increases the densification of Al–Cu composite [10]. Density of the samples also increased when copper weight percentage increased, as shown in Fig. 46.3.

This phenomenon occurred as electrical conductivity and density of copper is higher than aluminium. The HRC value of hardness remained almost same for three specimens. As the copper is a soft material, the addition of it does not significantly change the hardness value of Al–Cu MMC. SEM was done on the face of the plain sample. The specimen surface was prepared by polishing it with sandpaper (600 and 1200 grit size respectively) and cleaned by ethanol. Cluster of copper powder observed in SEM images on few part of surface on the samples as shown in Fig. 46.4.

High energy ball milling in a shorter period of time is effective to break the alumina skin on Al powder surface due to energetic collision with steel balls which

Fig. 46.3 Change of properties according to Cu %

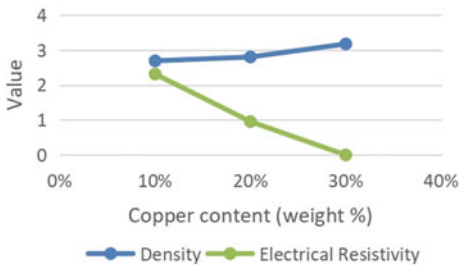
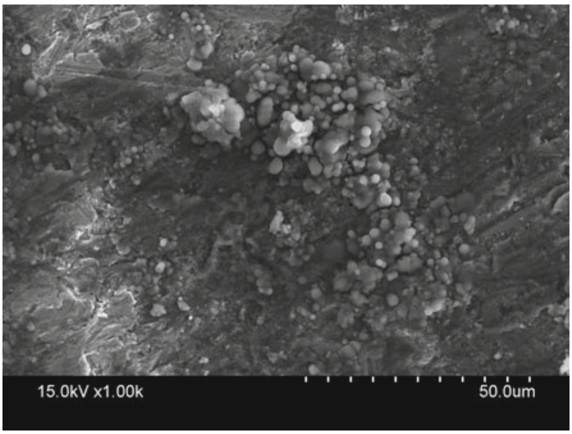


Fig. 46.4 SEM images of Al-30% Cu composite surface



is helpful for good interfacial bond between aluminium and copper powder. More uniform dispersion of copper powder in aluminium powder requires ball milling in lower RPM and higher duration of time but this process can severely damage powder structures due to long grinding duration by steel balls which badly affects the microstructure of Al–Cu MMC [16]. In this research work, high rpm and short duration ball milling is preferred over low rpm and long duration ball milling to avoid the drawbacks of it. This powder metallurgy route is helpful to achieve faster production rate of Al–Cu MMC with improved electrical and mechanical properties.

Acknowledgements The authors of this paper are grateful to IIEST, Shibpur and Heritage Institute of Technology, Kolkata, for their laboratory support.

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Chapter 47
Design, Additive Manufacturing and Application of Patient-Customized Orbital Implants

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Abstract Eye orbital floor fracture is a common occurrence due to traumatic eye injuries during contact sports, motor vehicle accidents or impact by blunt objects. Another cause is a sudden increase in intra-orbital pressure. The consequences include orbital volume expansion, double vision or loss of vision in severe cases. Owing to the complex orbital anatomy, such fractures are very difficult to manage. In case of large orbital floor fracture, surgical repair or reconstruction is carried out using implants to restore the orbit and its volume. Standard titanium implants used for this purpose are flat in shape and require manual bending. The manual process is not precise and causes non-conformity of the implant surface with orbital floor and lifting of the implant at posterior end, giving unsatisfactory outcomes. This

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A. Chakrabarti et al. (eds.), *Design for Tomorrow–Volume 3*,
Smart Innovation, Systems and Technologies 223,
https://doi.org/10.1007/978-981-16-0084-5_47

research aims at design and fabrication of orbital implants that are customized to the patient's anatomy. This implies matching the prominent 'S-shape' of the orbital floor, starting from the rim and extending up to inferior orbital fissure. The design starts with the generation of 3D anatomical model from digital imaging and communications in medicine (DICOM) files obtained from the computed tomography (CT) scan of the patient. The generated 3D model is then used to design a customized orbital implant using medical CAD software, ensuring that the degree of freedom of the eye is maintained. Considering the free-form shape of the designed implant, it is additively manufactured on direct metal laser sintering (DMLS) system using titanium-(6%)aluminium-(4%)vanadium extra low interstitial (ELI) powder. After post-processing and sterilization of the fabricated implant, it was surgically implanted in the patient. The post-operative CT images revealed that customized implant was conformed to the S-shaped orbital floor, thereby providing the required stability to the implant. The orbital volume was also restored to the normal value, thus correctly aligning the affected eye with the normal eye.

47.1 Introduction

Orbital floor fractures are the most commonly occurring mid-facial fractures, after nasal fractures. Facial skeleton damage usually results from low, medium and high velocity trauma [1]. About 85% of traumatic eye injuries happen by accident during contact sports, motor vehicle accidents or impact by blunt objects and about 15% are caused by violent assaults (Fig. 47.1a) [2]. Orbital floor fractures were first reported by Mackenzie in 1844. Later in 1957, Smith and Regan coined the term 'blow-out fracture' [1]. When there is fracture of floor of the orbit without involving the orbital rim, it is designated as pure blow-out fracture or often referred to as isolated orbital fracture. When there is an involvement of orbital rim in conjunction with other fractures, e.g. zygomaticomaxillary fracture, it is termed as impure blow-out fracture [3]. In adult population, orbital floor fracture results in orbital volume expansion because of orbital content sagging into the maxillary sinus, thereby causing eye to sink (enophthalmos) (Fig. 47.1b) [4]. Other consequences include drooping of the upper eyelid (blepharoptosis) and misalignment of eyes causing 'double vision'

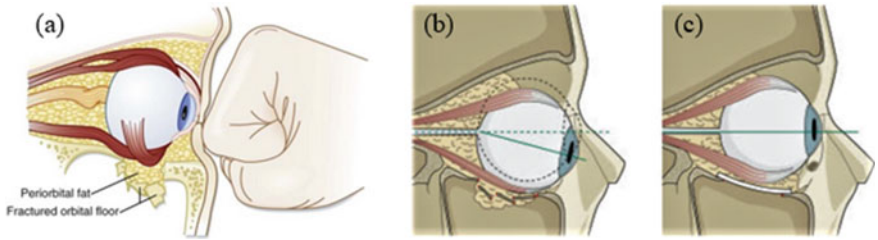

Fig. 47.1 Orbital floor fracture **a** mechanism, **b** sinking of eye, **c** repair using implant [5, 6]

(diplopia). In severe cases, increased intra-ocular pressure (IOP) may damage the central retinal artery, leading to partial or total vision loss [1].

Orbital floor injuries are complicated to manage because of the complex anatomy, requirement of extensive medical competencies and various other factors deciding the proper timing of the repair that affects the overall outcome of fracture treatment. The decision of surgical repair and reconstruction is taken if patient exhibits enophthalmos >2 mm, hypoglobus and large floor fracture >50%, based on the CT scan of the fracture site [4]. The main objective of surgical repair is to reposition the sagging orbital soft tissues and correction of the traumatic defect while preserving the orbital volume (Fig. 47.1c). In surgical procedures, autografts (made from own bone) are considered the 'gold standard' choice owing to the absence of adverse immunological response, but their use is limited because of difficulty in bending (due to rigidity) to match the *concave-convex* 'S-shape' of the orbital floor [1]. The other disadvantages include the need for additional surgery and donor site defects. Lately, standard titanium mesh/implants were found to be promising in orbital floor reconstruction and have shown more accurate results than those reconstructed with autografts [7]. However, the standard implants being flat in shape, require manual bending to match the complex anatomical shape of orbital floor [8]. The precision of bending depends on the skill of the clinicians; in many cases there is non-conformity of the implant surface with orbital floor and lifting of the implant at posterior end, leading to the difficulty in exactly restoring the orbital volume. As a result, post-operative cosmetic outcomes may be less than expected. Further, repetitive intra-operative removal of the implant for bending may harm orbital soft tissues [4].

According to the literature, an orbital floor repair which is a complete success from surgical point of view, might not be satisfactory to the patient, cosmetically. Therefore, it is suggested that each case should be taken individually to maximize the probability of restoration of orbit, cosmetic appearance and visual function [1], bringing in the need for customization. This study aims at design and fabrication of orbital implants that are customized to the patient's anatomy. Thereby ensuring the conformity of implant surface with the prominent 'S-shape' of the orbital floor, starting from the rim and extending up to inferior orbital fissure. The customization of implants also reduces the time consuming and fatiguing intra-operative bending and adjustment of the implants [4].

47.2 Material and Methods

47.2.1 Material

The selection of material for tissue reconstruction plays an important role in treatment of orbital fracture. Medical grade titanium alloys are ideal candidates for the repairing of bone defects, because of their high strength to weight ratio. Further, they have a better ability to integrate with the bone, attributed to the formation of high dielectric constant oxide layer on titanium surface [9]. Among different types of titanium alloys, two-phase α–β alloys possess improved biocompatibility, lower elastic modulus and improved notch fatigue resistance [10]. Therefore, titanium-(6%)aluminium-(4%)vanadium extra low interstitial (ELI) alloy powder was used in this study.

47.2.2 Implant Design and Manufacturing

The design process started with procuring the anatomical data of patients, diagnosed with impure orbital floor fracture, in the form of 2D digital imaging and communications in medicine (DICOM) files obtained from the computed tomography (CT) scan. Each patient's scan had a matrix size (n) of 512 × 512 and field of view (FOV) of 260 mm, with a pixel size ($d = \text{FOV}/n$) of 0.5 mm. To avoid any image blurring, the slice increment (SI) and slice thickness (ST) are recommended to be less than 1 mm. Hence, SI and ST were selected as 0.625 mm, resulting in clear CT scan for segmentation of region of interest. The DICOM files of patients were imported into medical modelling software Mimics (Materialise, Belgium) for the generation of 3D diseased anatomical model of patients' eye orbital. A smoothing factor of 0.5 was used to filters out the irregularities in the 3D model. A higher value of the factor can cause excessive smoothing, resulting in loss of original bone contours. The generated 3D anatomical models were imported into 3-matic software (Materialise) for designing customized orbital implants. Eye orbital being a biaxial symmetric part, mirroring technique was used for designing the implant.

Figure 47.2 shows the detailed steps for designing of customized orbital implant for one of the two cases taken for this study. After importing the standard triangle language (STL) file of diseased anatomical model (Fig. 47.2a) into 3-matic software, orbital framework was generated for designing the implant. This was done by superimposing healthy left orbit (shown in white colour) on the distorted right orbit

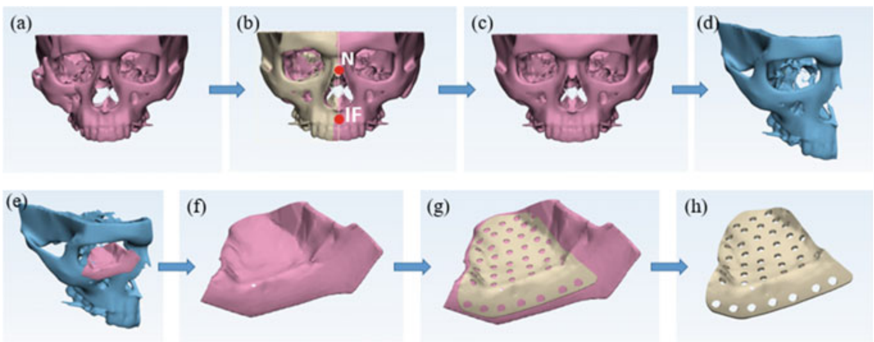

Fig. 47.2 Design flow of customized orbital implant

using mirroring operation. The healthy anatomy was mirrored about the mid-sagittal plane (MSP). The cephalometric method for MSP detection was adopted, wherein three landmarks: nasion (N), incisive foramen (IF) and basion (Ba) were manually marked (Fig. 47.2b) [11]. It was ensured that MSP passes through these landmarks. After aligning the superimposed orbit with the distorted one, symmetric right and left orbits were then merged to obtain a clean orbital framework (Fig. 47.2c). A region of interest was marked and model was trimmed and checked for any overlap accordingly (Fig. 47.2d). A thin wafer type offset of uniform thickness 1 mm, having 0.5 mm allowance for grinding and polishing, was generated on the selected region of interest, which was then trimmed, as per the guidelines of the clinician, to generate an implant template (Fig. 47.2f). The 2.5 mm diameter holes, for locking screws, were made on the template. The position of the holes were decided by the landmarks given by the jigs, used for implant placement. The other finishing operations were performed to generate final customized orbital implant design, with prominent S-shape (Fig. 47.3a) [8]. Similar steps were followed for designing the implant for the second case (Fig. 47.3b).

Before manufacturing the actual implants, the designed templates, implants and orbital framework were fabricated (Fig. 47.4a) in acrylonitrile butadiene styrene (ABS)-M30i, a bio-compatible material, using in-house Fortus 3D printer (Stratasys, USA). The objective of polymer implant fabrication was to verify its design and fitting. It also aided clinician in visualizing the defect and surgery pre-planning (Fig. 47.4b, c). The clinician examines the template and suggests if any modification is required. Based on the feedback of the clinician, small revisions in flanges and

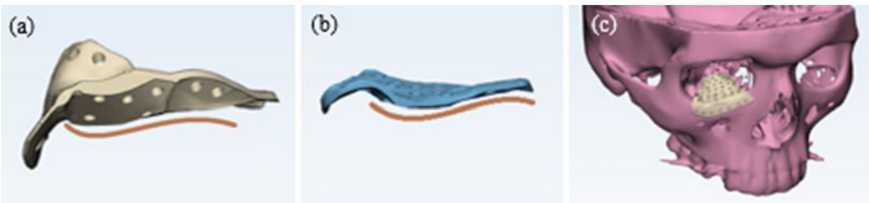

Fig. 47.3 CAD model of implant showing S-shape **a** case 1, **b** case 2, **c** virtual assembly of designed implant on 3D orbital framework

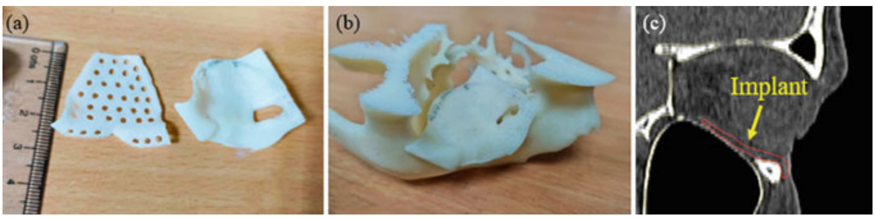

Fig. 47.4 Pre-operative planning **a** polymer implant and template, **b** surgery pre-planning on polymer framework, **c** implant fitting evaluation in CT

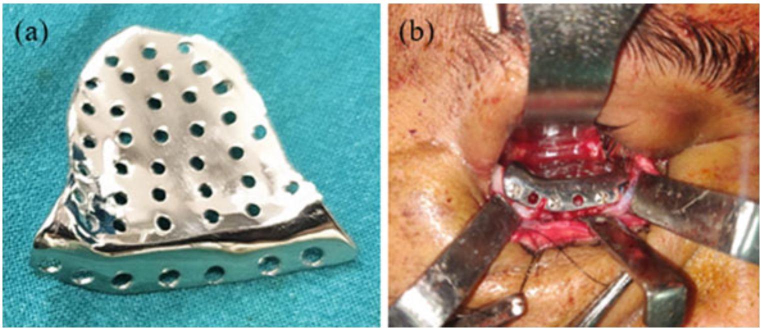

Fig. 47.5 **a** Customized titanium orbital implant for case 1 and **b** surgical orbital floor reconstruction

depth of the implants were carried out. After their reconfirmation, the implant designs in STL file format were forwarded to the manufacturing unit.

Owing to the free-form shape of designed implants, they were additively manufactured using Renishaw AM 400 3D metal printer, which works on direct metal laser sintering (DMLS) technology. The metal printer uses a 400 W ytterbium fibre laser, having beam diameter of 70 μm, for sintering fine layer of titanium-(6%)aluminium-(4%)vanadium extra low interstitial (ELI) powder, under controlled argon environment. The implants were 3D printed with 1 mm uniform thickness as designed. The manufactured implants were post-processed by bead blasting for removal of support material and further grinding and polishing of implant to a final thickness ranging from 0.5 to 0.7 mm (Fig. 47.5a). The manufactured implants were cleaned and sterilized, as it improves the implant surface and enhances osseointegration [12]. Finally, the sterilized implants were surgically placed into the patients by the clinicians (Fig. 47.5b).

47.3 Results and Discussion

Two orbital reconstructions were performed in this study. Case 1 was of a 34 years old man and case 2 was of a 30 years old man, both diagnosed with complex orbital floor and zygoma fracture, on right side. Figure 47.6 illustrates pre-operative CT images of both cases, showing orbital floor fracture.

As expected, post-operative CT images (Fig. 47.7) showed the implants to be conformal to the orbital floor. There was no sign of implant lifting at the posterior end, establishing proper placement of customized orbital implants.

For the calculation of orbital volume, clinicians suggested approximating the shape of bony orbit surrounding the eye as elliptical cone (Fig. 47.8). The dimensions of semi-mesiodistal axis (a, mm) and semi-vertical axis (b, mm) for distorted and corrected orbits were taken from pre- and post-operative CT models, respectively (Fig. 47.9). The height of the cone (h, mm) was taken equal to the length of implant,

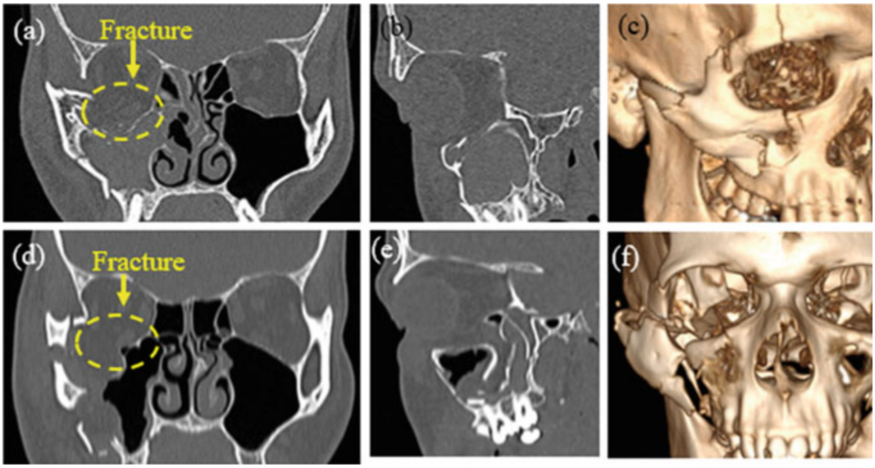

Fig. 47.6 Pre-operative CT images showing orbital floor fracture in coronal plane, sagittal plane and in 3D **a**–**c** case 1, **d**–**f** case 2

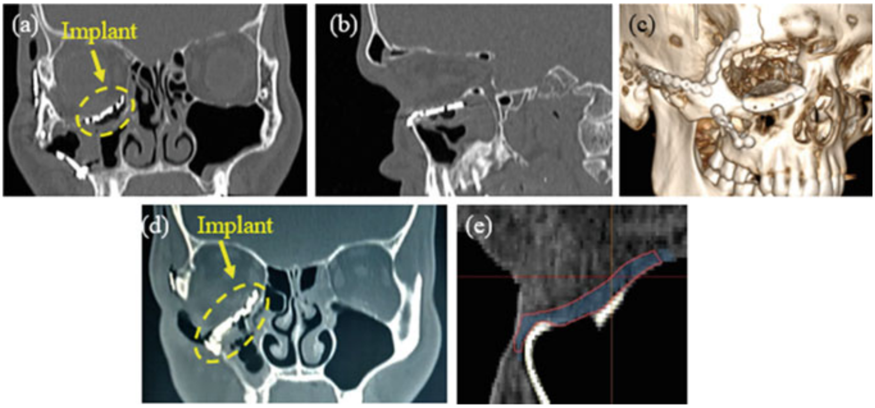

Fig. 47.7 Post-operative CT images showing positioning of customized implant **a**, **d** in coronal plane for case 1 and case 2, **b**, **e** in sagittal plane, resting on posterior lip of orbital floor, for case 1 and case 2, and **c** in 3D, for case 1

25 mm, for both cases. The value of orbital volume (OV, mm^3) was formulated as:

$$\mathrm{OV} = \frac{1}{3}\pi abh$$

Table 47.1 shows the pre-operative orbital volume (OV) for both the cases. CT evidence for case 1 revealed that there was a 9.2% increase in volume of traumatized right orbit (8,802.69 mm^3) as compared to opposing normal orbit (8063.18 mm^3).

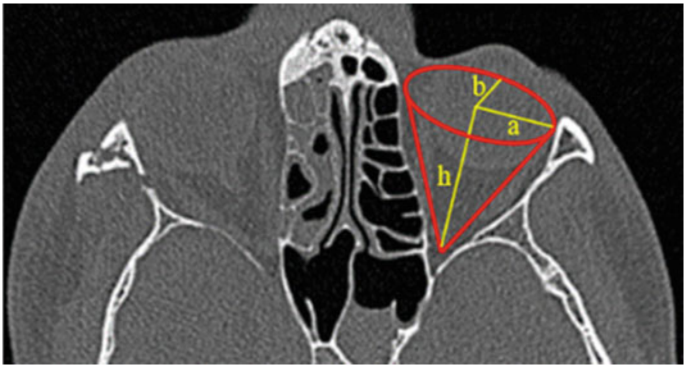

Fig. 47.8 CT image demonstrating shape of orbit (elliptical cone)

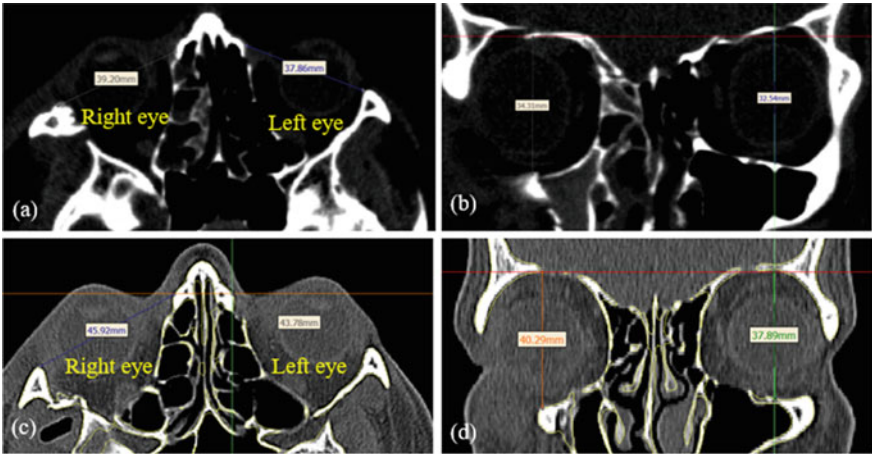

Fig. 47.9 Pre-operative mesiodistal axis and vertical axis dimensions for **a**, **b** case 1, **c**, **d** case 2

Table 47.1 Pre-operative orbital volume

	Normal orbit				Traumatized orbit			
	a (mm)	*b* (mm)	*h* (mm)	OV (mm^3)	*a* (mm)	*b* (mm)	*h* (mm)	OV (mm^3)
Case 1	18.93	16.27	25	8063.18	19.60	17.15	25	8802.69
Case 2	21.89	18.95	25	10,856.98	22.96	20.15	25	12,108.98

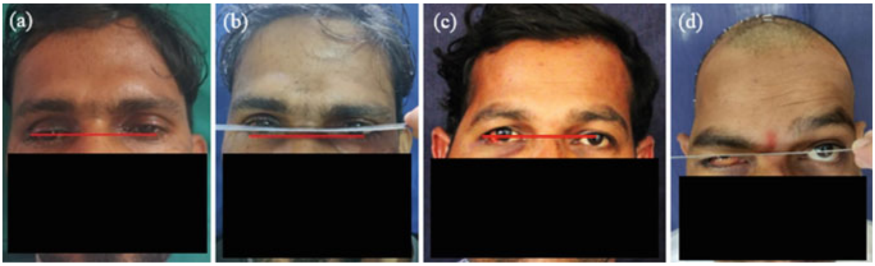

Fig. 47.10 Pre- and post-operative clinical pictures **a**, **b** case 1, **c**, **d** case 2

Similarly, for case 2, there was an 11.5% increase in volume of traumatized right orbit (12,108.98 mm^3) as compared to opposing normal orbit (10,856.98 mm^3). The orbital floor reconstruction is resulted in restoration of orbital volume of traumatized orbit.

Figure 47.10 illustrates pre- and post-operative clinical picture of both the cases. The pre- and post-operative pictures look somewhat different, though they belong to the same patient, because of the time gap of two months and the patient had some post-surgery swelling. Pre-operative picture of case 1 demonstrates classical case of enophthalmos (Fig. 47.10a). Post-operative correction shows orbital volume restoration (Fig. 47.10b). For case 2, pre-operative picture shows misalignment of the affected right eye with the normal eye (Fig. 47.10c), which was corrected post-surgery (Fig. 47.10d). A slight misalignment of corrected eye (Fig. 47.10d) was expected and attributed to the post-surgery swelling, which usually gets resolved within three months [1].

47.4 Conclusion

This study presented a step by step methodology for 3D modelling, design and manufacturing of customized orbital implants, and its practical implementation. The process helped in mimicking the concave-convex shape of the orbital floor, thus, producing an S-shaped implant. The customization of implant benefitted in terms of reducing intra-operative implant adjustments, orbital tissue damage and surgery times. In addition, the technique enabled visualization of the exact fracture site to the clinicians, helping them to pre-plan the surgery.

Additive manufacturing of implants, using DMLS technology, proved very useful because of its ability to produce complex shapes that can match unique bone contours. The mock implant and orbital framework, manufactured using fused deposition modelling (FDM) technology, allowed implant design verification and their fitting evaluation. The post-processing of implants helped in achieving a final thickness ranging from 0.5 to 0.7 mm, adding to precise alignment of the eye globe.

Both clinical cases presented in this study had complex orbital floor fracture. The conformance of S-shaped implant with the orbital floor ensured the implant stability. The post-operative CT images revealed that the diseased orbits were restored to the normal, with no sign of implant displacement at the posterior end; giving desired clinical and cosmetic outcomes.

Acknowledgements The authors would like to thank RG Science & Technology Commission, Government of Maharashtra and the Department of Science & Technology, Government of India, for the research funding to Biomedical Engineering and Technology Innovation Centre (BETIC), Mechanical Engineering Department, IIT Bombay. The authors would also like to acknowledge the support of Mr. Mahesh Dhoka, Incredible AM Pvt. Ltd., Maharashtra, and his team for manufacturing the implants.

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Chapter 48
Guidelines to Design Custom 3D Printed Jig for Orthopaedic Surgery

Shehbaz Ali Syed, Bhanupratap Gaur, Samrat Sagar, M. Suryawanshi Chetana, Suraj Naik, Burhan Khambati, Srivalli Natrajan, Rupesh Ghyar, and Ravi Bhallamudi

Abstract In osteosarcoma (bone cancer), one of the major challenges for the surgeon is to resect the bone tumour with a margin that is oncologically safe and then reconstruct the defect gap to original anatomical shape and size necessary for proper function. It is very difficult to carry out resections in complex anatomical regions such as pelvis or joints. To ensure good alignment and fixation of patient-customized prosthesis, the bone cut must be accurate and match the geometry of such prosthesis. Proper resection and implant fixation can be achieved by using patient-customized surgical jigs, which guides the surgical tool. This work deals with the design, fabrication and application of orthopaedic surgery jigs. The starting point is the CT scan image set of the patient, which is converted to a 3D CAD model using a medical modelling software. The customized jigs are designed over the 3D model of patient's

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A. Chakrabarti et al. (eds.), *Design for Tomorrow–Volume 3*,
Smart Innovation, Systems and Technologies 223,
https://doi.org/10.1007/978-981-16-0084-5_48

anatomy. There are, however, no well-established design guidelines and standards for creating and verifying such jigs. This makes the task challenging to someone inexperienced in medicine and manufacturing. This was addressed by evolving a systematic process for patient-customized surgical jigs. Depending upon the function, the customized jigs are classified as drilling jigs, osteotomy jigs and implant location jigs. For each type, essential element or module that need be provided have been identified. For example, osteotomy guide includes the surface that is conformal to bone, *k*-wire or other fixation and the overhanging handle or the curved-shaped beam that connects the two parts. Relevant design guidelines were developed. A standard CAD model was developed for each key element. Their shape and dimensions were fixed considering the strength and ease of use. For example, the minimum thickness of the cutting guides was 5 mm to take care of bending. The jig surface that is in contact with the bone was set at 3 mm. The *k*-wire size was 1.6 mm. Special care was taken to eliminate sharp edges. The full jig is developed by incorporating these elements, making the process faster and reducing random customization that can increase manufacturing cost. The proposed methodology and design guidelines are illustrated with cases of pelvis and tibia surgery jigs, which were validated by the surgeon and proved to be beneficial.

48.1 Introduction

Bone is the hard tissue in human body which act as a structure that carries various forces and supports motion. Bone may experience fracture, congenital deformity or cancer resulting in bone defects. Bone cancer is the rare, approximately 0.2% of all the cancers. The most common type of bone cancer or sarcoma is Ewing sarcoma, chondrosarcoma and osteosarcoma (OS). One of the major challenges in bone cancer surgery for the surgeon is to cut the bone tumour with a margin that is oncologically safe and to reconstruct the defect to their original anatomical form and size necessary for proper function. Also, it is very difficult to do resection in complex anatomical region such as pelvic region or near joint where adjacent joint is to be preserved after resection.

A simple method to achieve the proper resection and implants fixation is the use of customized surgical guides or jigs. A surgical guide or jig is a device used to guide the cutting tool in such a way that it maintains the correct position, inclination and alignment resulting in accurate outcome. Customized surgical guides are made patient specific with its size and shape matching exactly to the person for which it is made. Cutting or resection jig, drilling jig, fracture reduction and implant fixation jig are the types of surgical guides generally used [1]. The jigs can be fixed to the bone using screw or *k*-wires. *K*-wire is a stainless steel wire with pointed tip.

Perez et al. [2] studied the sterilization of FDM parts. Nine materials specimens made using FDM were tested by four different sterilization methods: ethylene oxide, autoclave, gamma radiation and hydrogen peroxide. The materials were found to be sterilizable by all four methods. Although the majority of the test samples were

Table 48.1 Material showing visible damages [2]

Material type	Autoclave	Flash autoclave	Ethylene oxide gas	Hydrogen peroxide gas plasma	Gamma radiation
ABSi	Yes	Yes	No	No	No
ABS-ESD7	Yes	Yes	No	No	No
ABS-M30	Yes	Yes	No	No	No
ABS-M30i	Yes	Yes	No	No	No
PC	No	Yes	No	No	No
PC-ABS	Yes	Yes	No	No	No
PC-ISO	No	No	No	No	No
PPSF	No	No	No	No	No
Ultem 9085	No	No	No	No	No

successfully sterilized by each of the methods, not all the materials were able to withstand the condition of sterilization of some methods (Table 48.1).

It is clear from the above result that suitable method should be used for a given materials. In this study, we have use ABS-M30i. Ethylene oxide gas (ETO) or hydrogen peroxide gas plasma method is suitable for the sterilization of ABS-M30i parts [3].

Choi et al. [4] investigated the causes of errors generated during the manufacturing of RP models and identified the factors each production phase that caused dimensional errors in. Sixteen linear measurements were made on a dry skull, a replicated 3D virtual model, and a RP model. The differences were observed with the absolute mean deviation between the dry skull and the RP model of about 0.62 ± 0.35 mm ($0.56 \pm 0.39\%$). The errors were mainly due to difficulty in the exact replication of landmark locations, threshold value and volume-averaging effect. Khan et al. [5] suggested that the MRI finding should be incorporated in jig design by using CT and MRI fusion to reduce the error in 3D model. Wong et al. [6] carried out resection on femur bone of a cadaver using surgical guide made of polyphenyl sulfone using FDM. The author recommended width of cutting slot should be 1.2 mm to accommodate 1 mm thick oscillating saw blade. Chepelev et al. [7] used patient data on pleomorphic sarcoma of pelvis bone from anonymous online repository and suggested the thickness of guide to be 10 mm and is made as offset of bone surface.

Despite a growing number of papers on customized jigs, studies have focused mainly on discussion of medical issues and the assessment of surgical outcomes, but hardly at all on guide design and design for additive manufacturing aspects. This leads to a faulty design that is not surgically feasible and eventually is rejected by the surgeon. This involves lots of time and effort which increase costs as well as delay in surgery. The objective is to formulate guidelines and procedure for designing a custom 3D printed jig. It will provide clear instructions to the designers for effective design of the jigs. The approach would be to divide the entire jig into modules which are designed individually and assembled to make a jig.

48.2 General Guidelines for Jigs/Guides

Input from doctors: Patient-specific guides are made as per the requirement of doctors. So, it is important to have all the inputs required to design the guide. The inputs include high-quality DICOM images, location of incision, critical anatomy near the affected area, the margin for bone cutting in case of bone tumour, rough surgical plan, tools to be used for bone osteotomy and landmarks on bone with respect to which the guide will be positioned on bone.

Guidelines for K-wire guide: For *k*-wire to be inserted correctly, it has to be properly guided. *K*-wire is inserted in the bone through the *k*-wire guide present in the jig present in the jig with the help of a powered high-speed hand drill. This induces torsional forces on the guide. Waessenar et al. [8] calculated the torque required to insert *k*-wire is 2.4×10^{-2} Nm. The FEA was carried using ABS M30i as material for the *k*-wire guide. The result of equivalent stress shows that the design is sufficiently strong, and the stresses are well within limits. The guide should have sufficient height to prevent misorientation. The height of the guide *k*-wire guide is fixed to 10 mm as observed by actual 3D printing and inserting *k*-wire.

The *k*-wire must not be placed too closed to each other. Two *k*-wire must be at least 1 cm apart. If the diameter of *k*-wire is *d*, then outer diameter of *k*-wire guide is taken as $d + 5$ mm as shown in Fig. 48.1a. Minimum three *k*-wire is necessary to restrict the moment of the jig. To prevent this, the *k*-wire must not be parallel to each other. A slight inclination helps to restrict the upward moment of the jig. The

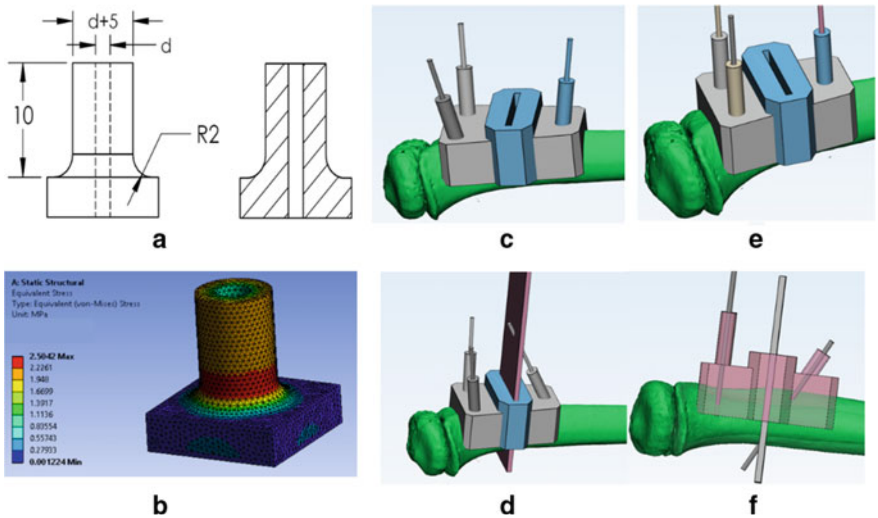

Fig. 48.1 **a** *K*-wire guide dimensions and section view, **b** FEA of guide, **c** inclined orientation of *k*-wire guide (good design), **d** *k*-wire obstructing the tool path form above, **e** parallel orientation of *k*-wire guide (bad design) and **f** from below

minimum angle of 100–150 between two *k*-wire is sufficient to restrict the lifting of *k*-wire. Care must be taken that *k*-wire should not obstruct the cutting tool path.

Contact Surface: The contact surface of the jig is the surface that comes in contact with the bone. Bone is covered with a layer of tissue called the periosteum. It supplies essential nutrition to the bone. The thickness of periosteum varies from 0.1 to 0.2 mm [9]. Therefore, an offset of 0.4–0.8 mm is provided to the conformal surface. The thickness of the contact surface should be about 3.5 mm thick to ensure sufficient strength. The contact surface should not obstruct the blood vessel, nerves or the area of bone connected to tendon and ligament.

48.3 Design of Patient-Specific Jig/Guide for Pelvis Bone

The bone is cut using an osteotome which has a plane oscillating saw having a width in the range of 14–24 mm. Using this tool, it is not possible to make a curved cut on the bone. So, the bone can be cut only in a linear path. To guide this cut planar block is the best option. Designing a customized jig is a difficult task. To simplify the design process, the generalization of design is required (Fig. 48.2).

The jig is to be divided into a basic standard module which would be present in all the design. This reduces the amount of customization required in the design. In pelvis jigs, all the cuts are linear and in desired planar orientation. The guide element must be a plane that defines a proper cut at a desired orientation. Considering all the functional requirements, the jig can be is divided into two modules: planar guide block and conformal contact surface.

Micucci et al. [10] carried out an experiment to calculate the optimum thrust force required to cut the bone. According to the study, the force of around 20 N produced optimum bone cutting. So, the jig is designed and analysed considering the load of 20 N. Depending on the contour of cut, the number of planar blocks to be used is decided. At the intersection of two planar block, a circular column must be provided to prevent stress concentration. The planar block should not bend while cutting the bone, otherwise, it will lead to the cut in the wrong orientation. To avoid this, ribs are provided at regular intervals. The ribs provide support to the planar block. The rib is required only if the length of the block is greater than 4 cm. Place the rib equidistant from each other.

In order to assemble, the jig first aligns the block along the length of cut each block along a single straight line. Place the cylindrical column at the intersection of the block. This helps in reducing stress concentration, thereby reducing the chances of cracking or breaking. Place the entire assembly on the contact surface. The contact surface should neither be too large or too small. Large contact surface area means stripping the periosteum of larger area of bone, thereby depriving their essential blood supply. Very small contact surface makes it difficult to place the jig at the correct position. Also, not all the DOF is restricted due to smaller contact area, so the jig can move or tilt from its original position leading to an improper fixation.

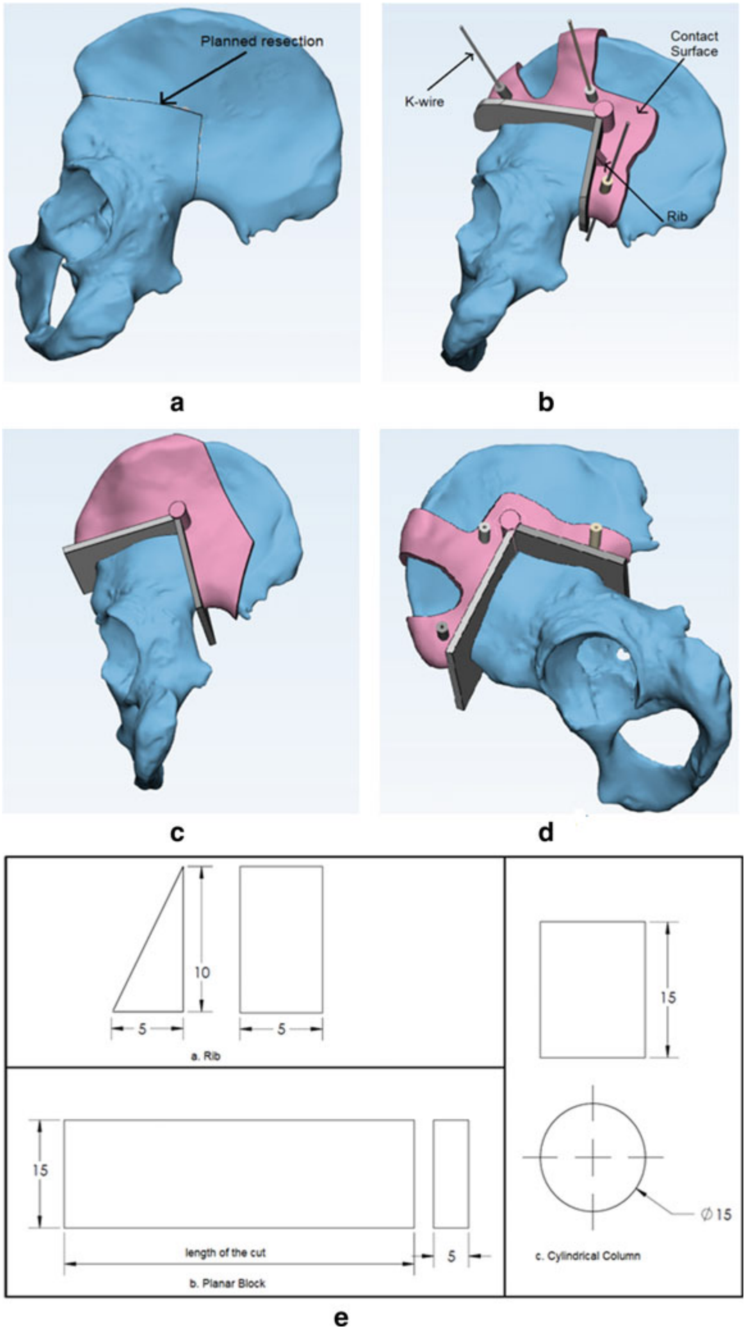

Fig. 48.2 **a** Planned resection, **b** final design of pelvis jig, **c** placing of planar block, cylindrical column and contact surface, **d** trim extra region and **e** detailed drawing of individual component of pelvis jig

The landmark should be selected with great care, planning, and by recommendation of the surgeon. The boundary of the iliac crest is the best accessible landmark in the pelvis. The location of landmark for anchoring the jig should be such that it should not be too far, thereby increasing the contact area, nor should it enter the tumour margin in case of sarcoma.

48.4 Design of Patient-Specific Jig/Guide for Orbital Implant Fixation

Due to blow out of the orbital area, it is difficult to place the implant manually with accuracy. So, the guide is necessary to place the implant. In order to have proper placement of the implant, there has to be a reference with respect to which the reconstruction is done. Teeth serve as the best site for reference and are easily accessible. So, the guide has to be made such that the exact placement of the implant is obtained by placing the surgical guide on the teeth. First step in designing the jig is to divide the entire jig into modules. Here, depending on the requirement, the jig was divided into three modules: base module, implant holding element and connector.

Base Module: Select a minimum of three unaffected teeth of the upper jaw as it is fixed and immovable. The lower jaw is movable, so it is not useful as a reference. Make the base module as a negative of selected teeth. For adequate strength, the thickness is taken as 3 mm and is made by using offset function. Provide chamfer for all the sharp edges. Take care that the base element does not damage the gingival membrane.

Implant Holding Element: The implant holding element holds the implant in the correct position accurately. It ensures exact alignment and orientation. The holding element should be made such that the implant is firmly attached to the holding element without any movement. The holding element is made as a negative of the upper surface element. The thickness of the contact surface that is the negative of the implant is 2 mm. Once the implant is placed in the body, the holding element should be easy and simple to remove.

The contact surface should not cover the screw holes, which will be used to fix the implant in the body. Sufficient constraint must be divided so that the implant does not move on the seat. To prevent implants from falling, one screw has to be used to fix the implant on the holding element. Cylindrical projections are provided at the contact surface that enters the hole present in the implant. As a result, the rotation of the implant is completely constrained. We can use one of the screw hole present in the implant or extra screw hole can be provided in the implant for this purpose if necessary.

Connector: The connector connects the base element of the holding element. The design of the handle for a long bone jig can be used as a connector. The length of the connector used is very less. For smaller length, the oval section is sufficiently strong. The oval section is easy to design. As a result the ovak section is preferred over the I section. The curvature of the handle should be kept as minimum as possible. Otherwise, it will become weaker in bending. At the end of the connector, rectangular plates 3 mm thick are attached so as to increase the contact are available to connect the connector to base module and implant holding element.

Steps in Implant Fixation Using the Jig: Fix implant on the holding element. Tighten it with a screw. Place the base element on the teeth. The implant will be directly positioned at the desired place. Fix the implant to the bone with the screw. Figure 48.3f above shows the complete design of the jig. This jig places the implant exactly at the desired location. Now for a single piece guide, it will be difficult to remove the guide once the implant is placed as the guide will get locked. So, the guide should be made in two parts and assembled together such that it can be disassembled and removed easily once the implant is fixed.

48.5 Result

The resection of bone was carried out using pelvis jig manufactured by 3D printing. The cut was achieved with desired accuracy with error less than 0.2 mm. The steps to design the pelvis jig were applied to make jig for different size of tumour in the same region and the resulting jig was able to perform the cut with desired accuracy. The orbital implant fixed using the jig was placed at the exact location as planned and confirmed by postoperative scans.

48.6 Conclusions and Future Work

This study presented a set of recommendations, guidelines and procedures for the design and manufacture of patient-specific guides or jigs. It establishes the innovative workflow for the design of patient-specific guides by the breakdown of the entire jig into various modules. The modules were defined based on the functional aspects of the parts, taking into consideration the constraints and specific design targets. Complete detailed design of jigs for long bones, pelvis resection was done along with the method to assemble it. The guidelines for the *k*-wire guide and conformal contact surface were established. The study also includes the design of guides for orbital implant fixation. The designs were tested using finite element analysis and qualify the strength requirements. This technique is effective, feasible and economically viable due to simplification in the design process. It reduces the iterative trial and error process, which is time consuming, shortens the design phase by improving the efficiency of the design process. This leads to reduced lead time in the development of patient-specific guides. By presenting these clear guidelines, recommendations and modularization, we have bridged the gap in the unavailability of literature on designing the patient-specific guides. Our work will encourage and assist researchers and designers in having a better understanding of the design process. Future scope

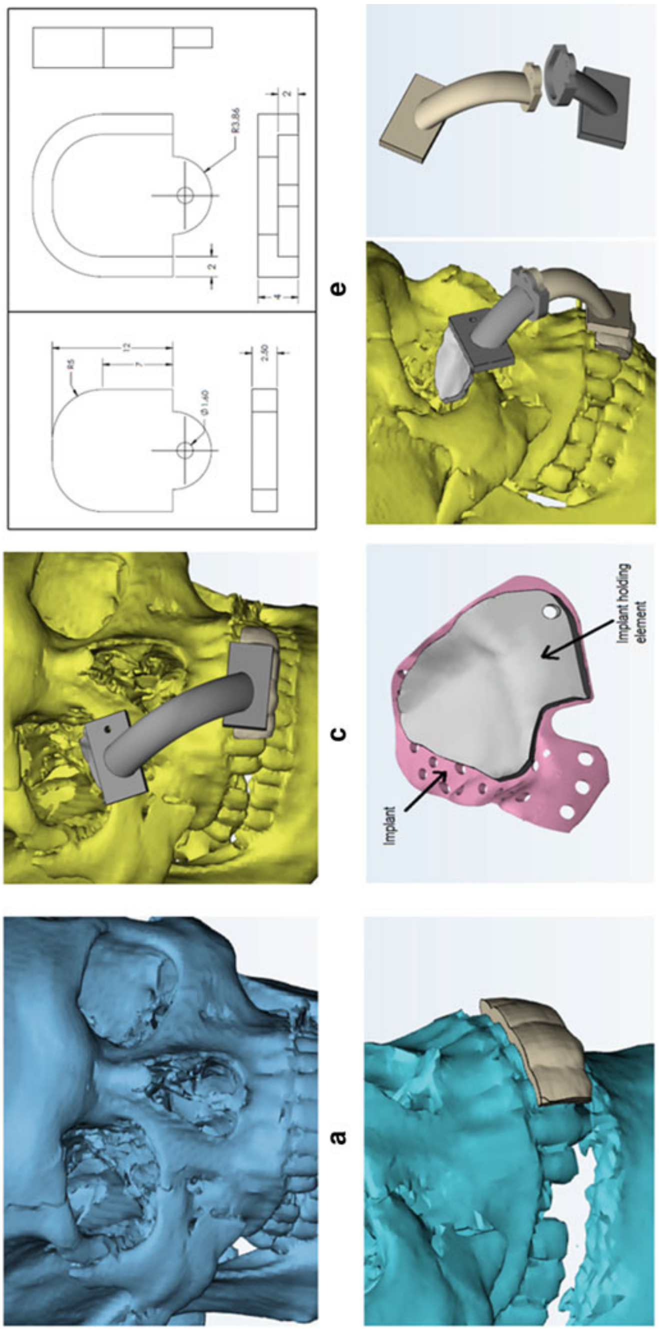

Fig. 48.3 **a** Orbital blowout in the right eye **b** base module **c** single piece jig for implant placement **d** implant holding element **e** dimension of joints **f** two-piece jig

includes the optimization of developed design for making it more effective and easier and also saving in materials. And also, the development of design guidelines for other anatomical regions.

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Chapter 49
Design and Prototyping of a Novel Head-Mounted Ophthalmic Device for Monitoring Glaucoma

Arvind Bhallamudi and Nitin Khedkar

Abstract Glaucoma is an eye disease leading to progressive loss of vision. It can be detected and monitored by measuring the intraocular pressure (IOP). Conventional tonometers used for this purpose are cumbersome (require qualified ophthalmologists) and invasive (uncomfortable for the patients). In this work, a novel portable instrument for IOP measurement was developed, based on a combination of indentation and applanation principles. It employs a three-axis slider system mounted on headgear for accurate and rapid positioning of an indenter assembly over the eyelid. The assembly comprises an indenter, adjustment compartment and knob. The compartment also houses a spring, force-sensitive resistor and printed circuit board to check the IOP after applanation. The corresponding reaction force from the eye is obtained on a force-sensing resistor using Imbert-Fick's principle. This activates an LED signal for high levels of IOP that indicate a risk of glaucoma. The main components of the device were prototyped through 3D printing in ABS plastic. The device provides an efficient way to accurately position it over the eye for different face structures and varying eye positions among patients. It also allows sliding the instrument along a horizontal rail to conveniently check both eyes in the same setting. The proposed innovation can be used by healthcare workers to screen Glaucoma patients in rural medical camps. It can also be used at home for regular check-up by patients themselves and take suitable precautionary measures.

49.1 Introduction

Glaucoma is the third leading cause of irreversible blindness. It affects an estimated 65 million people worldwide; at least 3 million people become permanently blind. It is not accompanied by any pain or discomfort and is therefore not noticeable until a sudden significant worsening of vision loss (Fig. 49.1). However, with regular eye checks, early detection and treatment, it is possible to preserve the eyesight.

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A. Chakrabarti et al. (eds.), *Design for Tomorrow–Volume 3*,
Smart Innovation, Systems and Technologies 223,
https://doi.org/10.1007/978-981-16-0084-5_49

Fig. 49.1 Deteriorating glaucoma vision from left to right

The major indicators of glaucoma are elevated intraocular pressure (IOP), optic disc cupping, optic nerve damage and visual field loss. The IOP depends on the amount of fluid in the eye. The aqueous humour fluid in the front part of the eye (produced by the ciliary body) flows out through the pupil and is absorbed into the bloodstream through the drainage canals around the outer edge of the iris. This helps keep eye pressure at a normal level. When the drainage system of the eye becomes clogged, the fluid builds up and causes IOP to rise. This gradually damages the sensitive optic nerve, leading to loss of vision. Elevated IOP is not a diagnostic factor and many people with high pressures have normal vision. However, IOP is the only established risk factor for glaucoma.

49.2 Previous Work

Intraocular pressure (IOP) is defined as the difference between the pressure inside the eye and the atmospheric pressure. The distribution of IOP within the general population is in a range of 11–21 mm Hg [1]. This pressure is required to maintain the proper shape. The assessment of intraocular pressure is known as tonometry; and the instrument used for this purpose is known as tonometer. They broadly use one of the two principles: applanation or indentation, as follows.

Applanation tonometry is based on the Imbert-Fick principle, which states that the pressure inside an ideal dry, thin-walled sphere equals the force necessary to flatten its surface divided by the area of flattening ($P = F/A$, where $P =$ pressure, $F =$ force and $A =$ area). In this method, the cornea is flattened and the IOP is determined by varying the applanating force or the area flattened. The Goldmann applanation tonometer measures the force necessary to flatten an area of the cornea of 3.06 mm diameter. At this diameter, the resistance of the cornea to flattening is counterbalanced by the capillary attraction of the tear film meniscus for the tonometer head. The IOP (in mm of Hg) equals the flattening force (in grams) multiplied by 10. The Perkins tonometer is essentially a portable Goldmann applanation tonometer that can be used with the patient in either upright or supine position [2]. The ocular

Fig. 49.2 Schiotz tonometry technique. *Source* entokey.com/intraocular-pressure

response analyser is a newer type of non-contact tonometer, which uses a column of air of increasing intensity as the applanating force.

Indentation tonometry is based on the principle that a force will indent a soft eye (lower IOP) further than into a hard eye (high IOP). The Schiotz tonometer (Fig. 49.2) that uses this principle comprises a curved footplate placed on the cornea of a supine subject. A weighted indenter is allowed to sink into the cornea (inversely proportional to the pressure in the eye). A scale at the top of the indenter gives a reading depending on how much the indenter sinks into the cornea, and a conversion table converts the scale reading into IOP measured in mm of Hg [3].

Some tonometers use both principles. The pneumotonometer is an applanation tonometer with some aspects of indentation tonometry, and its readings correlate well with Goldmann applanation tonometry within normal IOP ranges [4]. The 'Tono-Pen' involves both applanation and indentation processes [5], and its readings also correlate well with Goldmann tonometry within normal IOP ranges [6].

While the Goldmann method is considered the gold standard for measuring IOP, it has several disadvantages. For the patient, the procedure is highly invasive and uncomfortable. First, the head of the tonometer must come into direct contact with the cornea. Second, to prevent reflexes during measurement, anaesthesia must be applied to numb the eye. A fluorescein strip must also be applied to the eye to detect the applanated state. All of these steps require a skilled ophthalmologist. Since doctors only periodically check IOP, which has been known to fluctuate widely throughout the day, the measurement obtained may under or overestimate the actual pressure in the eye. As a result, patients at risk for glaucoma may not receive proper treatment (false negative) or those with normal vision may be treated unnecessarily (false positive). Ideally, patients must be able to monitor their IOP by themselves. This points to an unmet need for a simple, portable and self-use device for this purpose. Such devices will also be very useful for screening a large number of people for onset of glaucoma, even in rural medical camps by health workers.

The novel device developed in this work is based on the research work that utilized a combination of indentation and applanation principle to measure IOP [7]. It involves positioning an indenter over the eye of the patient such that it just touches the eyelid.

Then it is moved forward to gently applanate the cornea by a standard indentation to obtain the reaction pressure from the eye. The effect of varying thickness and properties of the eye in different patients is isolated using the slope of graph (reaction force versus indentation) that changes once the eyelid is fully compressed and the cornea is being flattened. The device was successfully validated by measuring the IOP in over 50 patients, which matched well with the values obtained using Goldmann tonometer.

49.3 Device Design

The overall goal is to build a portable device to allow patients with glaucoma to measure their intraocular pressure. The functional requirements were derived by discussions with expert ophthalmologists and are as follows:

- Usable by general medical practitioners
- Provide accurate indication of normal or elevated IOP
- User-friendly and not require complex instructions and training
- Should not require aesthetic drops (not permitted for home use)
- Minimize patient discomfort
- Cost effective.

The proposed design is in the form of headgear with a screening module attached to it. The patient can directly wear this headgear, increasing the feasibility and convenience for diagnosis for the clinician. This overcomes the difficulty in keeping the device stationary above the patient's eye during applanation.

The screening module houses five parts in an enclosure—screw cap, force sensitive resistor, spring and indenter. (Fig. 49.3) For assessment of IOP, the force resistive sensor (FSR) is placed on the indenter (Fig. 49.3). Using the Imbert-Fick principle, the force on the sensor can be obtained by multiplying the area of the indenter tip by the pressure of the eye. An additional spring force also acts on the sensor. The function of the spring is simply for pulling the indenter back to its original position after it is pushed for applanation. The total force on the sensor would be checked, and it should be less than the limiting force. If the IOP of the patient crosses the limiting value, then the increased load on the FSR will signal through a red LED.

The device that was developed in this project relies on the detection of limiting IOP, over which the risk of glaucoma is high. From previous literature, the pressure of the eye has been calculated to be 2253 Pa when applanated, for the limiting IOP of 21 mm Hg [1]. A standard indentation of 4 mm is given on the cornea, over the eyelid to check that pressure. An indenter in the device will move downward pressing the cornea. From Imbert-Fick's principle, the area of the tip of the indenter is used to calculate the applanation force:

Force needed to flatten cornea over eyelid

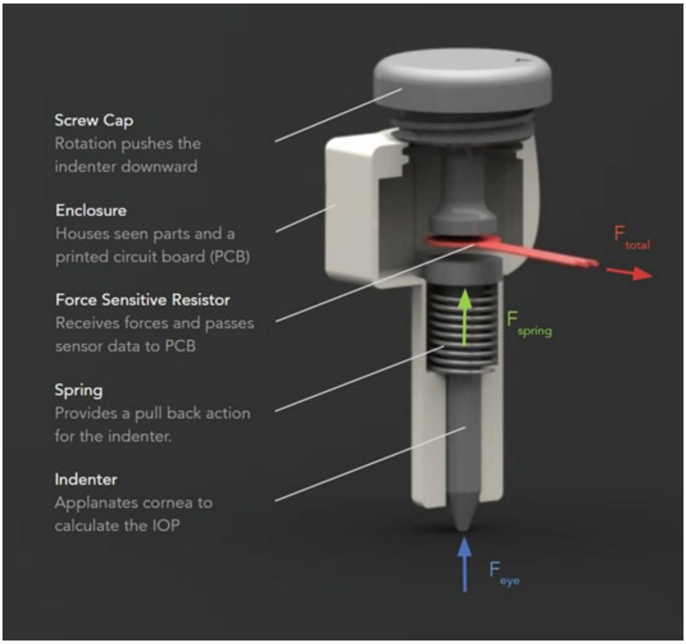

Fig. 49.3 Placement of components inside the enclosure

$$= \text{Applied Pressure} \times \text{Area of Contact}$$

To obtain a round figure of the reaction force from the eye, a force of 0.01 N was considered with which the area of contact of the indenter tip was reverse engineered. A circular cross section was used for the tip of the indenter.

$$0.01\,\text{N} = 2253\,\text{Pa} \times \pi(r)2r = 0.00118\,\text{m} \approx 1.2\,\text{mm}$$

$$F_{\text{eye}} = 2253\,\text{Pa} \times \pi \times 1.2\,\text{mm}^2 \times 10^{-6} = 0.0101923\,\text{N}$$

For the pullback of the indenter after diagnosing one eye, a spring is placed along the indenter's length which contributes to the force on the FSR. One rotation of the enclosure cap should move the indenter down by 4 mm for correct applanation. For this screw thread, the pitch is 4 mm. The spring was designed for stainless steel (304 SS) with squared and ground ends. Other design parameters include: wire diameter (d) = 0.7 mm, outer diameter (OD) = 16 mm, free length (L_{free}) = 20 mm and number of active coils (n_a) = 8. Using these dimensions and material properties, the spring constant can be calculated, and in turn, the compressive force $F_{\text{spring}} = kx =$ 0.072 N/mm × 4 mm = 0.288 N.

The sum of applanation force and spring force after 4 mm compression would be the total force acting on the indenter which is used to diagnose patients of their condition.

$$F_{\text{total}} = F_{\text{eye}} + F_{\text{spring}} = 0.01\,\text{N} + 0.288\,\text{N} = 0.298\,\text{N}$$

The screening module consists of a push-button switch, force-sensing resistor, integrated circuit, two LEDs (green to show the device in ON and red for indicating elevated IOP) and potentiometer (to vary the limiting force for indication). The circuit is designed such that when the force on the FSR reaches this limiting value, a red light will flash. Figure 49.4 shows the FSR with two external connections, to the top of the indenter and the switch, respectively. In Fig. 49.4 (left), there is no force and the LED stays green. The indication works when a manual force is applied on the FSR as shown in Fig. 49.4 (right). This value at which the red LED flashes is set using the potentiometer for the load of 0.298 N.

During the prototyping phase, a pair of 3 M safety goggles with some modifications were used as the headgear (Fig. 49.5). A group of 15 participants wore these

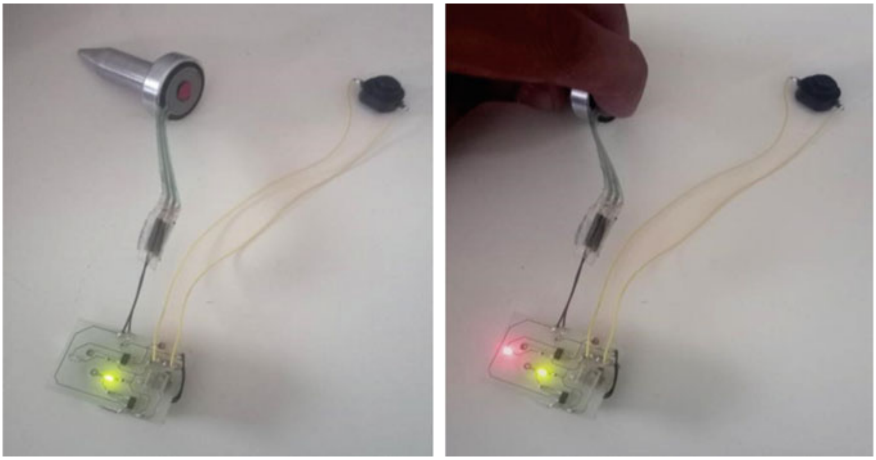

Fig. 49.4 FSR without force (left), FSR with force (right)

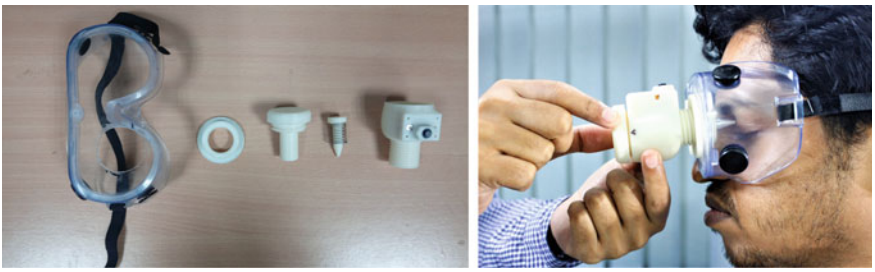

Fig. 49.5 Initial prototype of the device

goggles and were asked to look straight ahead. With a marker, dots were marked on the goggle surface vertically above the eye. The distance of these points from a reference was calculated. The concentration of points was within 1 cm^2 which was within the range where the elastic and goggle can be re-adjusted to position the indenter. A hole was cut in the goggles through which a holder was fixed. The holder with screw threads acts as an interface between the goggles and the enclosure. This way, the clinician can position the enclosure in the z-axis such that the indenter tip touches the eyelid.

There were a few limitations in the prototype. The sensor to PCB strip within the enclosure would occasionally get twisted or bent due the unavailability of space after the screw rotation. This constraint for space can be accommodated for with a slot along the cylindrical axis of indenter movement or with a hole in the device enclosure through which the connection strip can protrude from and vice-versa. However, the generalized placement of the indenter in this prototype has its drawbacks because of anatomical differences in people's faces. To solve this, an indenter positioning system was designed which is described next.

49.4 Positioning System

The headgear system must have improved functionality in terms of indenter placement and to make the device convenient and easy to use which can be operated by an individual with minimal or no training. It required a system by which the indenter can be moved through three degrees of freedom, i.e., the *x*-, *y*- and *z*-axis and be positioned such that the indenter tip is just touching the eyelid. The user should also be able to fix that position of the indenter by locking the slider movement of each axis.

With these requirements, three concept directions were explored through sketches (Fig. 49.6). The following factors were considered in the design:

- Space for the nose to prevent interference with indenter movement
- Accommodate differences in face shapes for various patients

Fig. 49.6 Ideation sketches of three concepts of the headgear: **a** Rotating (left), **b** fixed rail (middle), **c** linear (right)

Table 49.1 Concept screening matrix of headgear

Criteria	Rotating (a)	Fixed rail (b)	Linear (c)
Fitting	–	+	+
Indenter positioning	0	–	+
Alignment visibility	+	0	+
Stability and comfort	+	0	0
Ease of use	0	+	0
Manufacturing cost	–	+	+
Sum ‘0′s	2	2	2
Sum ‘+’	2	3	4
Sum ‘–’	2	1	0
Net score	0	2	4

- Contact surfaces and materials of the sliders
- Smooth and controlled movement of the indenter through all three axes.
- Ability to see whether indenter is exactly above the eye
- Locking mechanism to fix the indenter in position.

The above three concept directions were explored using a screening matrix (Table 49.1). The linear headgear system (c) with three-axis movement ranked better in most criteria and was selected. A possible concern in this design is the stability of the indenter position, which is a key requirement during glaucoma diagnosis. The helmet-mounted design (a) with a rotating indenter positioning system would be more stable than the other two that are held by an elastic, but it lacks other features.

The final design is in the form of a thin cuboidal frame, with a slider system and a screening module. (Fig. 49.7). To address this problem of stability the selected idea, a three-way elastic can be added for an additional grip around the user’s head. It can be fastened around the head with the use of a modified band. It would be attached to the frame through three slots, two on either side and one on top.

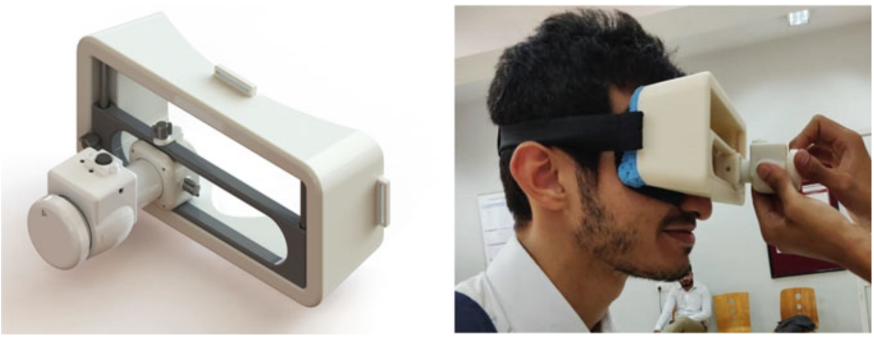

Fig. 49.7 Final product rendered (left), prototyped for testing (right)

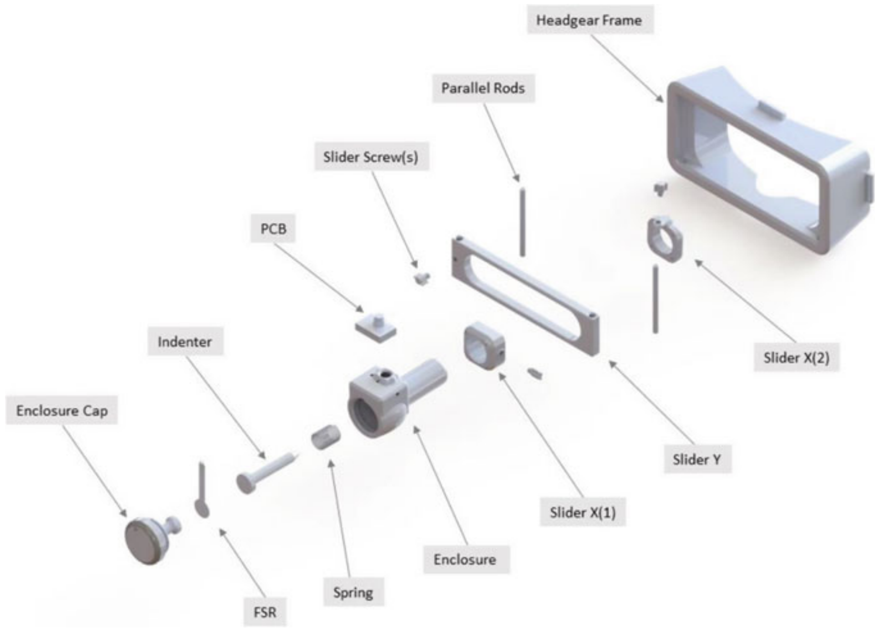

Fig. 49.8 Exploded view of the device assembly

The front of the headgear has two parallel rods on which a slider moves in the *y*-axis (Fig. 49.8). For convenience, this part is named Slider-*Y*. The rods as well as the frame have a hole such that the rods can be fixed in place with a nut and bolt. Slider-*X* is split into two parts which are fixed on either side of Slider-*Y*. This part can move in the x-axis, relative to Slider-*Y*. The Slider-*X* is cuboidal in shape with a central hole through which the enclosure's bottom extrusion will slide along the *z*-axis. There are three set-screws provided to lock the movement in each axis. One is on Slider-*Y* and two on Slider-*X*. Since the enclosure body moves through the hole in Slider-*X*, the second hole is used to lock the *z*-axis movement.

The enclosure contains the spring, indenter, PCB and FSR. The spring is placed along the length of the indenter and gets compressed by the indenter head when pushed down. The PCB is fitted in a chamber at the top of the enclosure. A screw top closes the enclosure and functions as the control for indenting the eye. It has an extrusion from the bottom which is one of the two faces between which the FSR is actuated. The other is the top of the indenter head, both the surfaces being flat.

The proposed design introduces a convenient screening method that can be performed at home and without any prior training. It is easy to operate and read the diagnosis, which switches on a red LED, indicating elevated IOP in the eye. After wearing the headgear and switching on the device, three steps are followed (Fig. 49.9):

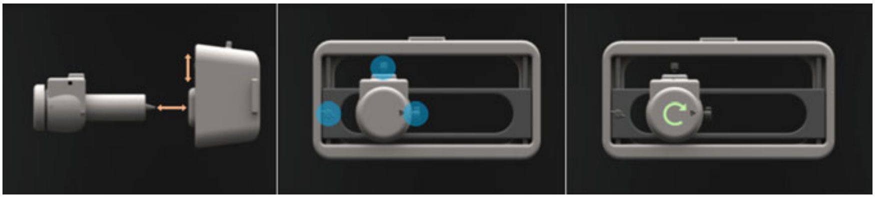

Fig. 49.9 Three steps in the diagnosis: **a** Align (left), **b** fix (middle), **c** rotate (right)

1. **Align**: Move the sliders in X-, Y-, Z-axes and position the screening module above the cornea.
2. **Fix**: Held in that position, fix the screws on each axis.
3. **Rotate**: From the starting point of the arrow demarcation, rotate the cap by 360° till the arrows meet again.

49.5 Conclusion

This work demonstrated the possibility of convenient self-assessment of elevated intraocular pressure to monitor glaucoma condition and ensure adequate treatment to prevent or delay the onset of blindness. The proposed design overcomes the limitations of existing devices, including the need for ophthalmologists, anaesthesia drops, invasive procedure and discomfort to patients. The major novelty is the slider system that allows the user to easily place the indenter above the eye. After that, one rotation of the screw can actuate an indicative light to warn patients of elevated IOP.

Future possibilities include advanced additive manufacturing methods to create parts using two materials joined together to further improve the functionality and manufacturability. Having rubber as the material for the elastic slot and the rest of the frame in plastic would reduce the chances of failure on the slots. Furthermore, the indication of elevated IOP is currently only through a red light. This can be improved with a digital interface which can display the IOP value of the patient using relevant data from the sensor. These improvements are planned in future versions of the product.

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Chapter 50
Design of an Expert System for Decision Making in Complex Regulatory and Technology Implementation Projects

Kausik Bhattacharya, Sandipan Gangopadhyay, and Carlton DeBrule

Abstract Project planning is a critical event for overall success of a project. Project planning in business technology projects is a multidisciplinary activity. Many times, project planning overlooks interdependencies and fails to utilize the historical knowledge and best practices, resulting in re-work. To address this gap, an AI expert system was designed that can facilitate flawless intake and planning. This system ensures work “starts right” by enforcing the entry criteria and allows tailoring of the project plan based on project type and complexity. This technology system is built using a rules-based design engine and optimized search algorithm that covers multiple domains like software engineering, regulations and risk management, and computer system validation. This system aligns very closely with the software development best practices of industry standards such as CMMi and GAMP. This system also seamlessly interfaces with project management systems to enable stage gate reviews and track project outcomes at the later stages of execution and project close out.

50.1 Introduction

As software development projects started becoming more complex, the project management and software engineering processes became more and more mature. A capability and maturity model was established by SEI. As the processes became better and the organization became more mature, it was realized that one size does not fit all, and hence, a process tailoring became essential based on how certain best

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A. Chakrabarti et al. (eds.), *Design for Tomorrow–Volume 3*,
Smart Innovation, Systems and Technologies 223,
https://doi.org/10.1007/978-981-16-0084-5_50

practices and controls fit in the context of a project or group of projects. However, tailoring is not about bypassing or avoiding the current procedure/process. It is a mechanism to execute the task with appropriate modification of the current procedure/process so that software quality is not compromised. Over a period of time, organizations have developed methods and criteria about how to tailor process that best suit the overall objective of the project and organization. This historical knowledge and expertise is a key element in project management for software development including during project planning.

50.1.1 Prior Work

The use of expert systems in various fields representing human knowledge goes back to older days. Numerous applications of expert systems were reported in literature. A methodology for designing expert system was published in 1965 [1]. As project management is a complex human activity, expert systems were built for project management as well. The role of an expert system in project management was reported in 1987 and 1989 [2, 3]. Earlier work was more focused on the use of a computer to replace specific tasks carried out by humans. Later, the use of expert systems for complex reasoning and managing uncertainty came in 1990 [4] and probabilistic models started being applied in 2002 [5]. In recent years, more advanced models are being developed for managing risks and evaluating maturity [6, 7]. Process tailoring is a very important step as per SEI-CMMI [8]. In recent years, agile has become a popular choice as a framework for technology development. In 2015, a comprehensive review of various agile tailoring methods was carried out from the literature [9]. One important point about tailoring is that it needs to be done based on solid criteria, and hence, an expert knowledge applying those criteria objectively and consistently is necessary for process tailoring.

As the healthcare domain is a highly regulated industry governed by the international and country-specific complex legal framework, several bodies of work were reported on developing legal expert systems. In 1986, an expert system was reported which was designed by capturing knowledge and expertise captured in myriad of legal documents [10]. Development of systems like MYCIN, ONCOCIN, and INTERNIST gave rise to the strong expectations that AI-based expert systems can be applied to everyday medicine [19]. A new rule-based expert system was reported in 2012 for telemonitoring of patients [11]. Rules-based expert systems started gaining attraction by industry and academicians quite a long time ago. A comparative study of various structured learning for belief rule-based (BRB) systems was published in 2013 [12]. This work spoke about evidence-based reasoning approach. It further touched upon the size reduction of a BRB system using principal component analysis techniques. A work done in 2011 showed how rule-based intelligent agents can comply more with norms that govern their behavior [13].

As project management including project planning became more and more complex and involved effort, the development of an expert system in project management started at the end of the last century [15]. References are available in literature and conferences like IEEE, PMI, and computer science (artificial intelligence) about expert systems in project management [16–18]. These articles describe in detail how to design expert systems, its key design characteristics, and numerous applications like scheduling, route planning, and configuration.

50.1.2 Why We Need an Expert System

In our case, we found that planning and delivery of software development projects in healthcare needs to fulfill various regulatory requirements and processes such as GxP and Part 11 requirements, information security and privacy. Therefore, these software development projects must follow the process and standards from software engineering, project management and computer system validation.

A detailed study was carried out to understand the current state of the software development framework and its processes. Various things were done under this study ranging from gap assessment with industry standards, collecting software quality metrics from software development projects, measuring cycle time of key planning deliverables, the extent of re-work involved and conducting voice of customer sessions to gather inputs from software developers and other stake holders.

Through this study, we found critical gaps in the software development process impacting the quality, timeline and project cost. Because of the gaps that exist in the early part of the software development lifecycle, it resulted in more costs to fix the defects later. Literature [15] reported 20–30 times cost escalation because of inability to catch defects at an early stage.

A wide range of variations were observed in project performance in the project portfolio which comprises of both medium software development projects and large and complex programs constituting multiple projects. Table 50.1 shows % re-work we saw in various software development planning deliverables. This re-work primarily

Table 50.1 Re-work and cycle time of key project deliverables

Planning deliverable	Un-planned effort as "%" of planned effort
Compliance assessment and planning	214
User requirements specification	156
Technical design	700
Test artifacts	480
Traceability matrix	85

occurred because while completing the task or deliverable during the planning phase, it overlooked the need of a specific domain, step or control which was found out later.

Hence, it was realized that we need a consistent and objective solution for process tailoring which balances the activities and controls with the overall project effort and delivery. A new automated technology solution was conceptualized which can enable integrated project planning by combining multiple domains and thereby allowing process tailoring. This technology solution should allow projects to start right by taking it through a consistent stage gate at the beginning that objectively evaluates the project against standard entry criteria. This automated solution should also allow automatic generation of project schedule templates by incorporating tasks and deliverable along with the RACI information as an outcome of project tailoring.

50.2 Goals

In this project, we came up with a goal to build a rule-driven expert system. The rules engine and calculator, which is the core of this system, needs to be dynamic that captures the need of all regulatory domains and have internal validation to avoid overlaps and conflicts. One key aspect of the initiative was to introduce a capability to learn from project metrics and feedback these into heuristic calculators through a formal governance process. However, our review of the prior work above showed that all expert systems reported in literature were special purposes and were intended for very specific use. Nothing has been reported on use of expert systems for multi-discipline knowledge-based planning of projects having high regulatory implications.

Hence, the main research goals of our work were:

- How can we design an expert system that captures the knowledge from multiple disciplines?
- Will such an expert system be useful for the projects to improve project performance?

Approach taken was to first design and build the expert system that can meet the first goal. Before success evaluation of the second goal, a pilot was done to verify the ability of the new system and fine tune it before deployment.

50.3 Development of Expert System

50.3.1 Solution Design

We designed a "propositional logic"-based expert system to do rule-based decisioning during project planning. Figure 50.1 shows the overall solution architecture. This rule-based decisioning will allow the project manager or project owner a "knowledge"-based ability:

- To know applicable software engineering capabilities that are required for a given project to ensure high quality and compliance
- Tailor the project activities and deliverables consistent with standard software development process
- Identify the roles and responsibilities that are required to complete the project tasks and deliverables as well as review and approval as per the standard software development process
- Identify the applicable standard project plan template and suitably update the template with tasks and deliverables coming out of tailoring.

The design implementation was done using the Microsoft Business Rules Engine leveraging GalaxE's platform and playbooks for automation in SDLC management, validation, quality assurance, portfolio, work and project management called GxPrime(TM). Figure 50.2 shows the various knowledge domains covered by the expert system and number of rules (i.e., business logics) represented in that domain.

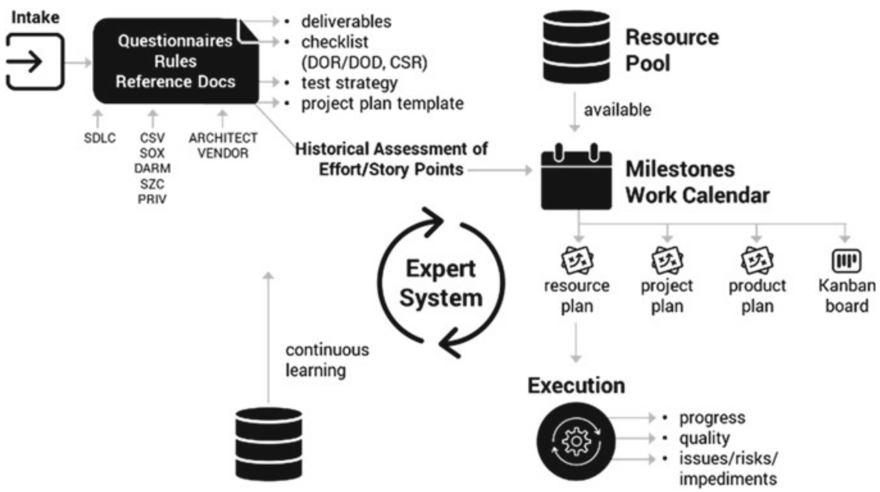

Fig. 50.1 Solution architecture diagram

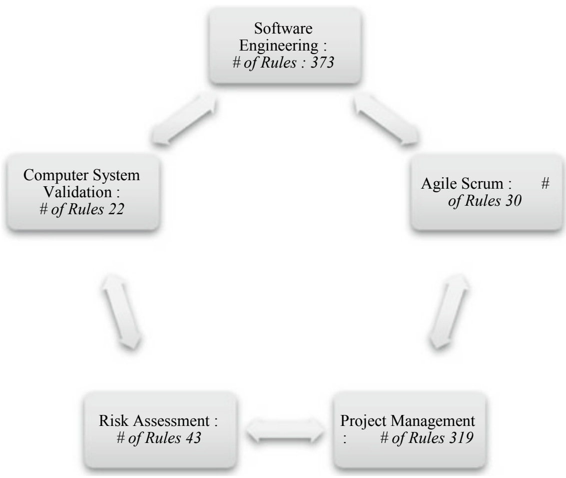

Fig. 50.2 Knowledge domains and number of rules

50.3.2 Implementation

We adopted the Scrum-based software development for implementation. For verification of the rule engine, we followed both static and dynamic verification testing. Under static testing, we mainly did the algorithm review. This was done during the implementation phase. It was a peer review where the subject matter experts reviewed the propositional logic statements. Also, the interdependencies between domains were also closely scrutinized. Dynamic testing was done at the end of each sprint. Under this, we did functional testing to verify the outcome using use cases. Each use case had expected outcomes created manually by the subject matter experts. The results produced by the expert system were compared against the manual results. In addition to the above tests, the software development team performed the various other testing like unit testing, system testing, integration testing and performance testing. Special emphasis was given to the performance testing to check response time.

50.4 Results

50.4.1 Pilot Study

A pilot study was undertaken first with eight global projects to use the expert system in actual project decisioning. The objective was to understand the improvements and any pain areas before rolling out to a wider base of project. Since our main objective was to discover any unknowns, we picked up a representation of projects with moderate to large complexities. These projects were often about implementation

Table 50.2 Pilot benefits summary

Metrics	Results
Reduction of cycle time in # of days (baseline of 38 day)	22 days
% reduction in planning effort	38%
Reduction in # of hand-offs (baseline of 17 hand-offs)	14
Cost avoidance ($)	~$2.8 M

of ERP systems and had strong regulatory implications. Table 50.2 gives a summary of project benefits we observed in the pilot.

After all the lessons and feedback from the pilot were addressed, the expert system was deployed to live projects. Deployment happened in waves in multiple industry segments and global regions against a meticulously developed deployment plan. A detailed success evaluation was carried out more than 12 months after deployment. This long period of time was chosen to give sufficient time for consistent adoption including training, coaching for stake holders and for long-term sustainable benefits to emerge.

50.4.2 Success Evaluation

Success evaluation was done with two groups of projects drawn from 2016 (without expert system) and 2018 (with expert system) project portfolio. In each group, high performers were identified using the success criteria defined by the portfolio organization. Table 50.3 shows the comparisons of project performance between 2016 and 2018.

Mann-Whitney test results ($U = 1.5$, p-val $= 0.0136$) conducted on these two groups showed evidence of improvement (level of significance, $\alpha = 0.05$).

Table 50.3 Comparison of project performance

Industry segment	% High performance projects	
	2016 (%)	2018 (%)
Consumer products	75	85
Corporate	82	94
Pharmaceutical	85	98
Supply chain	92	95
Overall	83	94

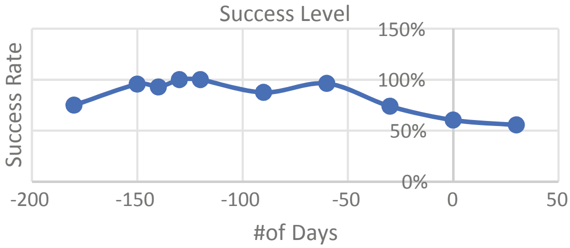

Fig. 50.3 Project success rate versus # of days between planning and execution

50.4.3 *Key Factors for High Performance*

Analysis of project performance data showed many key factors that help projects to achieve high performance. However, following two factors were found to be consistent and by logic most appropriate:

- Tailoring of project plan and effort-based sizing before execution:
  Tailoring of the project plan and effort-based sizing using the expert system was identified as a key factor for project success. Figure 50.3 shows project success rate versus # of days (between planning and execution). The definition of each term is given below:

$$\text{Success rate} = 100 \times \frac{\text{\# of project withGreen status as per portfolio criteria}}{\text{Total \# of projects in the portfolio}},$$

$$\text{\#of days} = \text{Plan Approval Date} - \text{Execution Start Date},$$

  Hence, negative value of the "# of days" indicates that the planning was done before start of execution.
- Quality assessment score:
  High degree of adherence to the rules of the expert system ensures successful outcome. This was verified by Fig. 50.4 which shows a greater number of projects with Green status that have higher quality assessment score. Quality assessment score indicates degree of adherence with the rules of expert system. Project Green

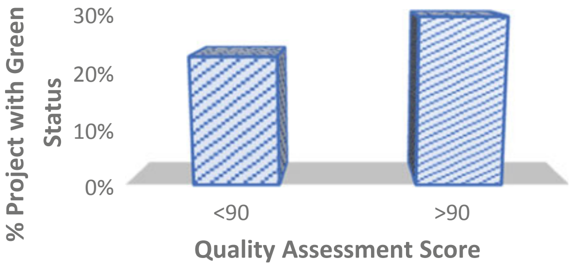

Fig. 50.4 % of Projects with Green status vs Quality Assessment score

status is measured against the Red-Amber-Green criteria defined by the portfolio department.

50.5 Discussion

This newly developed expert system embodies the knowledge and best practices of various compliance domains (including SoX, DARM, PCI, HIPAA, security, privacy and records retention), software engineering and project management. Hence, adoption of it was found to be critical for sustainable benefits. Analysis of the high performing projects above (Table 50.3) revealed following key factors for success:

- Determination of methodology/framework and deliverables via rules-based analysis in the portfolio planning phase
- Identifying software engineering capabilities and effort involved for a given project scenario
- Ensuring appropriate regulatory controls are in place and identifying regulatory gaps and risks using rule-based assessment
- Leveraging historical knowledge with appropriate parameters to arrive at more accurate estimates
- Maintaining traceability of project data over the entire project planning life cycle
- Identifying all dependencies during planning stage which helped to set the expectations from multiple shared services upfront. This reduces re-work, minimizes lag time leading to effective utilization of resources
- Determination of resource requirements upfront lead to effective resource utilization and eliminated idle time cost
- Effective feedback of actual performance (to continually update the rules and calculators) increases project efficiency and success rates.

Analysis of project success rate showed that approval of plan before start is recommended for a higher success rate. There is an optimum time range before project start, when success rate was found to be higher. This is because doing planning at a very early stage produces inaccurate plan because there were more unknown factors influencing the project. Doing planning immediately before start date produces inaccurate plan too, because not adequate time was spent in planning due to time pressure.

Quality assessment score was found out to be another key success factor, as this was measured by the independent quality assurance staff. The assessment methodology is based on industry fame works, and hence, by design, it assesses the adoption of best practices which the expert system is tasked with to include in the project plan.

50.6 Conclusion

We developed for the first time an expert system multi-discipline planning tool for projects with regulatory implications. Design of this expert system was done using the propositional logic and this can assist rule-based project decisioning. Pilot study demonstrated significant benefits in terms of making the process simple and thereby reducing the cycle time and efforts involved compared to traditional process. Success evaluation showed long-term sustainable benefits and we established the key factors that can help project success.

In this work, we focused on replicating human knowledge and expertise for decision making in complex scenarios. Also, our emphasis was on upfront planning, quality and risk assessment. In future, we would like to extend this work further by introducing maturing assessments and probabilistic risk planning.

However, the adoption of such an expert system for large scale use as conducted in this project needs careful planning to address operational needs. There are two important operational needs we would like to emphasize. First, the core of this expert system is its rule engine, and hence, we need a strong multi-domain governance board to manage the inter-disciplinary rules. This governance board is very critical for resolving any rule conflict between departments and in fact helps break down silos in large organizations. Second, the use of such an expert system in day to day business would require significant change in processes requiring user education. Hence, a strong change management process is another important pre-requisite.

Acknowledgements Authors recognize the effort and help of other co-workers and partners who helped in this work at different points of time and during the execution of this project.

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Chapter 51
Tendon-Driven Detachable End-Effector Mechanism for Minimally Invasive Surgery (MIS) Instruments

Mrunal Chavan, Prabhat Kumar, Rupesh Ghyar, Ballamudi Ravi, and P. S. Gandhi

Abstract Innovation in minimally invasive surgical technologies can have a substantial increase in the number of surgeries performed and the patient outcome. Based on the survey done among 100 laparoscopic surgeons throughout India, the need for highly articulated surgical instruments for laparoscopy was put forth irrespective of the experience of the surgeon. The present innovation is directed toward an end-effector mechanism that provides the wristed motion with no singularity in roll, pitch, and yaw. Besides, the end-effector is detachable, making it interchangeable and cost lowering. To obtain the desired yaw and pitch motions, various concepts were analyzed, and the best mechanism in terms of manufacturability, innovation potential, and various design constraints was selected to be tendon-driven rolling joint end-effector mechanism. In this mechanism, each disk is configured to rotate in at least one degree of freedom or DoF for each neighboring disk, which gives either yaw or pitch motion. To control the movements of the disk elements, actuation cables or tendon elements are used to manipulate the end-effector. Each link is in contact with the neighboring disk with a revolute joint. The kinematic model is developed for the novel end-effector using the D-H parameter convention to get the position and orientation of the tip in the fixed reference frame. The end-effector is characterized in terms of instrument workspace and surgical workspace, which is compared with the existing instrument workspace using MATLAB.

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A. Chakrabarti et al. (eds.), *Design for Tomorrow–Volume 3*,
Smart Innovation, Systems and Technologies 223,
https://doi.org/10.1007/978-981-16-0084-5_51

51.1 Introduction

Two very crucial pillars support the future of the Indian healthcare domain: first, the leadership and vision of hardworking surgeons of the country, and second is the innovation in technology, surgical techniques, and products that can ensure better health care and patient outcome. The adoption and developments in laparoscopic surgery in India are proof of the impact innovation which has had in enhancing patient health.

Laparoscopy is probably the most common form of minimally invasive surgery, which is a technique of inspection and surgery performed through small incisions of about 3–10 mm inside the abdominal cavity or pelvis, unlike the traditional surgical procedures which are manually performed. Overtime it is evolved from a diagnostic procedure to a surgical procedure and is performed in two ways: one being traditional MIS, and the other is robot-assisted MIS. Both have the apparent advantage of reduced damage caused to extraneous tissues and their side effects after the procedure. It is almost no scar surgery with better patient outcomes. The patient can walk within 2–3 h of surgery, is discharged within 24 h after surgery, and can resume work within a week [1]. But both traditional MIS and robot-assisted MIS have their differences. In traditional MIS, the instrument has only 4 DoF with no wristed movement, the surgeon stands next to the patient, and the instruments are operated manually without any tremor filtration; the camera provides only a 2D vision; the surgery cost is less compared to the high initial investment cost and high consumable costs involved in robot-assisted MIS. In contrast, the patient outcome for both types of surgeries is similar. The instruments used in robot-assisted MIS provide 360° of wristed movement but are restricted to only 10 surgeries per instrument; the surgeon is at the surgeon's console, which has a 3D surgeon-controlled camera, and the instruments respond in real time [2].

Since development in the end-effector has a large innovation potential within it, various novel end-effector mechanisms have been developed before. Some of those which cover different ways to obtain the wristed motion include cableless, magnetically driven instruments [3], which open a lot of possibilities for miniaturization. Magnetic actuation is used instead of traditional cable-driven mechanisms with the aim of providing high dexterity in hard-to-reach locations. However, vibration control is one of the challenges. Another alternative is a compliant mechanism or bending joints [4]; the joint essentially acts as a spring since the joint is formed of a single piece and operates within the range of the material's elastic range of deformation. Such a spring requires a continuous force to remain in a bent state, which is one of the challenges for compliant mechanisms. Also, there are end-effector mechanisms in which the instrument has a wristed motion given by oblique bevel gears and two concentric shafts [5]. Gear-based mechanisms are prone to backlash and are difficult to miniaturize.

51.2 Unmet Clinical Needs

The surgeon operated instruments only provide 4 DoF, thus inducing high physical and mental stress on the surgeon, whereas the robotic instruments have high costs of about 5 lacks per instrument and can only be used for 10 surgeries. Because of being undetachable, it is challenging to clean and sterilize [6].

After going through a thorough survey throughout India, the following areas were identified, which require innovation and are in the scope of this research.

- The need for innovation in the instrument for better articulation and maneuverability.
- The need to consider surgeons physical and mental comfort while performing surgery.
- The need for a cost-effective solution for the Indian population.
- The need for effective cleaning of the instruments.

All these needs can be taken care of by innovation in laparoscopic instruments.

51.3 End-Effector Design

A grasper is the first instrument that the surgeon will insert inside the abdomen during laparoscopic surgery. Figure 51.1 is the CAD model of atraumatic grasper with a double-action jaw. The end-effector consists of 12 components, including the shaft. The wristed motion is actuated with the help of five stainless steel wires (Φ0.45 (mm)). The yaw part and the pitch part are responsible for producing the two wristed

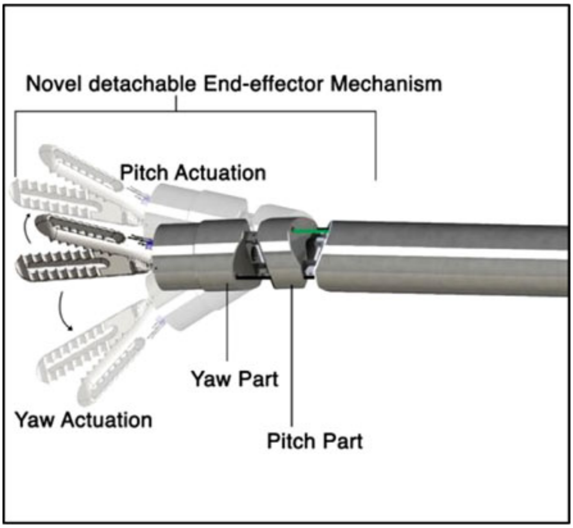


Fig. 51.1 CAD model for the atraumatic grasper

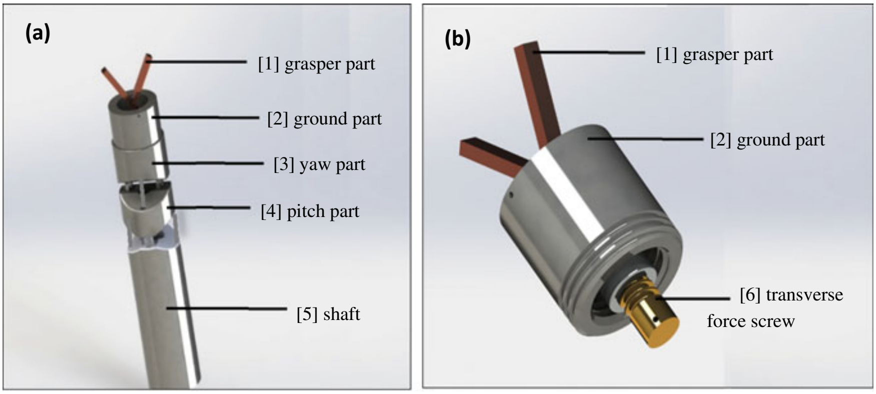


Fig. 51.2 **a** Complete end-effector assembly, **b** detachable tip

DoF. The range of motion of the wrist is ±45° in both the perpendicular planes, and the grasper can open up to 90°.

The ground part (Fig. 51.2) is completely detachable. The advantages of a detachable end-effector mechanism are:

- Interchangeability: Specialized tips like grasper, scissors, etc. can be interchanged with various handles.
- Cost lowering: Basic components like tip inserts and handles can be ordered separately.
- Thorough cleaning: Partial detachability allows better cleaning, which was not possible earlier.
- User-friendly assembly and disassembly as during surgeries only one component needs to be interchanged.
- There is no need to unlock the instrument during ongoing surgery.

51.4 Kinematic Modeling and Forward Kinematic Analysis

In this section, the forward or configuration kinematic equations are developed for the novel end-effector mechanism using the Denavit-Hartenberg Convention, aka D-H parameter convention [7]. The novel mechanism has six DoF, excluding the grasper opening and closing. There is a rotational motion (yaw, pitch, and roll) about the pivoting point, aka the remote center of motion (RCM), which also coincides with the trocar center, a translation along the axis, and two DoF because of the wristed motion at the tip of the end-effector.

The forward kinematic equations are generated to determine the position and orientation of the end-effector tip, given the values for the joint variables as input to the derived kinematic equations.

- **Link length ($\mathbf{a_i}$)**: The length of the common normal, which is the distance between the previous z-axis (z_{i-1}-axis) and the current z-axis (z_i-axis).
- **Link twist angle ($_\mathbf{i}$**: The angle around the common normal between the previous z-axis (z_{i-1}-axis) and current z-axis (z_i-axis).
- **Link offset ($\mathbf{d_i}$)**: The distance between the previous x-axis (x_{i-1}-axis) and the current x-axis (x_i-axis), along z_{i-1}-axis.
- **Joint angle ($\mathbf{\Theta_i}$)**: The angle around the z-axis between the previous x-axis (x_{i-1}-axis) and the current x-axis (x_i-axis).

The kinematic model of the multi-degree of freedom instrument with a novel end-effector mechanism is proposed in Fig. 51.3. Based on the kinematic model, the homogeneous transformation matrix for each joint is calculated. The D-H parameters for each joint in Fig. 51.3 are summarized in Table 51.2. Table 51.1 summarizes the range of the variable parameters of each joint for this novel end-effector mechanism.

The transformation matrix between every two successive frames can be formulated using the homogeneous transformation matrix equation, and the D-H parameters summarized in Table 51.2 for each joint. The transformation matrices for joint 1 to joint 7 are calculated below based on the values of different joint angles and link lengths (Table 51.2).

$$^{0}T_1 = \begin{bmatrix} c_1 & -s_1 & 0 & 0 \\ s_1 & c_1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}; \quad ^{1}T_2 = \begin{bmatrix} c_2 & 0 & s_2 & 0 \\ s_2 & 0 & -c_2 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix};$$

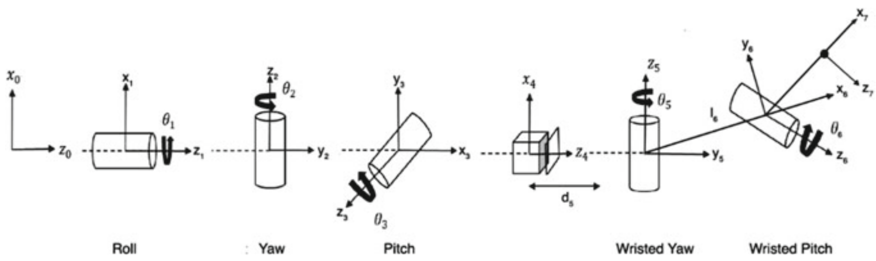


Fig. 51.3 Kinematic model of multi-DoF instrument with the novel end-effector

Table 51.1 Range of θ_i, l_i, and d_i

θ_1	θ_2	θ_3	d_5 (cm)	θ_5	l_6 (cm)	θ_6	l_7 (cm)
120°	120°	180°	20	90°	0.55	90°	1.05

Table 51.2 D-H parameters for multi-DoF instrument with novel end-effector

Link (i)	Link twist angle (α_i)	Link length (a_i)	Link offset (d_i)	Joint angle (θ_i)
1	0	0	0	θ_1
2	90°	0	0	θ_2
3	90°	0	0	θ_3
4	90°	0	0	0
5	90°	0	d_5	θ_5
6	−90°	l_6	0	θ_6
7	0°	l_7	0	0

$$
{}^2T_3 = \begin{bmatrix} c_3 & 0 & s_3 & 0 \\ s_3 & 0 & -c_3 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix};\ {}^3T_4 = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix};
$$

$$
{}^4T_5 = \begin{bmatrix} c_5 & 0 & s_5 & 0 \\ s_5 & 0 & -c_5 & 0 \\ 0 & 1 & 0 & d_5 \\ 0 & 0 & 0 & 1 \end{bmatrix};\ {}^5T_6 = \begin{bmatrix} c_6 & 0 & -s_6 & \mathrm{l}_6 c_6 \\ s_6 & 0 & c_6 & \mathrm{l}_6 s_6 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix};
$$

$$
{}^6T_7 = \begin{bmatrix} 1 & 0 & 0 & \mathrm{l}_7 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix};
$$

where

$$
\begin{aligned}
&\mathrm{c}_n : \cos(\theta_n),\ \mathrm{s}_n : \sin(\theta_n),\ \mathrm{s}_{n-1n} : \sin(\theta_{n-1} + \theta_n),\\
&\mathrm{s}_{n\,n-1} : \sin(\theta_{n-1} - \theta_\mathrm{n}),\ \mathrm{c}_{n-1n} : \cos(\theta_{n-1} + \theta_n),\\
&\mathrm{c}_{n\,n-1} : \cos(\theta_{n-1} - \theta_n)
\end{aligned}
$$

Now, the position of the end-effector tip with respect to the fixed reference frame is given by:

$$
{}^{\mathbf{B}}\mathbf{T}_{\mathbf{W}} = {}^{\mathbf{0}}\,\mathbf{T}_{\mathbf{7}} = {}^{\mathbf{0}}\,\mathbf{T}_{\mathbf{1}}.{}^{\mathbf{1}}\mathbf{T}_{\mathbf{2}}.{}^{\mathbf{2}}\mathbf{T}_{\mathbf{3}}.{}^{\mathbf{3}}\mathbf{T}_{\mathbf{4}}.{}^{\mathbf{4}}\mathbf{T}_{\mathbf{5}}.{}^{\mathbf{5}}\mathbf{T}_{\mathbf{6}}.{}^{\mathbf{6}}\mathbf{T}_{\mathbf{7}} \tag{51.1}
$$

$$
= \begin{bmatrix} c_{12}c_{53}c_6 - s_{12}s_6 & c_{12}c_{53}s_6 + s_{12}c_6 & c_{12}s_{53} & (l_6 + l_7)[c_{12}c_{53}c_6 - s_{12}s_6] - d_5 s_{12} \\ s_{12}c_{53}c_6 + c_{12}s_6 & s_{12}c_{53}s_6 - c_{12}c_6 & s_{12}s_{53} & (l_6 + l_7)[s_{12}c_{53}c_6 + c_{12}s_6] - d_5 c_{12} \\ s_{53}c_6 & s_{53}s_6 & -c_{53} & (l_6 + l_7)[s_{53}c_6] \\ 0 & 0 & 0 & 1 \end{bmatrix}
$$

where

$$^{B}T_{W} =^{0} T_{7} = \begin{bmatrix} r_{11} & r_{12} & r_{13} & \boldsymbol{d}_{x} \\ r_{21} & r_{22} & r_{23} & \boldsymbol{d}_{y} \\ r_{31} & r_{32} & r_{33} & \boldsymbol{d}_{z} \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{51.2}$$

Thus, equating Eqs. 51.1 and 51.2, the position and orientation of the end-effector tip with respect to the fixed frame of reference are given by solving the following equations:

$$\begin{aligned}
r_{11} &= c_{12}c_{53}c_{6} - s_{12}s_{6} \\
r_{12} &= c_{12}s_{53} \\
r_{13} &= -c_{12}c_{53}s_{6} - s_{12}c_{6} \\
r_{21} &= s_{12}c_{53}c_{6} + c_{12}s_{6} \\
r_{22} &= s_{12}s_{53} \\
r_{23} &= -s_{12}c_{53}s_{6} + c_{12}c_{6} \\
r_{31} &= s_{53}c_{6} \\
r_{32} &= -c_{53} \\
r_{33} &= -s_{53}s_{6} \\
d_{x} &= (l_{6} + l_{7})[c_{12}c_{53}c_{6} - s_{12}s_{6}] - d_{5}s_{12} \\
d_{y} &= (l_{6} + l_{7})[s_{12}c_{53}c_{6} + c_{12}s_{6}] - d_{5}c_{12} \\
d_{z} &= (l_{6} + l_{7})[s_{53}c_{6}]
\end{aligned}$$

51.5 Instrument Workspace Calculations and Comparison

Given the geometry of the laparoscopic instrument and manipulator, the workspace calculation for the instrument is based on defining the position of a point in the spherical coordinate system. The three-dimensional workspace region is chopped up into infinitesimally small pieces, where each piece is associated with a value. When this value is integrated or added over the entire workspace region limit, we get the required volume. The end-effector tip position is defined by (ρ, θ, Φ). The instrument workspace is calculated by integrating the volume element in the spherical coordinate system and is given by:

$$\mathbf{Volume}, \mathbf{V} = \iiint \boldsymbol{\rho}^{2} \sin\theta \mathbf{d}\rho \mathbf{d}\theta \mathbf{d}\emptyset \tag{51.3}$$

Based on this methodology, the instrument workspace is calculated and plotted using MATLAB and is compared among manual laparoscopy instruments, da Vinci instruments, and the tendon-driven detachable instrument. The manual laparoscopy instruments have only four degrees of freedom, unlike the other two, with each having six degrees of freedom [8]. For obtaining the plot view for 6 DoF instruments, a moving reference frame with the articulation was considered.

51.6 Results

Based on Tables 51.3 and 51.4, we can conclude that by increasing the degree of freedom for the instrument, we can get a workspace increment greater than 19% compared to the manual laparoscopy instruments. Whereas when the da Vinci instrument is compared with the novel instrument, the da Vinci instrument covers 3.26% more work volume than the latter. This workspace volume difference comes out to be insignificant when it is compared with the organ volume for cholecystectomy (surgical removal of gall bladder) of 683.3 cm^{3,} which is considered as the reference

Table 51.3 Instrument workspace comparison for different instruments

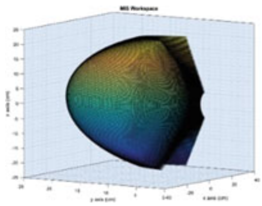
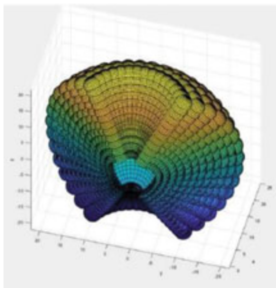
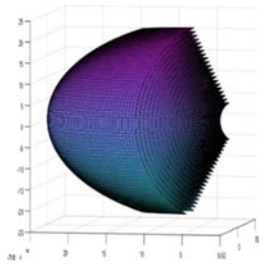
Sr. No.	Instrument details	Plot view
1	**Manual laparoscopy instrument** DoF: 4 $P = [5\text{ cm}, 25\text{ cm}]$ $\theta = [P_i/6, 5 * P_i/6]$ $\Phi = [P_i/6, 5 * P_i/6]$ Instrument workspace volume = 1874.26 cm^3	
2	**Da Vinci instrument** DoF: 6 $P = [5\text{ cm}, 25\text{ cm}]$ $\theta = [P_i/6, 5 * \text{Pi}/6]$ $\Phi = [P_i/6, 5 * \text{Pi}/6]$ Articulation = $[-P_i/2, P_i/2]$ Instrument workspace volume = 2319.16 cm^3	
3	**Novel tendon-driven detachable instrument** DoF: 6 $P = [5\text{ cm}, 25\text{ cm}]$ $\theta = [P_i/6, 5 * P_i/6]$ $\Phi = [P_i/6, 5*P_i/6]$ Articulation = $[-3 * P_i/8, 3 * P_i/8]$ (effective value) Instrument workspace volume = 2245.80 cm^3	

Table 51.4 Percentage instrument workspace volume comparisons

Sr. No.	Laparoscopy instrument name	Workspace volume	Percentage increase in workspace volume compared to		
			Manual	Da Vinci	Novel detachable
1	Manual	1874.26	NA	−19.18	−16.55
2	Da Vinci	2319.16	23.74	NA	3.26
3	Novel detachable	2245.80	19.83	−3.16	NA

volume. Better articulated and dexterous instruments provide mental and physical comfort to surgeons as more work volume is covered by the instruments' end-effector mechanism.

51.7 Conclusion and Future Work

This study presented a novel detachable end-effector mechanism for laparoscopic surgery instruments for which forward kinematic analysis was performed, followed by validation using instrument workspace calculations and reference organ volume. The kinematic analysis final equations give the position and orientation of the instrument tip with respect to the initial fixed reference frame. Based on the workspace calculations, the instrument workspace for da Vinci and novel end-effector instruments are comparable, whereas those values are considerably higher than the volume covered by traditional 4 DoF laparoscopic instruments. Thus, with 6 DoF and grasper, opening–closing action, the instrument provides better maneuverability and provides physical and mental comfort to the surgeons.

In future, FEA analysis needs to be performed to validate the design, followed by manufacturing a working prototype to identify and further optimize the design in the following iterations. The manufactured prototype can then be tested for its repeatability and the grasping force, and it can generate at the end-effector tip. Only after that, the end-effector mechanism design will be finalized, and the prototype will be fabricated, and feedback will be obtained from experienced surgeons on its usability.

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Chapter 52
Design, Development and Testing of a Mechanized Terrace Forming Equipment

M. Angelus Khoh and Amarendra Kumar Das

Abstract Terrace fields are often seen in hilly or mountainous regions in different parts of the world. These terrace fields are man-made flatbeds on hilly terrains for the purpose of farming. Slopes are cut to form flatbeds to contain soil erosion, retain water for wet cultivation, aquaculture/pisciculture, etc. With context of the North Eastern Region of India, along with terrace cultivation, Jhum/Shifting cultivation is still practised in few pockets although the later has been banned in India. Therefore, there is an urgency to encourage the farmers of the region to adopt terrace cultivation. Majority of the existing terrace fields are formed with traditional hand tools, thus making it a labour-intensive and time-consuming process. Mechanization of the process can hardly be observed even to the present day due to various reasons, viz., agricultural machinery used in plain areas are not always suitable in hilly areas, lack of motorable roads to transport or manoeuvre such machinery and equipment, safety concerns, landholding patterns, socio-economic considerations, lack of innovative machinery or equipment suitable for hill terrains. This research explores the areas where mechanization of the agricultural processes in hilly areas is required. It has been identified that terrace field forming process is one vital area. Since heavy machinery is not suitable for hilly terrains, compact power tillers are considered a more suitable alternative. However, the present power tiller available are not equipped for forming terrace fields, therefore, this paper presents the design and development of a mechanized terrace forming equipment suitable for hilly areas. Four concepts were generated and discussed for their merits and demerits, and the most suitable one is chosen based on inputs from individuals familiar with design processes and a concept selection matrix to develop the prototype further. The prototype of the sub-units components developed is discussed in this paper. The paper deals with concept to prototype stage of the design. Immediate future works will focus on testing the equipment and analysing the result(s) and making any design changes if required. Mechanizing the agricultural processes in general and terrace cultivation processes

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A. Chakrabarti et al. (eds.), *Design for Tomorrow–Volume 3*,
Smart Innovation, Systems and Technologies 223,
https://doi.org/10.1007/978-981-16-0084-5_52

in the hilly regions of north eastern India will increase the agricultural productivity of the farmers of this region.

52.1 Introduction

Agriculture is the basic livelihood of the people in North-Eastern Region (NER) of India. The region consists of both plain and hilly areas endowed with rich flora and fauna due to its diverse ecosystem. The region has inaccessible terrain, fragility, marginality, excessive sloping land with rolling topography, rich biodiversity, unique ethnicity and socio-ecological set-up. The agricultural practices of the region are broadly of two types, viz., (i) settled cultivation practiced in plains, valleys, foothills and terraced slopes and (ii) shifting cultivation in hilly areas of all the states with the exception of Sikkim, where settled cultivation is practiced on terraces [1]. Low productivity of the region is due to numerous factors, such as traditional farming methods, use of poorly designed tools, tough terrains, lack of good agricultural practices (GAP), lack of irrigation, and demand of extreme physical labour etc. Mechanization of agriculture in the hilly terrain remains a huge challenge due to undulating terrains, small land holdings, cost of initial investments, and lack of power for mechanization and also lack of transportation networks. One of the main reasons of lower agricultural productivity in the region is due to prevalence of traditional method of cultivation and lower mechanization level [2]. Moreover, the traditional agricultural practices, lack of proper technology interventions and ineffective state policies have inhibited the agricultural growth, resulting in a clear developmental divide between the NER and the rest of the country [3]. Jhum/Shifting cultivation has been banned in the country for long time. Viable alternative to jhum cultivation is terrace cultivation. But terrace cultivation in the hilly terrains demands a lot of physical labour for initial preparation of terrace in hilly terrain.

Considering such factors of the farmers of the region, in this research a terrace forming equipment has been designed which can assist mechanized terrace forming process in the hilly areas of the region. The initial concepts were developed on a CAD platform. The advantages and disadvantages of each concept were discussed and appropriate concept selected for prototyping. The main objective of this research is to design and develop a system which can be used for forming terrace fields in the hilly areas of the region. The paper deals with concept to prototype stage of the design.

52.2 Need Identification

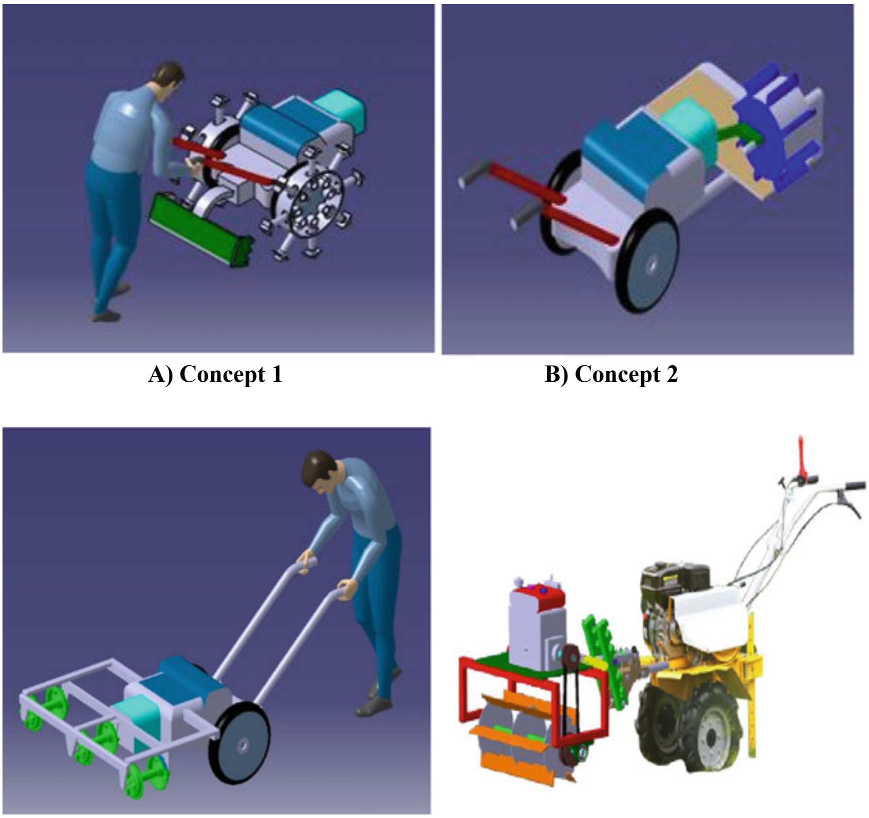
The farmers of the region forms terrace fields using hand tools such as spades, pickaxe, shovel, etc which is physically taxing and economically inefficient. In the present day, even though there are many agricultural machinery being developed for plain areas, these are mostly unsuitable for forming terrace field for the farmers of the region due to a number of factors such as tough terrains, The absence of motorable roads, socio-economic status, safety concerns, etc. As terrace field forming process takes a lot of time and human labour, there is a need to design and develop a mechanism which will mechanize formation of terrace fields. The fact that modern heavy machinery is unsuitable for hilly terrains made power tillers emerge as a potential, versatile machine for mechanizing agriculture in such regions. However, these power tillers are not equipped for forming terrace fields. Therefore, there is a need for terrace forming equipment which can be attached to a power tiller. Such a system should be able to work in hilly terrains with relative ease and should be cost-effective so that small land-holding farmers of the region can afford it.

52.3 Concept Generation

The hilly regions require an alternative, innovative approach to mechanize the agricultural processes as compared to plain cultivation, and it holds true for forming terrace fields as well. Since heavy machinery is not suitable for hilly regions, power tillers are considered as a more suitable option to mechanize the agricultural processes. With that in mind, the concepts were developed as equipment which can be attached to a power tiller for forming terrace fields. The concepts were generated based on preliminary studies of different types of earth work machines and taking inspiration of certain concepts from some existing machines, using trial and error method to evaluate the advantages and disadvantages of each concept.

52.3.1 Concept 1: Height Adjustable Wheels with Scraper

In this concept, the idea is to adjust the height of the wheels according to the steepness of the slope so that the engine and other components of the machine are balanced. This proposed machine consists of four main components, viz. the engine, the body or the chassis, wheels with height adjustable spokes and a scraper. A number of slots corresponding to the number of spokes are cut out at designated locations along the circumference of the wheel for the spokes to slide. The spokes length can be adjusted by attaching or removing parts of the spoke. Spokes of one side of the wheel can be shortened and the other side lengthened to negotiate the steepness of the slope so as to maintain the machine in a horizontal position. The scraper is attached on the rear side of the machine between the main body and the handles of the machines. This scraper will be the unit in contact with the soil for cutting the bench terrace. The machine is intended to be hand-guided by an operator as shown in Fig. 52.1a.



A) Concept 1 B) Concept 2

C) Concept 3 D) Concept 4

Fig. 52.1 Concepts Ideation

52.3.2 Concept 2: Front Rotary Cutting Blades with Conveyor Belt System

In this approach, the idea is to pave a pathway for the machine to manoeuvre over hilly terrains by cutting the slopes and forming terrace fields. The system consists of five sub-units, viz., the engine, the chassis or the body, a power take-off (PTO) unit, a rotary cutting unit and a conveyor belt unit (Fig. 52.1b). The rotary blade unit is placed in front of the engine connected by a power take-off unit for transmitting power from the engine to the rotary cutting unit. The vertically height adjustable rotary cutting unit will be positioned close to the surface of the hill/mountain slope in order to cut the soil. The falling debris or the loose soil which are cut out will fall on the conveyor belt unit. They will then be transferred for filling up to the other end of the machine which is at the lower level area of the slope. This approach will provide a stable and safe area for the machine and the operator to work along the hilly terrains.

52.3.3 Concept 3: Height Chain Driven Front Cutting Blades

This concept consists of four sub-units, viz., the engine, the chassis or the body, a power take-off (PTO) unit, a chain drive cutting unit as shown in Fig. 52.1c. In this concept, power from the engine of the power tiller is transferred to the chain drive system by the PTO unit. The cutting blades will be mounted along the length of the chains which in turn are mounted on the sprockets and will cut the soil when the chain rotates. The middle pair of sprockets acts as the pivot about which the cutting unit of the chain drive system rotates so that the height of cutting operation can be adjusted.

52.3.4 Concept 4: Front Rotary Cutting Unit with Its Own Engine

This concept proposes a rotary cutting unit with its own separate engine attached to the front of a power tiller as shown in Fig. 52.1d. This concept is designed to provide movement of the rotary cutting unit along the vertical and horizontal directions and also provide the ability to cut the soil at a certain angle away from the normal position of the rotary unit. The operator/handler will walk behind the power tiller, so the thrown off soil will not affect the operator. The cutting blades were designed to "throw off" to the cut soil opposite to the direction of the cutting action.

52.4 Concept Selection

The selection of the most appropriate concept is based on three levels; discussing the advantages and disadvantages of each concept, receiving inputs and opinions from individuals familiar with design processes, decision matrix to rate each concept. While evaluating the merits and demerits of each concept, it was observed that the first concept might need more power as the cutting action will be provided by the scraper which is attached behind the engine and the wheel. It was also observed that the height adjusting wheels might not provide sufficient traction to carry out the work or negotiate steep slopes. In the second concept, addition of a belt conveyor unit might not be suitable for hilly terrains where the ground clearances keep varying. The third concept with the cutting blades on the chain drive appears to be a more complex system in terms of design, efficiency of the cutting blades and also the maintenance

Table 52.1 Selection matrix

	Concept 1 (reference)	Concept 2	Concept 3	Concept 4
Selection criteria				
Ease of handling	0	+	+	+
Ease of manufacture	0	+	+	+
Cutting along vertical direction	0	+	+	+
Cutting along horizontal direction	0	–	–	0
Power requirement	0	+	+	+
Manoeuvrability	0	–	–	0
Cost	0	–	0	–
Transferring cut soil	0	+	+	+
Portability	0	+	+	+
Sum +s	0	6	5	6
Sum 0s	9	0	1	2
Sum −s	0	3	2	1
Net score Rank Continue?	0 3 No	3 2 No	3 2 No	5 1 Yes

requirement of a chain drive system. In all the three concepts discussed, the cutting action is along a single path that is, along the horizontal path in case of the first concept and along the vertical direction in the second and third concepts. In case of the second and the third concepts, the problem of power transmission from the engine of the power tiller to the cutting unit arises. The fourth concept provides the ability to move the rotary cutting unit along the vertical and horizontal directions which is one important criterion. Employing dual engines solves the problem of reducing power requirement and power transmission although it requires designing some sub-systems. Further, a list of criteria based on the need of the target group were listed and the concepts were rated with respect to concept 1 as the reference as shown in the selection matrix Table 52.1. Considering these three approaches of selecting the concepts, it is evident that concept 4 is the most suitable design. Hence, mock-up models of the sub-units are developed and further development processes were carried out.

52.5 Mock-up Model

For the purpose of visualization, proof of concept (POC) and to check how the system will function, mock-up models of the sub-units have been developed. Figure 52.2a

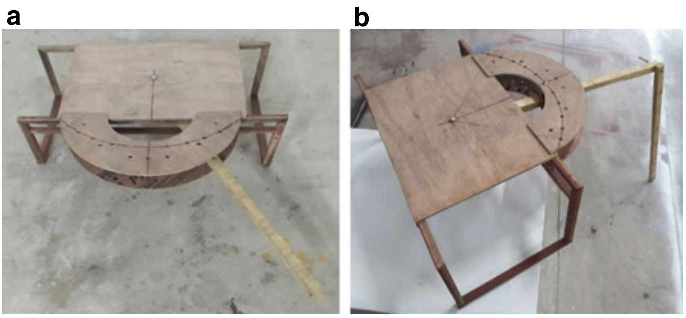


Fig. 52.2 Mock-up model: **a** Cutter unit pivoting about the vertical axis; **b** cutter unit pivoting about the horizontal axis

explores the possibility of rotating the rotary cutting unit up to some degrees from the normal position (which is considered with respect to the shaft emerging from the power tiller). Figure 52.2b explores the possibility of lifting the rotary cutting unit along the vertical direction. The horizontal movement will be derived from the forward and reverse speed given by the power tiller. The arm is attached to the frame of the rotary unit by means of a pin and acts as the pivot point with respect to the vertical axis about which the rotary unit along with the support frame rotates. The other end of the arm is attached to the shaft extending from the power tiller by means of a bracket.

52.6 Development of Prototype

To develop the prototype, a detailed 3D model was developed on a CAD platform (CATIA) adopting the Design for Manufacture and Assembly (DFMA) approach. A bottom-up approach was followed while designing the system by designing each part on the CAD platform. The system consists of three main sub-units, viz., rotary cutting unit, support frame with engine mounted on it, and a vertical lifting system. An existing power tiller is considered as another sub-unit required to provide the forward and reverse speed of the whole system. The power required for cutting the soil to the rotary cutting unit will be provided by the engine mounted on top of the rotary cutting unit. Each individual part were created first in “Part Design” workbench and later assembled on “Assembly Design” workbench. The assembled design of the system was simulated on “DMU Kinematics” workbench (Fig. 52.3).

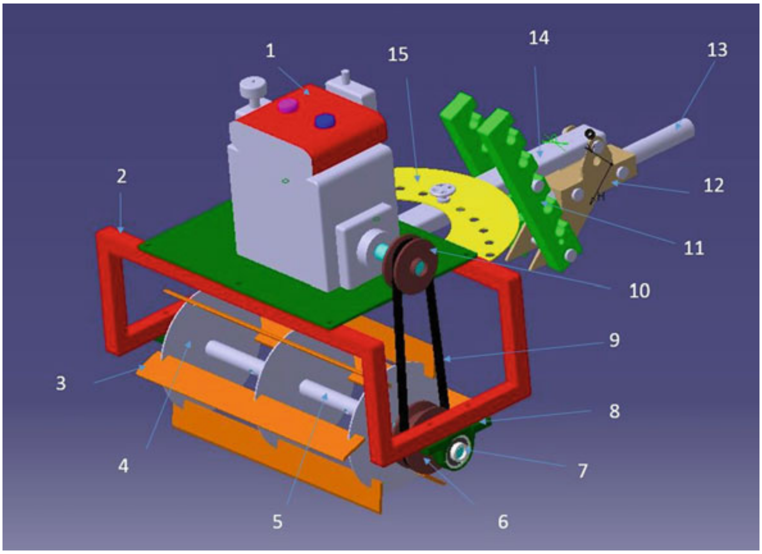


Fig. 52.3 (1) Engine block; (2) Support Frame; (3) Blade; (4) Flange; (5) Rotor shaft casing; (6); Pulley; (7) Rotor shaft; (8) Bearing; (9) Pulley belt; (10) Pulley; (11) Vertical lifting arm; (12) Bracket; (13) Shaft connecting to the power tiller; (14) Arm; (15) Arm locking plate with pin

52.6.1 Design of the Rotary Cutter

It consists of six blades made of tool steel of 5 mm thickness mounted on three flanges mounted on the shaft casing pipe. The flanges are in the shape of a circular disc having six cut out slots along the circumference in order to house the blades (Fig. 52.4a).

52.6.2 Support Frame Unit

The support frame unit consists of the main frame upon which the engine will be mounted. The bearings and the shafts to be connected to the rotary cutting unit are mounted to this frame as well. A plate in the shape of an arc which provides locking positions of the arm, and the support frame is also fixed to this frame. A positioning pin is fixed to the frame to act as the pivot point about which the frame will rotate with respect to the arm. The support frame with its constituent components is shown in Fig. 52.4b.

The positioning plate has a number of slots on it where the position of the support frame can be fixed with respect to the arm with the help of a pin as shown in Fig. 52.4c. The total angle about which the frame can rotate is designed to be 90°. This angle can be increased or decreased depending on the requirement.

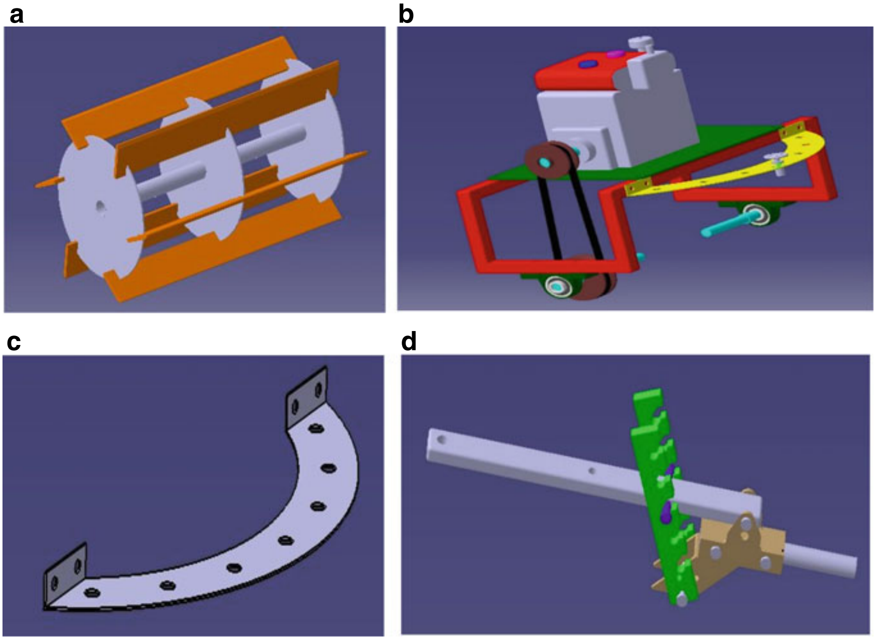


Fig. 52.4 **a** Rotary cutter unit; **b** support frame unit; **c** arm locking arc; **d** lifting unit

52.6.3 Lifting Unit

Hilly terrains present varying degrees of slope along its range and a mechanism or a system with a fixed cutting position of cutting height is not always suitable for forming terrace fields. To address this problem, a mechanism for movement along the vertical direction (lifting and lowering the rotary cutting unit) was designed. The mechanism of the lifting unit is proposed as a solution so that the rotary cutting can be lowered or lifted to a specified height. This unit consists of an arm which is jointed to the support frame and a pair of lifting arms fixed to each side of a bracket Fig. 52.4d. This unit, in turn, is connected to the power tiller by means of a shaft emerging from the power tiller.

52.7 Development of Modified Wheel

In hilly terrains manoeuvring power tillers or even vehicles for that matter is a challenge due to factors such as steep ascend or descend, poor road conditions, narrow roads, lack of motorable roads and landslides, etc. During rainy seasons, it becomes even more dangerous for operators of such machines. Therefore, a modified wheel design is proposed for the power tiller so that it can provide sufficient traction

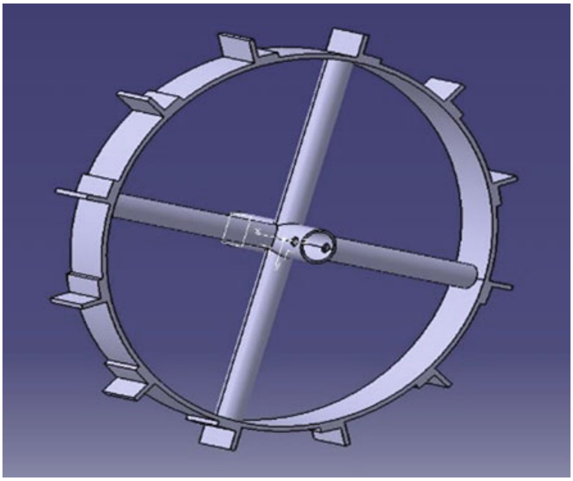


Fig. 52.5 Modified wheel

while working on such terrains. This wheel design is simple, easy to assemble or disassemble. The CAD model of the wheel is shown in Fig. 52.5. The circumference of the wheel is provided with lugs of the same width as that of the wheel so that it "bites" into the soil to provide traction without skidding while forming new terrace fields.

52.8 Conclusion

Agriculture is the basic livelihood of the people in North-Eastern Region (NER) of India. The region consists of both plain and hilly areas which include inaccessible terrain, fragility, marginality, excessive sloping land with rolling topography, rich biodiversity, unique ethnicity and socio-ecological set-up. Mechanization of agriculture in the hilly terrain remains a huge challenge due to undulating terrains, small land holdings, cost of initial investments, and lack of power for mechanization and also lack of transportation networks. Since modern heavy machinery is unsuitable for hilly terrains, this research explores the areas where mechanization of the agricultural processes in hilly areas is required. It has been identified that terrace field forming process is one vital area. This paper presents the design and development of a mechanized terrace forming equipment to be attached to a power tiller suitable for hilly areas. Four concepts were generated and discussed for their merits and demerits, and the most suitable one is chosen based on inputs from individuals familiar with design processes and a concept selection matrix to develop the prototype further. The prototype of the sub-units components developed is discussed in this paper. The paper deals with concept to prototype stage of the design. The design concepts were generated with primary focus on the functionality of the equipment. They were initially developed on a CAD (CATIA V5R20) platform. Selection of the most appropriate concept was based on three levels; discussing the advantages and disadvantages of each concept, receiving inputs and opinions from design experts, decision matrix to rate each concept. The detailed design of the selected concept was carried on CAD platform, and the mock-up models of the sub-systems were developed to test the functional aspect. Presently, prototype development and testing of the selected concept is being carried out but it is not included within the scope of this paper. Immediate future works will focus on testing the equipment and analysing the result(s) and making any design changes if required. Mechanizing the agricultural processes in general and terrace cultivation processes in the hilly regions of north-eastern India will increase the agricultural productivity of the farmers of this region.

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Chapter 53
Rethinking Tuberculosis Diagnostics in Low-Resource Areas

Geetika Garg, Aditi Singh, and Parag Anand

Abstract Advancing technologies ensure that we have medical devices to diagnose and treat diseases once considered incurable. For larger reach, however, it is also necessary that they fit different demographics such as that observed in Indian markets. For this, design is a critical facilitator. This paper discusses a design for tuberculosis (TB) diagnostic device called 'MycoKit', which quickly and accurately conducts a molecular analysis of sputum to detect the presence of Mycobacterium-TB. Its design keeps systemic considerations of rural areas and human-error minimisation at its core. An intuitive interface and easy operation have been prioritised to enable people with basic literacy from local communities to perform molecular testing on-site. MycoKit has a combination of manually driven and battery-operated components which make it ideal for electricity-scarce remote areas. Single-use containers are designed to prevent exposure of healthcare provider and patients to potentially infected samples and cross-contamination of samples during testing. The process is tracked and recorded, end to end, to minimise errors in the test conduction. The benchmark for new diagnostic devices in rural India is usability and reach in remote low-resource areas. Thus, this paper also discusses comparison of MycoKit with existing devices and methods. It is seen that designing a device from the perspective of a user at the grassroot level is more efficient than converting sophisticated technologies from their perspective as an afterthought. Equipping the community with such devices can ensure that diseases like TB, that go unnoticed and unnotified, be diagnosed and treated.

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A. Chakrabarti et al. (eds.), *Design for Tomorrow–Volume 3*,
Smart Innovation, Systems and Technologies 223,
https://doi.org/10.1007/978-981-16-0084-5_53

53.1 Introduction

The past century has witnessed an advancement in medical device innovation, credited to the cutting-edge inventions in science and technology. Conventionally, the focus has solely been on accuracy and performance. This was, however, questioned in the recent decades, when the success of the device was also attributed to its reach and usability. To this effect design, human-factors engineering and ergonomics played a crucial role in improving user and patient experience. Today, this user-centric toolkit of a designer, powered by interdisciplinary creative thinking, is creating disruptive innovations, which in certain areas, surpasses technological advancements [2].

In India, the rural areas pose a unique challenge in terms of availability of healthcare resources as well as support infrastructure. By understanding rural user, the parameters of diagnostics may be narrowed down to meet their unique set of challenges. So far, for TB, remote areas have only received a lower, watered-down version of highly sophisticated devices designed for premium healthcare facilities.

This paper explores these notions by rethinking medical diagnosis for tuberculosis (TB) and designing a device implementing insights from user experience from the get go, rather than as an afterthought.

Pulmonary TB is an airborne disease of the lungs that spreads easily by inhaling disease-causing bacteria suspended in the air. It is fatal in itself, and with comorbidities, it severely degrades the immune system. TB treatment called Directly Observed Treatment, Short-course (DOTS) is fairly simple to execute and takes about 5–6 months of medication for completion. Reference [5] Despite it, at 26,90,000 incidences in 2018, India shares a significant portion of the global TB burden with roughly 7,00,000 undiagnosed cases. Yet, this is only the tip of the iceberg.

The TB bacteria may exist in a person without causing TB disease (Latent TB). People with latent TB exhibit no symptoms. About 1/3 of the world is said to have latent TB, out of which 5–10% would develop TB disease and lead to complications in situation of comorbidities. Reference [3] There is a dire need to address missed cases as well as to screen potential cases in order to reduce the disease burden.

In the course of research, a number of issues ranging from the nature of disease, infrastructure in rural areas, shortage of healthcare professions and incompatible diagnostic devices were identified.

This paper discusses an early diagnostic kit that can reduce the disease burden. A device which is easy to use and accessible to non-professional healthcare providers can make TB diagnosis accessible to every patient.

53.2 Methodology

To ascertain the significance of product design in medical device innovation, an extensive research was conducted which pointed towards the necessity to design medical design based on user and patient needs. Simultaneously, it was identified that the root cause of TB disease burden was missed diagnosis. As we looked deeper, our primary area of focus became, 'how can we make TB diagnosis more accessible to people in remote areas?'

We conducted our design research as follows:

- Literature review and inputs from domain experts to get acquainted with the disease, how it spreads and commonly used diagnostic methods and devices,
- Two weeks immersion in Tilonia and Harmara in Rajasthan and Seoli, Jakhauli and Jhundpur in Haryana, to study the diagnostic and systemic challenges in Indian villages,
- Observation of challenges faced by laboratory technicians and patients in the urban and rural healthcare setups such as hospitals, collection centres and small pathology laboratories.

Further literature research established technical process to be followed, i.e., Polymerase Chain Reaction (PCR) followed by its simplification and translation to hardware requirements and design concept generation for each tactical element. With further iterations, a final design for each component was ascertained and prototyped. Ergonomic and functional viability was improved by generating proof of concepts using rapid prototyping techniques such as FDM printing, wood and paper modelling. Parts that demanded precision and endurance were prototyped by thermoforming, lathe operations and TIG welding. The design was then physically resized to accommodate all parts while ensuring portability. Simultaneously, the user interface and experience were refined. The usage was then validated by domain experts.

53.3 Insights from Design Research

Traditionally, product design is used to reinforce functions of a medical device by adding user-friendly components to it. For rural areas, watered-down versions of these high-end devices often prove ineffective due to their incompatibility with available supporting resources. Alternatively, a vast set of literature suggests that in order to create devices that may be easily and correctly used by intended users, it is essential to factor in the unique systemic parameters and user experience when establishing the systemic constraints, technological guidelines and design parameters, right from the beginning of device development.

An excellent example of user-centric product development is the Foldscope—the paper microscope at par with standard benchtop microscope costing under $1. Reference [11] It was developed to replace expensive and fragile high precision microscopes, by combining optical physics with the principles of origami. Another example is Gritt's Leveraged Freedom Chair (LFC) concept designed for rural areas. A fresh and relevant set of constraints led to a model, which utilises user abilities to replace the most complex part of the machine. Both these examples illustrate that a focus shift from scientific constraints to systemic requirements can create a revolutionary alternative better suited to emerging markets [8].

Upon research, the following factors were identified as significant contributors to undiagnosed TB cases in rural areas:

– There is a scarcity of Primary Health Centres (PHC) in areas with low population density with only one PHC in 165 km^2 area or more. Coupled with an absence of roads and motorised transportation, formal healthcare is inaccessible to remote dwellers. Less than 30% of qualified consulting doctors reside in semi-rural or rural areas for about 70% of India's population. Reference [1] Consequently, people rely on word of mouth and home remedies for a disease like TB, which is often confused with flu, making it go undiagnosed and unnotified. References [7, 14] A vast network of roughly 2.5 million community health workers (CHW) such as Accredited Social Health Activists (ASHA) and Auxiliary Nurse Midwife (ANM) are the first point of contact for medical care in these communities forming a vital link to areas where medical centres and highly qualified professionals are difficult to reach. CHW are literate individuals, chosen from their community and given a brief and specific training to perform basic health check-up and encourage healthy living [9].
– On studying currently available TB diagnostics, it was found that most of the tests are dependent on skill of healthcare professional and high-end infrastructure, for both testing and result interpretation (Table 53.1). They require a clean working environment, and sample purity and risk of exposure is highly dependent on the performance of healthcare provider [12–14].

53.4 Results

This paper presents the design of a TB diagnostic kit, called MycoKit, developed upon translation of aforementioned insights into an actionable brief.

53.4.1 MycoKit

MycoKit has been designed to equip the key user, the CHW, with a portable tool that could provide a quick and early diagnosis at point of care (PoC) with easily interpretable results, such as a TB positive/TB negative response.

Owing to the high specificity, sensitivity and quick turnover time, a pre-established protocol of PCR was adopted to identify the presence of Mycobacterium-TB in the sputum of the test taker.

MycoKit consists of a processing unit, supporting single-use disposables and a dedicated Mobile App (Fig. 53.1). Six tests can be performed simultaneously, in one

Table 53.1 TB diagnostics [15]

Diagnostic test/characteristic	What is it?	Result turnaround time	When can the test be taken (and when not)?	Sensitivity/specificity	Testing/infrastructural requirements
Interferon-Gamma Release Assay	Infected white blood cells in blood release (IFN-g) when mixed with antigens derived from M. TB	24 h	Confirmatory latent/active TB (does not distinguish)	90%/95%	Sample collection on-site 2+ visits needed Bench instruments, refrigeration required Healthcare professional needed to conduct test and interpret result
Tuberculin skin test	Tuberculin purified protein derivative (PPD) is injected into the inner surface of the forearm, and the size of induration is measured	72 h	Screening latent/active TB (affected by BCG vaccination)	80%/60–90% dependent on BCG administration	Point of care testing No visit to PHC required Refrigeration of PPD essential ANM may be trained to conduct test and interpret result
Xpert MTB/RIF assay	Nucleic acid amplification (NAA) sputum sample is collected and prepared, and the rest of the process is fully automated	2 h	Confirmatory after disease progresses	94%/98%	Sample collection on-site 2 + visits needed Bench instruments, refrigeration required Healthcare professional needed to conduct test and interpret result

(continued)

Table 53.1 (continued)

Diagnostic test/characteristic	What is it?	Result turnaround time	When can the test be taken (and when not)?	Sensitivity/specificity	Testing/infrastructural requirements
Sputum smear microscopy	Sputum sample is stained, and the targeted bacteria, now stained, is observed under the microscope	24 h	Confirmatory after disease progresses	50–60%/97–99%	Sample collection on-site 2 + visits needed Bench instruments required Healthcare professional needed to conduct test and interpret result
TB culture	Sputum sample is incubated to grow bacteria on different substances	4–8 weeks	Confirmatory after disease progresses		Sample collection on-site 2 + visits needed Bench instruments, refrigeration required Healthcare professional needed to conduct test and interpret result
X-ray	Lung imaging	1 h	Confirmatory after disease progresses	90%/65%	Imaging done at healthcare setup 1 visit needed Imaging equipment required Healthcare professional needed to conduct test and interpret result

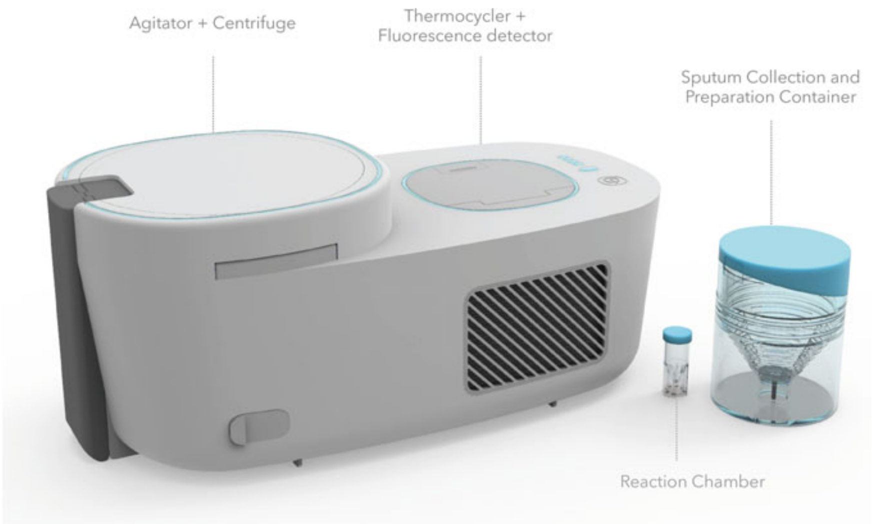

Fig. 53.1 Components of MycoKit

cycle, and four such cycles on one charge of battery. Figure 53.2 illustrates how the test is to be conducted by the user and machine, in parallel.

The Processing Unit

The processing unit has a footprint within an A4 and consists of a combination of a manually driven agitator and centrifuge, and a mini PCR. The former uses a planetary gear and spring mechanism to achieve high torque-to-speed ratio, thus enabling user to hand crank 6, 2 mL samples at as high as 5000 RPM, in ideal conditions. Iterations were made to position and shape the handle of the hand crank for maximum efficiency and ease of usage. The latter is a battery-powered mini thermocycler with fluorescence detector.

The two sections of processing unit are covered by vastly distinct lids equipped with indicators and electronic locks to encourage the right action and prevent the wrong ones. Clear indicators for device on/off, Bluetooth connectivity and battery life have been provided for effective and unambiguous indication (Fig. 53.1)

Disposables

A set of two single-use disposables are to be used in succession and to hold the sample in complete containment. The first, called sputum collection and preparation container (SCC), is used to collect a sputum sample and to prepare it for steps to follow (Fig. 53.3b). The second, called the reaction chamber (RC), holds the sample in processing unit, while creating a physical interface between sample and machine, without hampering the test or sample within (Fig. 53.3a).

Both these disposables hold pre-measured reagents to be used before and during test procedure. Provision of self-healing rubber and incorporation of vacuum vials

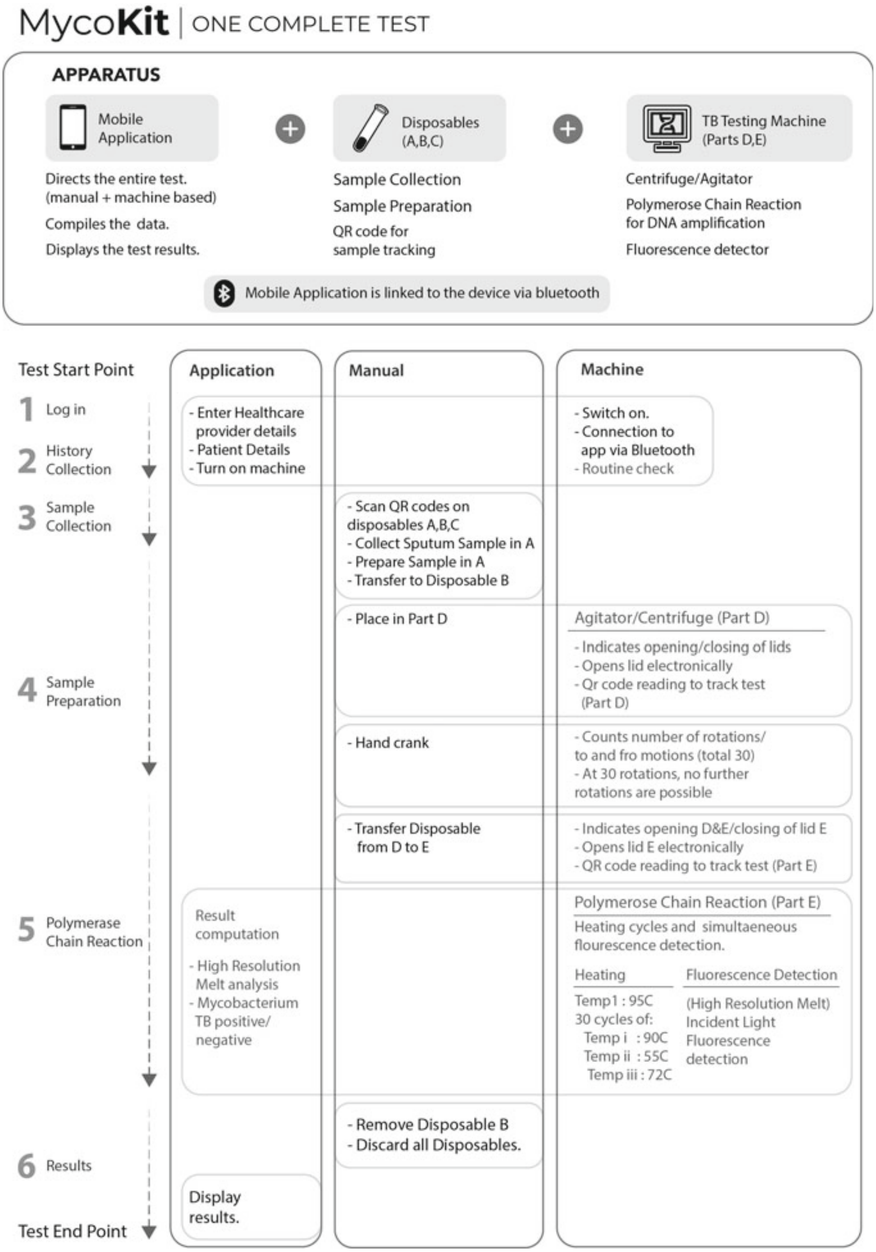

Fig. 53.2 Steps to be done and corresponding response of the device in the course of one complete test

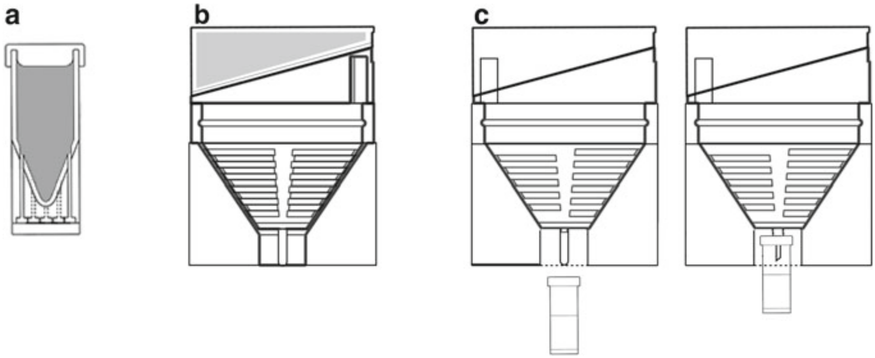

Fig. 53.3 **a** Reaction chamber, **b** sputum collection container, **c** leak-proof transfer of sample

ensure perfectly leak-proof transfer of measured amounts of sample solution from one to the other, when the process demands it (Fig. 53.3c). The design incorporates mechanically driven mechanisms internally, such as to release reagent, to filter out sputum from spit and to transfer solution from centrifuge friendly vial to PCR friendly microwells.

User Interface
The complete process is navigated and controlled by a dedicated app, called the MycoKitApp. The app tracks the ongoing test through checkpoints and error announcement and works as a dashboard for quick access to test results, patient history, system status, platform to give feedback and alert for errors. Controls between the app and the device have been mapped straight-forwardly.

53.5 Discussion

WHO's global TB strategy aims to reduce TB deaths by 95% and to cut new cases by 90% between 2015 and 2035. Aligning with these goals, MycoKit is a portable, early TB diagnostic kit, designed to equip members within communities to easily detect TB at doorstep, thereby improving notification of the disease [5].

Given the process-driven nature of PCR testing, numerous design considerations were made during the course of development, such as to navigate through lack of resources in remote rural areas, to ensure safety of patient and user, sample purity and to ensure instructions are followed correctly.

Traditionally, machines used for PCR diagnostics require a power line. In MycoKit, however, power-intensive tasks have been accomplished by utilising human abilities without leaving any scope of human errors/comprise on correctness of the task done. For example, the centrifuge is hand cranked, thereby reducing burden on battery. Management of fluid is done via cleverly designed single-use disposables. Also, the kit has been designed to conduct six tests in roughly two hours as that is enough for low population density areas. Power requirements for running such a small volume are low and can be met by a small li-polymer battery, without compromising on the portability of the device [6].

When employing human abilities to perform tasks, potential sources of mistakes have been identified and checks have been placed to prevent them. For instance, to ensure the right amount of centrifugation, the number of rotations is counted by an electronic counter. The handle is electronically released only when it has to be used. Thus, the decision to start or stop hand cranking the device is predetermined.

The disposables have been designed cleverly, enabling HCW to do all the work with laboratory like precision without exposure to hazardous substances. While handling, measuring and adding precise amounts of reagent, ensuring safety is a complex task in PCR and is one of the most frequent sources of error in laboratories. To simplify this, reagent for each sample is stored within the assigned sample collection container, and mechanisms have been designed to release this reagent, internally, without requiring human intervention, which is a sharp contrast to laboratory testing. Fluid handling throughout the device is executed in a smooth, clean and uninterrupted manner (Fig. 53.4a, b).

By design, a complete isolation of sample has been achieved for biohazardous containment at every step to eliminate potential sources of exposure to HCW, patients and cross-contamination of samples, as well as to ensure sample purity and device cleanliness. As electronic screens encourage touching, the HCW is required to use

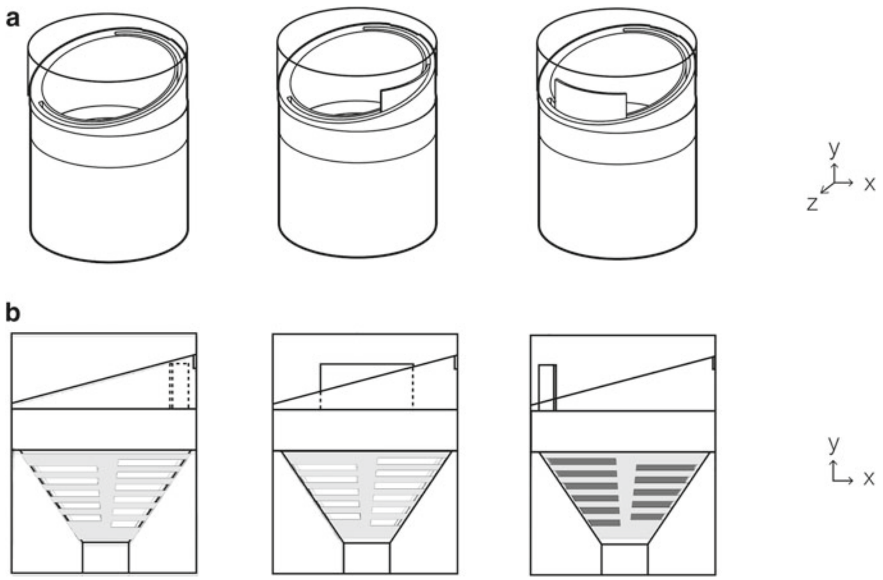

Fig. 53.4 **a** Mechanism to hold and release reagent internally, **b** upon one rotation about *y*-axis, sputum/spit separation is immediately followed by release of reagent

the MycoKitApp on a dedicated mobile function as a dashboard for all operations during the testing.

These design decisions also bring down the manufacturing cost of the kit as compared to those requiring expensive electro-mechanical system.

Care has been taken to avoid panic-inducing signifiers. The diagnostic kit discussed in this paper employs a simple, user-friendly, unambiguous system. Good communication and feedback between the machine and user which are key to creating an error-free interface. Thus, significance has been given to heuristics, signifiers and affordances. Also, instead of relying solely on the training of CHW, various checkpoint acknowledgment is expected before proceeding to the next step [10].

Given the nature of the job, repetitive tasks can easily be overlooked in case of distractions leading to carelessness and errors, and thus, HFE has been applied to minimise unintended device effects and assist users to do the 'right thing' and harder to do the 'wrong thing'.

Thus, by designing features that encourage optimum action and strongly inhibit any undesirable action, the shortcomings of laboratory-based testing as well as fully automated testing have been addressed. The working has been simplified while paying utmost attention to user experience and their safety as well as strict adherence to protocol/instructions.

53.6 Conclusion

This paper states a user-centric approach to design a TB diagnostic kit for greater reach in remote rural areas. The design process addresses user and systemic challenges right from the initial development phase, unlike medical innovation which typically prioritises technology over user experience, which is applied later as an afterthought.

Upon design research, it was found that remote rural areas have a shortage of PHC and healthcare providers with adequate know-how to use available medical devices and equipment, if any. An absence of supporting infrastructure such as electricity and transportation makes these facilities inaccessible.

It was identified that community health workers form a vital link between people and formal healthcare setups. The trust in them is an invaluable asset to convey the urgency and need that accompanies a referral to the hospital. By equipping CHWs with a portable, user-friendly tool, it is possible to widen the reach of TB diagnostics [13]. MycoKit, TB diagnostic kit that has been presented in this paper, is portable and battery operated and would enable CHWs to take the diagnostic capacity of a high-end laboratory to the doorstep of rural households.

Diseases that were once considered life threatening are now easily treatable due to the advent of antibiotics. Various rapid testing measures have also been devised. Despite rapid advancements, lack of accessibility to said advancements is a major contributor to TB burden and needs to be addressed. Diagnostic devices must be developed with the aim to reach the grass root level and make an impact to communities that are worst hit.

This paper emphasises that the success of a device also needs to be determined by its reach and usability. Medical devices, despite all their technological complexities, need a design which is user friendly for widespread benefits. Instead of pinning the device's success on the human's ability to use it correctly, devices need to be designed keeping user ability at the centre. With no compromise on the quality, these changes need to be at par with testing capabilities of well-equipped laboratories currently only available in large metropolitan cities.

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Chapter 54
Role of Age in Perceiving Car's Attractiveness—A Case Study in Indian Context

Jetti Rahul and Debyan Dhar

Abstract Cars were means of luxury till the late '90s, but now they have become a common need (Soltani in Transp Res Part A Policy Pract 96:90–100, [1]), which led to increase in car production. In the process of developing and selling cars, form and functionality both become mature over a period of time. These comprehensive varieties of car designs have provided an opportunity for customers to choose a car to their liking at their affordance. Usually personality and financial status influence the car purchase behaviour, but barely we know the effect of age on car selection. Literature highlights a significant number of studies that have focused on evaluation of car form that specifically investigated its perception among a target group. However, there have been very few studies that focused on the role of age and its effect on perceived attractiveness of a car. The study reported in this paper presents an ethnographic investigation along with a small experiment to identify and observe the role of age in influencing perceived car attractiveness. A total of 166 persons who own a car and are from the age group of 18–60 years have been interviewed in the study. A detailed qualitative report was generated from the interviews, and it was analysed to draw insights. Results acquired from both the qualitative and quantitative studies highlight that age affects the perceived attractiveness of cars. Further, design cues were extracted to develop a prescriptive framework suggesting motifs that influence a particular age group. The study results would be particularly helpful for automotive designers as they can correlate design motifs and cues with particular age groups, and thus, it would support them in taking informed design decisions to optimise the design process.

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A. Chakrabarti et al. (eds.), *Design for Tomorrow–Volume 3*,
Smart Innovation, Systems and Technologies 223,
https://doi.org/10.1007/978-981-16-0084-5_54

54.1 Introduction

Products sale in any segment is defined by how they can satisfy the consumer needs. There was a time where the functionality and usability of a product were the most important factors in making consumer purchase decision [2, 3]. However, it changed with the markets needs due to the increased car usage. This increased utility of cars led to an increase in the number of cars which target a specific market segment of consumers [4]. Most of the cars that target a single market segment have similar functionality that corresponds with their varying exterior forms [5]. This kind of alternatives perplexes consumers' needs and emotions into the product manufacturing process that became inevitable. However, understanding the behavioural aspects is most challenging, due to the behavioural complexity. To deal with this challenge, we need to understand how consumers perceive the world.

This study aims to understand the elements that cause form attraction and also to define some generalised factors which can generate a winsome product form in the Indian context.

54.2 Background Study

54.2.1 Product Form Attraction

AIDA is one of the models to define consumer purchase behaviour. It is a four-step model consisting of attention, interest, desire and action [5]. Attention factor in AIDA was also supported by a Norman's visceral characteristics [6]. Visceral characteristics are animalistic instincts which solely is instigated by form. Sundar et al. [7] stated that aesthetic forms of products were identified to make the consumers believe that they are more functional comparatively.

In India, passenger cars are the most sellable type of cars [8]. Passenger cars which target a market segment are similar in functionality leaving form aspect, which varies with every model. Chang proposed that any product form attraction originates from its aesthetic feeling, novelty and fashion, identity suitability, apparent function and symbolity [5]. As per Chang's model, most of the form perception is dependent on cultural aspects.

54.2.2 Culture and Demographics

Culture is a progressive factor which can define the personal and social values through one's worldly interactions. It is also hereditary factor that can be transferred from one person to another [9]. Bachrach stated that culture and demographic entities might look disjoint, but they are correlational [10]. Demographics may not clearly define culture; however, identification of cultural influencers and their impacts can be clearly observed. Demirbilek and Sener [11] states that even perception towards a product is susceptible to cultural changes of a person through interaction with the demographic elements surrounding them.

54.2.3 Demographics and Indian Context of Owning a Car

Demographic data is a combination of socio-economic factors like age, gender, employment status, household income, household type and size. However, in all of these, 20–30 years age grouped people with postgraduate education level are most influenced to own car in India. This age group is always considered the most influential group on car buying decision as they are more mobile. However, there are influencers like family, friends who affect the purchase decision [12]. In most of the literature, this age group is predominantly studied to discover car form's preferences [5, 13].

Product form as discussed previously is clearly affected by demographics. Likewise, car's form is also affected by demographics. Majority of the literatures have focused on factors other than age variance and change of car's form perception. These two factors were found to be the least studied, and age is mostly considered as a control variable [1, 14–17].

54.2.4 Perception of Consumers and Designers

Perception of a consumer's may be different from the designer's due to the difference in cultural aspects. This makes us understand the need for making a bridge in this newfound gap. In closing the gap, emotional perceptions of consumers and designers need to be integrated to form design cues for a new product. The consumers' emotions can be collected in the form of words, attitude and behaviour [13]. The easiest and suitable method for collecting a large amount of data is collecting opinions through words. Later, they will be treated statistically to create a Kansei structure. Further, the observed data is introduced to a new domain and designing a new Kansei product [18].

Research Gap: There is a shortage of literature regarding the emotional perception of exterior form with respect to all age groups.

Objective

(1) To make a group of motifs which can represent a set of consumer' and designer' form perceptions.
(2) To make a framework from motifs identified, which can suggest design cues in making a car form which can influence a particular age group.

(3) To identify the variation of perception among all age groups, which can help us identify whether they are significant to define market segment preference.

54.3 Materials and Methods

Perceptions of a consumer may be different from the designer's due to the difference in cultural aspects. This makes us understand the need for making a bridge in this newfound gap.

54.3.1 Identification of Kansei Words

In this study, 2020s most aspiring cars of Indian and Japanese manufacturers were considered to create a set of adjective words which defines form perception. The selected five cars are Maruti Swift, Mahindra Bolero BS6, Hyundai Creta, Hyundai Elite I20 and Nano. Further, five more cars were added from all top branded concept cars, they are Benz Vision AVTR, Audi AI-CON, Volkswagen ID-Vizzion and Maruti Suzuki Futuro-E.

After the selection of cars, those ten were shown to a group of ten people and asked to select two cars, each one from top five cars and concept cars. Later, participants were asked reason for selecting those choices. The consumer group's responses were all collected to form 139 adjective words. Further, affinity mapping is conducted with eight people, five are from consumers, and other three are from designers. Affinity mapping was used to stack all the adjectives into separate groups by these eight participants. The group of words were named according to the property they possessed. These properties include both hard and soft functionality elements [19].

The identified motifs from the adjectives are smooth, rough, feminine, sharp, masculine, fragile, volatile, pleasant, vintage and futuristic as given in Table 54.1.

Forms can have contrast adjective pairs which can coexist at different sections. Therefore, in this study, contrast pairs like feminine–masculine are not used to prevent data loss. The motifs identified are directly made into a questionnaire and circulated in social-networking sites.

This study followed all the steps shown in Fig. 54.1 excluding the development of a new product, i.e., phase 6, which also involves connecting emotional perceptions to physical properties.

Table 54.1 Adjective words

Smooth					
Aerodynamic	Regular	Glassy	Undeviating	Effortless	Polished
Unbroken	Fluid	Flawless	Frictionless		
Rough					
Abrasive	Bumpy	Coarse	Harsh	Rocky	Rugged
Ridged	Ruffled	Wrinkled	Bony		
Feminine					
Gorgeous	Elegant	Soft	Stunning	Cool	Exquisite
Curvy	Graceful	Tender	Faired	Clean	Cosy
Doughy	Lustrous				
Sharp					
Acute	Pointed	Razor-sharp	Stinging	Agile	Keen
Tapering	Edged	Horned	Jagged	Pronged	
Masculine					
Enduring	Hard	Forceful	Tenacious	Vigorous	Secure
Committed	Stout	Muscular	Dense	Sturdy	Impenetrable
Forceful	Mighty	Expansive	Sculpted	Resistant	Rigid
Robust	Braced	Proud	Diplomatic		
Fragile					
Delicate	Petite	Cute	Light	Small	Mild
Flexible	Plastic	Mouldable	Fancy		
Volatile					

(continued)

Table 54.1 (continued)

Striking	Beastly	Eccentric	Twisted	Unpredictable	Impulsive
Destructive	Explosive	Intangible	Indestructible	Changeable	Adjustable
Instable	Sparkling	Playful	Energetic	Animated	Mercurial
Smoky					
Pleasant					
Serene	Habituating	Comfortable	Impressible	Soothing	Agreeable
Charming	Relaxed	Cheerful	Delightful	Engaging	Appealing
Likable	Lovely	Nourishing			
Vintage					
Primitive	Original	Ancient	Classic	Complex	Venerable
Antiqued	Exemplary	Prototypical	Prime	Renowned	Undying
Conservative	Symbolic	Human-faced	Royal		
Futuristic					
Innovative	Inventive	Advanced	Electric	Simplistic	Surrealistic
Graphical	Modern	Pioneering	Progressive	Revolutionary	Unconventional

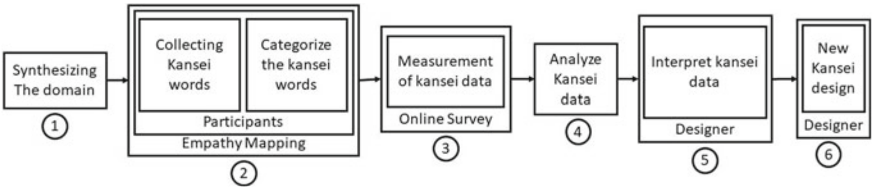

Fig. 54.1 Adopted from Kansei product development process collaborated by Kansei engineer (Researcher) [18]

54.3.2 Questionnaire

The questionnaire was designed into a total of three sections:

(1) The study reported in this paper focused on attractiveness of four-wheelers. The study was conducted in age range of 18–60 years. We have considered this age range because 18 is the least and 60 years is the maximum age which according to India's Regional Transport Office rules are allowed holding a legitimate license. Later, the age range is further classified into different age groups 18–24, 25–29, 30–40, 41–50 and 51–60. Participants were asked to specify their place along with age, to identify whether the sample is equally distributed all over India. These age groups were adopted from an experiment related to product and emotions of a person [15].

(2) Second section is about finding a preferable **type of car**. Preferable car type will be one of the design direction while generating the car's exterior form.

(3) Third section is used to find what kind of group labels/motifs will form to be a design cue. The identified motifs were utilized along with a five-point semantic differential scale. The antonym pair on both ends of the scale used are 'least preferable and most preferable' where least = 1 and most = 5. In the questionnaire, these factors were represented by a collage of car images, to make common people understand the perception of participants present during affinity mapping stage.

54.4 Results

Initially, pilot testing was done with 30 participants using questionnaire. The instrument consists of ten group labels (motifs) given in Table 54.1. Reliability of the instrument is found to be high using Cronbach's alpha that is 0.905, and significance of 0.000.

Table 54.2 Demographic data_age

Age				
18–24 years	25–29 years	30–40 years	41–50 years	51–60 years
57	56	28	12	13

54.4.1 Demographic Data

Using literature as a reference, the age groups were divided into 18–24, 25–29, 30–40, 41–50 and 51–60. However, groups 41–50 and 51–60 have significantly less data; they are combined into a single group 41–60 which comprises of 25 respondents as given in Table 54.2. The regions participants were identified to be well distributed all over India, showing the low external threat in taking age as variable.

For all the age groups, **Sedan** is the most preferred ones, and the other cars preferred are **Hatchback**, **CUV** and **SUV**.

54.4.2 Emotional Perception Assessment Results

54.4.2.1 Factor Analysis with Age Group's Data

Reliability of the instrument consisting of the ten group labels/motifs was defined through value of Cronbach's alpha. Later, the factor analysis is done using principal component analysis, and oblique rotation is used, especially Varimax. The test can be further studied to find the factor loading and the factors identified, and this is clearly evident in Table 54.3 [20].

As the study aims to find the design cues for all age groups, factor analysis has to be done individually.

54.5 Discussion

Sample size of 166 was considered to conduct a study. Factor analysis was utilized to identify the design cues for each age group using the motifs. Factor 1: pleasant, futuristic, volatile and vintage, and Factor 2: masculine, smooth and fragile are extracted using factor analysis as given in Table 54.3. The factors are combination of variables which are marked bold in Table 54.3, and the major variables in each factor are identified and made by prioritizing the factor loading values defined. The two factors identified for the total age.

Groups contribute around 67.824% of variance in features. Among the two factors, Factor 1 has the highest variance which defines most of the form elements. Similarly, factors for all age groups were identified as given in Tables 54.4, 54.5, 54.6 and

Table 54.3 Post-rotation factor loading_all age combined

Component	Factor 1 (Royal roadster)	Factor 2 (Pangolin)
Pleasant	**0.857**	0.209
Fututristic	**0.815**	0.155
Volatile	**0.745**	−0.021
Vintage	**0.611**	0.419
Sharp	**0.580**	0.329
Feminine	**0.579**	0.448
Masculine	−0.168	**0.834**
Smooth	0.273	**0.687**
Fragile	0.419	**0.601**
Rough	0.276	0.490
Eigen value	3.355	2.323
KMO (Kaiser–Meyer–Olkin)	0.803	
Cronbach's alpha	0.848	

Table 54.4 Post-rotation factor loading_age group 18–24

Component	Factor 1 (Royal roadster)	Factor 2 (Meteorite)	Factor 3 (Snow)
Pleasant	**0.609**	0.162	0.550
Vintage	**0.648**	0.363	0.200
Volatile	**0.869**	0.090	0.146
Futuristic	**0.878**	0.053	0.152
Fragile	0.225	0.330	**0.576**
Smooth	0.394	−0.164	**0.658**
Masculine	0.070	**0.876**	0.119
Sharp	0.027	**0.775**	0.301
Rough	0.243	**0.667**	−0.155
Feminine	0.051	0.109	**0.885**
Eigen value	2.589	2.128	2.065
KMO (Kaiser–Meyer–Olkin)	0.745		
Cronbach's alpha	0.825		

54.7. Later, the factors were labelled by some entity, which can help us to iterate the exterior form. The factors from Table 54.3 are named Royal roadster and Pangolin to represent the characteristics of Factor 1 and Factor 2, respectively. Characteristics can be further implemented into forms through connotative and denotative understanding of a designer. Let us assume the case of factor named Pangolin; the car features will be an iteration of the animal Pangolin's characteristics. The desired

Table 54.5 Post-rotation factor loading_age group 25–29

Component	Factor 1 (Angel)	Factor 2 (Spear)	Factor 3 (Lady bug)
Pleasant	**0.867**	0.254	0.030
Futuristic	**0.844**	0.010	0.025
Volatile	**0.692**	0.261	0.126
Vintage	**0.557**	0.128	0.500
Smooth	**0.757**	−0.064	0.101
Sharp	0.491	**0.580**	0.012
Feminine	0.454	0.219	**0.349**
Masculine	0.320	**0.723**	−0.003
Rough	−0.209	**0.859**	0.155
Fragile	0.012	0.021	**0.938**
Eigen value	3.419	1.799	1.303
KMO (Kaiser–Meyer–Olkin)	0.722		
Cronbach's alpha	0.801		

Table 54.6 Post-rotation factor loading_age group 30–40

Component	Factor 1 (Humanoid)	Factor 2 (Royal Dagger)	Factor 3 (Hammer)	Factor 4 (Pudding)
Smooth	0.547	−0.337	−0.123	**0.628**
Rough	−0.135	0.237	**0.874**	0.194
Feminine	−0.062	0.199	0.246	**0.833**
Sharp	−0.174	**0.785**	0.143	0.010
Masculine	0.381	−0.092	**0.815**	0.033
Fragile	0.359	0.442	0.073	0.623
Volatile	**0.723**	0.369	0.258	0.031
Pleasant	**0.799**	−0.004	−0.028	0.073
Vintage	0.208	**0.785**	−0.030	0.234
Futuristic	**0.894**	−0.092	0.093	0.139
Eigen value	2.628	1.791	1.607	1.596
KMO (Kaiser–Meyer–Olkin)	0.504			
Cronbach's alpha	0.757			

form can look discontinuous on closer observation; however, on the whole, it looks very aerodynamic and strong. Similarly, all the other labels can be used to generate the respective car forms.

Table 54.7 Post-rotation factor loading_age group 41–60

Component	Factor 1 (Yin-Yang)	Factor 2 (Med Needle)	Factor 3 (Mud Pot)
Pleasant	**0.962**	0.125	0.070
Futuristic	**0.722**	0.519	0.136
Feminine	**0.697**	0.177	0.590
Masculine	**0.676**	0.382	0.062
Volatile	0.056	**0.889**	0.256
Vintage	0.432	**0.800**	0.102
Sharp	0.313	**0.739**	0.191
Rough	−0.026	0.337	**0.843**
Fragile	0.123	0.517	**0.794**
Smooth	0.521	−0.295	**0.693**
Eigen value	5.258	1.510	1.350
KMO (Kaiser–Meyer–Olkin)	0.652		
Cronbach's alpha	0.892		

54.6 Conclusion

Kansei engineering was utilized in this study to integrate consumers' and designers' emotional perceptions to develop car forms. The ten motifs adopted were scrutinized and were found non-identical among themselves and varied significantly. This variance an important correlation between user's age and perception of car's form. This finding is unique because almost no studies in the context of car form perception by end users have ever reported this. The motifs highlighted in this study may provide designers with a perspective to design novel car forms. The study carried out acts as a guide for designers to innovate their own way of extracting and generalizing preferences in a most efficient manner.

The study results should be interpreted cautiously as responses were low particularly from the age groups of 41–50 and 51–60, and hence, results should not be generalized. It is suggested that the outcomes of the study if and when required to be referred for any design activity, should be validated particularly by the motifs through a participatory approach.

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Chapter 55
From Industrial Design to Healthcare Innovation—A Comparative Study on the Role of User-Centered Design and Stanford Biodesign Process

Neelarnab Dutta and Debayan Dhar

Abstract User-centered design (UCD) process is a comprehensive and widely accepted methodology practiced by designers across numerous areas of specializations like product design, user experience design, interaction design, web design etc. The central philosophy of this approach is to empathize with the user at various design decisions in order to fulfill user requirements. Like UCD approach, the Stanford Biodesign process is also an accepted and widely used framework specifically for health technology innovation. UCD philosophy and the Stanford Biodesign process both lay strong emphasis on deep understanding of user(s) and stakeholders as their basis for focused ideation and development. However, health technology innovation brings additional challenges and constraints in its course of design and development, which not only require to satisfy user requirements but also clinical and demographic requirements for successful healthcare implementation. This paper discloses such challenges of health technology design and development and synthesizes the requirements that need to be considered in a design methodology. Later, based on these requirements the paper compared both Stanford Biodesign process and UCD process in terms of methodological effectiveness for highly sensitive healthcare innovation. The paper also highlights issues where UCD approach fails to address some of the requirements for healthcare innovation and suggests additional contexts and stages to be considered by a UCD practitioner as an easy adaptation for healthcare design projects.

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A. Chakrabarti et al. (eds.), *Design for Tomorrow–Volume 3*,
Smart Innovation, Systems and Technologies 223,
https://doi.org/10.1007/978-981-16-0084-5_55

55.1 Introduction

Design methodologies have been well accepted in the design community as practice, framework, philosophy, and discipline in delineating the overall design and innovation activities in an optimal way. Among various widely known design methodologies, UCD approach has been more comprehensive, widely accepted and practiced in various areas of design like product design, user experience design, interaction design, web design etc. [1]. Regardless of how one defines, modify or extend UCD framework, the central philosophy remains the same, i.e., users at the center of various design decisions and activities [1, 2]. Today UCD methodology and philosophy have been used as a basis for design pedagogies and have been widely accepted in the industrial design practices.

Within the frame of reference of design methodologies, another key contribution was in the field of biomedical design with the introduction of "Biodesign innovation process" (also known as "Biodesign process") from Stanford University, USA, in year 2000. The Stanford Biodesign innovation process is considered as the foundation of systematic methodological approach to healthcare innovation. The process lays strong emphasis on deep understanding of user, stakeholders, and clinical unmet needs as ground for healthcare innovation and development [6, 7].

Although both UCD and biodesign process share certain philosophical and methodological similarities, they differ in underlying approaches and activities as the latter is more instrumentalize to deal with healthcare-related design problems. The context of health technology innovation brings in additional challenges and constraints due to criticality in nature of the problems, risks involved, dependency of healthcare delivery system, clinical practices, quality compliances, regulatory barriers, etc. [6]. This paper discloses such challenges and constraints of health technology design and development which are typically unknown to a UCD practitioner. Various methodological requirements are synthesized as a common ground for a detail comparative analysis of the UCD and the biodesign process in order to evaluate their effectiveness in addressing such challenges and constraints. This paper further provides insights into the intricate detail of some of the considerations and activities that a trained UCD practitioner can consider to ensure successful design intervention in healthcare design and innovation. The following section defines the two design methodologies in terms of their phases, processes, and activities.

55.2 Defining User-Centered Design and Biodesign Process

Design frameworks and systematic approach to design have been in practice not only to streamline the process of design and innovation but also to increases the chances of commercial success to a higher extent. User-centered design and biodesign process are two such widely practiced frameworks. These frameworks are discussed below:

55.2.1 User-Centered Design

The central approach of the UCD process can be divided into three phases broadly: design research phase, design phase, and design evaluation phase [1]. Although some literatures and industrial practitioners define the UCD process with higher number of stages, they share the same central approach and set of activities [2–5]. The three phases of UCD process are reported below:

Design research phase. The goal of design research phase is to identify need, understand the context of use, and to specify user requirements. Following are some of the key activities that are holistically practiced.

(a) *Planning for design research,* where the designer identifies users and stakeholders by knowing business or design goals and make necessary decisions about ways of conducting user or stakeholder research.
(b) *Conducting Design Research,* where the designer identifies user or stakeholder requirements via various contextual inquiry methods such as user interview, shadowing and observing user sufferings, conducting background research as needed on the subject matter from literature, assessing competitors' work, etc. Such informations are stored and mapped in ways that is easy to retrieve and follow.
(c) *Analyzing Design Research,* where the designer performs need or requirement analysis using various analytical techniques such as debriefing with the UCD team, listing early guesses, key findings, key recommendations, mapping and clustering the data and noting trends on similar needs or requirements.
(d) *Reporting on Design Research,* via various deliverables such as requirement specification, written report of findings and recommendations, presentation, persona creation, process flow, usability test plan etc.

Design phase. The design phase involves ideation, conceptualization, and concept realization-related activities, in order to address various requirements as specified in the design research phase. UCD process-related literatures do not emphasize much on how practitioners tactically bring research findings to the design process [1]; however, over the year's researchers have come up with various ideation, mapping tools and techniques to support this phase of UCD process which are widely available in design literature and practice. The key deliverables in this phase are ideas, concepts, wireframes, process flows, low fidelity prototypes, etc.

Design evaluation phase. Evaluating the design in an UCD philosophy typically involves testing it for usability. Usability includes measuring user experience by collecting, analyzing, and presenting usability metrics for various concepts and prototypes generated in the design phase. Beyond formal usability testing, other design evaluation techniques include use of expert reviews, concept evaluation matrices, etc. The key deliverables in this phase are usability test plan and usability test report [1].

55.2.2 Biodesign Process

An important component of biodesign process is focused attention on needs finding and characterization, which differs from the traditional "tech-push" model in healthcare innovation [7]. Biodesign process comprises of three phases which are strategized to support health technology innovation and successful implementation [6, 8].

Identify phase. This phase emphasizes on identifying and characterizing clinical needs before stepping toward inventing a solution. Innovators undergo deep clinical immersion at various healthcare facilities to identify problems about specific disease state, treatment and preventive measures, issues in healthcare delivery, patient pain points, etc. [8]. Later, a pool of need statements is articulated which encapsulates the identified clinical problems, the specific population of concern, and measurable outcome of potential solutions. Next, a need selection process is carried out to identify best workable needs by considering various factors like clinical impact of the need, degree of understanding of pathophysiology, a consideration of existing and emerging clinical approaches, preliminary assessment of the market potential, etc. A set of need criteria is made on selected needs. Typically, there are 3 to 6 "must-have" criteria and a similar number of "nice-to-have" criteria [7]. Clinicians play a key role at this stage because their ability to comprehend pathophysiology and clinical intervention.

Invent phase. The invent phase involves design-thinking process for ideation. Several team-based brainstorming sessions are conducted with expertise from both engineering, design and medicine background. The team generate multiple possible solutions for each need generated during identify phase [8]. A designer plays a vital role in realizing and rendering concepts by connecting ideas, thought processes of the team, technologies and clinical practices. Next, a second screening process is applied with a goal of filtering concepts. The filters in this phase include intellectual property (IP) scope, likely regulatory pathway, reimbursement potential, technical feasibility, viability of the business model needed to bring the solution to patients [7], etc. Next, serious prototyping of the top concepts are carried out to conduct usability study. User feedback and expert opinion play important role in final concepts selection. The invent phase of biodesign process is not a linear process. It is highly constrained between generated set of need criteria and implementation phase challenges. So often this phase gets iterated several times to arrive at optimal solution for successful implementation.

Implement phase. In this phase, the top 1 or 2 concepts that got selected after rigorous filtering process undergone further research for commercialization and development. This phase assures sustainability and successful implementation of the solution to meet the unmet need. In-depth analysis of each concept is carried out which includes understanding of the IP landscape, planning for credible reimbursement pathway, understanding of the engineering feasibility, and resource requirements to undergo further research and development. At this stage, the designer takes necessary actions for design optimization and sometimes iterates activities of invent phase if necessary. A detailed plan for device testing is devised, including pre-clinical and clinical trials [7]. The next set of activities requires product safety evaluation from authorized facility, collaboration with healthcare professional and institute for clinical efficacy study and planning for regulatory clearance and certifications. Once again, the design goes for final tweak if necessary to meet clinical or regulatory requirements. Once the design got approved for implementation further activities necessary for commercialization is carried out which include design for manufacturing, business planning, manufacturing strategy planning, pilot production, understanding sales and distribution channels, financial modeling, formulating funding, marketing strategy, creating a value proposition [7, 8] etc.

Though both UCD and biodesign process have certain similarities in their underlying phases, processes, and activities, the central differences lie in: extent of design-thinking process applied, factors that need to be considered during design phase and related activities that each methodology provide for successful design implementation. Before we can compare the two methodologies and evaluate their effectiveness for healthcare design, it is important to understand the methodological aid or requirement a health technology design and innovation project demand in order to address specific challenges and constraints in its course of design and development. The following section reveals the nature of healthcare problem and related issues.

55.3 Challenges and Constraints in Health Technology Innovation and Implementation

Healthcare technology innovation and implementation bring additional challenges and constraints than generic product design and development. Following such issues are derived based on various available case studies and literature report [6, 9–16].

55.3.1 Multifactorial Nature of Healthcare Problems

The context of healthcare problem is not only clinical but multifactorial that includes socioeconomic, demographic, and healthcare infrastructure-related dependencies, which are not always visible at the surface level. As shown in Fig. 55.1, healthcare problem identification and requirement analysis demand deep clinical immersion at various tiers of healthcare for thorough understanding of clinical gaps and opportunities, issues in disease management, healthcare stakeholder's requirements, infrastructure issues, patient pain points, socioeconomic barriers, and healthcare delivery systemic challenges.

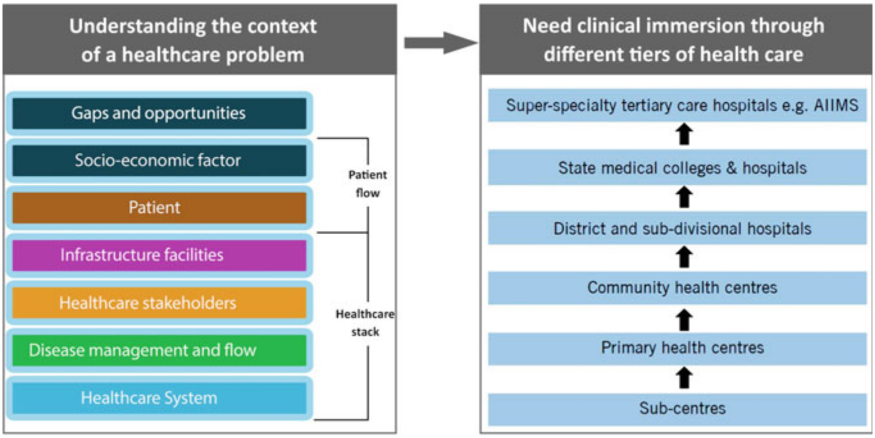

Fig. 55.1 Multifactorial nature of healthcare problems

55.3.2 *Complex Nature of Disease States, Bio-mechanisms, and Pathophysiology*

Synthesizing solution for a clinical problem needs thorough understanding of disease states, involved bio-mechanism, pathophysiology, and clinical practice, which are complex to understand for someone from non-clinical background as represented in Fig. 55.2. Health technology innovation needs designing and developing solutions within the constraints of clinical practices, treatment options, pathophysiological understandings, technology and healthcare delivery challenges.

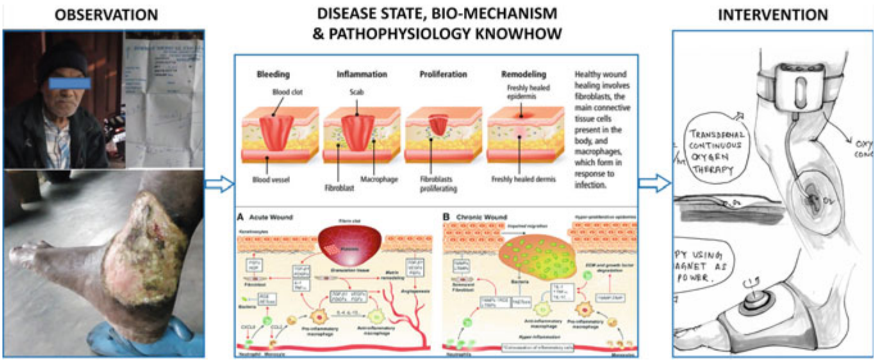

Fig. 55.2 Complex nature of disease states, bio-mechanisms, and pathophysiology [17, 18]

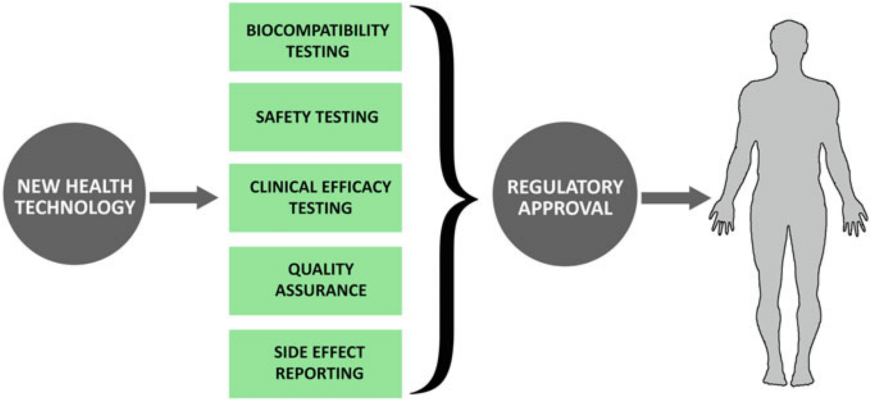

Fig. 55.3 Critical nature of intervention, biocompatibility, and patient interaction

55.3.3 Critical Nature of Clinical Intervention in Terms of Biocompatibility and Patient Interaction

Implementation of an innovative health technology needs validation for patient safety and solution efficacy. This is due to critical nature of a healthcare problem. Depending on the classification of device and degree of patient interactions, health technology design and development process require strategies for product safety testing, quality control, clinical validation, and regulatory clearance. Figure 55.3 reports various requirements for getting healthcare technology market ready.

55.3.4 Entry Barriers and Indigenization Issues to Bring a Solution into Market

Successful health technology implementation requires prior strategies for commercialization as well as time and money in its course of design and development. Yet there exist certain entry barriers for new health technology implementation like capturing new market share, disrupting current clinical practice, providing competitive advantages, intellectual property protection etc. which often needs to be planned properly since design and development phase. Successful commercialization of innovative health technology requires strategies for intellectual property management, competitive analysis and value proposition, R&D planning, production planning, technology licensing, funding, business planning, sales, marketing and distribution planning, etc.

Addressing above challenges and constraints in health technology design and development process are vital for successful implementation. Following a systematic design methodology should aid in delineating the overall design and development

Table 55.1 Healthcare innovation and implementation challenges and requirements for methodological aid

Challenges and constraints of healthcare innovation and implementation	Requirements for methodological aid
A. Multifactorial nature of healthcare problems	To strategize for: • Conducting healthcare centric research • Unmet clinical gap identification and selection • Deriving user and stakeholder requirements
B. Complex nature of disease state, bio-mechanisms and pathophysiology	To strategize for: • Capturing clinical contexts, mapping requirements and synthesizing design solutions • Concept selection
C. Critical nature of clinical intervention in terms of biocompatibility and patient interaction	To strategize for product safety testing, quality control, clinical validation, and regulatory clearance
D. Entry barriers and indigenization issues to bring a solution into market	To strategize for successful health technology implementation by overcoming entry barriers and commercialization challenges

process along with fulfilling the requirements to address such challenges. Table 55.1 depicts the reported healthcare innovation and implementation challenges in tabular format. In order to address such challenges and constraints, a set of requirements are formulated to be considered as desired methodological aid.

The following section will consider above requirements to compare and evaluate the methodological effectiveness of UCD and biodesign process in the context of healthcare design and development.

55.4 Comparing UCD Versus Biodesign

Both UCD and biodesign process come under common frame of reference, i.e., "design methodologies for product design and innovation." The two structured processes corroborate some of the central philosophy of user centeredness but they differ in, the extent the two methodologies address challenges of health technology innovation and implementation. Table 55.2 reports these differences based on previously identified requirements for methodological aid in Sect. 55.3.

Above comparison reveals that the biodesign process has methodological effectiveness over the UCD process in the application areas of healthcare design and development. The following section discusses these points in more detail.

Table 55.2 Comparison of biodesign and UCD process against methodological aid requirements

Requirements for methodological aid	Biodesign process	User-centered design process
1. To strategize for conducting healthcare centric research	The process provides roadmap for conducting healthcare-centric research to understand healthcare delivery-related context and constraints. Various contextual enquiry methods like clinical immersion, field research techniques are part of the process	The process provides a generic roadmap for user or stakeholder research
2. To strategize for unmet clinical gap identification and selection	The process involves identification of set of unmet healthcare needs after contextual enquiry on the problem statement or strategic focus area. This is followed by need selection process by doing detail research on disease state, pathophysiology, treatment options, stakeholder requirements, healthcare delivery challenges, etc.	The process typically starts with specific business goal or predefined problem statement
3. To strategize for deriving user and stakeholder requirements	The process helps in deriving user and stakeholder requirements (called need criterions)	Similarly, UCD process also helps in deriving user and stakeholder requirements
4. To strategize for capturing clinical contexts, mapping requirements and synthesizing design solutions	The process emphasizes on multidisciplinary team work, use of various ideation, mapping tools and techniques to tactically bring research findings to design solution	Similarly, UCD process also emphasizes on multidisciplinary team work, use of various ideation, mapping tools and techniques to tactically bring research findings to design solution
5. To strategize for concept selection	The process suggests certain health technology evaluation metrics which considers factors like intellectual property opportunity, regulatory ease, business potential, technical feasibility, team feasibility, stakeholder feedback etc. for concept selection. There is dependency on implementation phase's challenges in concept selection process	UCD process emphasizes on usability testing for concept selection, i.e., measuring user experience by collecting, analyzing, and presenting usability metrics for various concepts and prototypes generated in the design phase

(continued)

Table 55.2 (continued)

Requirements for methodological aid	Biodesign process	User-centered design process
6. To strategize for product safety testing, quality control, clinical validation and regulatory clearance	The process ensures solution efficacy and safety by planning for bench testing, safety testing and certification, quality control strategy, clinical validation strategy, regulatory strategy	Not part of UCD process
7. To strategize for successful health technology implementation by overcoming entry barriers and commercialization challenges	The process ensures successful health technology implementation by carrying out activities like design for manufacturing, business planning, manufacturing strategy planning, understanding sales and distribution channels, financial modeling, formulating funding, marketing strategy, creating a value proposition, etc	Not part of UCD process

55.5 Discussion and Proposal for Consideration

UCD practitioners coming from industrial design background often lack information on challenges and constraints of health technology innovation and implementation as discussed in Sect. 55.3. The comparisons made at Sect. 55.4 reveal that the UCD process provides a generic roadmap for user or stakeholder research. It is efficient in identifying need, understanding the context of use and in specifying user requirements when a specific business goal or problem statement is given. However, industrial designer aspiring for health technology innovation need to investigate healthcare delivery-related context and constraints as defined in the biodesign process. The designer should acquire detail knowledge on disease state, pathophysiology, treatment options, stakeholder requirements, healthcare delivery challenges, etc., before need identification and selection. This needs deep clinical immersion and field research. The UCD process lacks such contextual enquiry activities. The requirement analysis and design phase of both UCD and biodesign process share similarities in underlying activities. However, concept selection in biodesign process not only consider testing for usability but also consider certain factors like intellectual property opportunity, regulatory ease, business potential, technical feasibility, team feasibility, stakeholder feedback etc. for filtering. Again, biodesign process ensures health technology implementation demands such as design validation for patient safety, clinical efficacy, and strategic planning for successful market reach and commercial sustainability. These set of activities need some sort of roadmap to

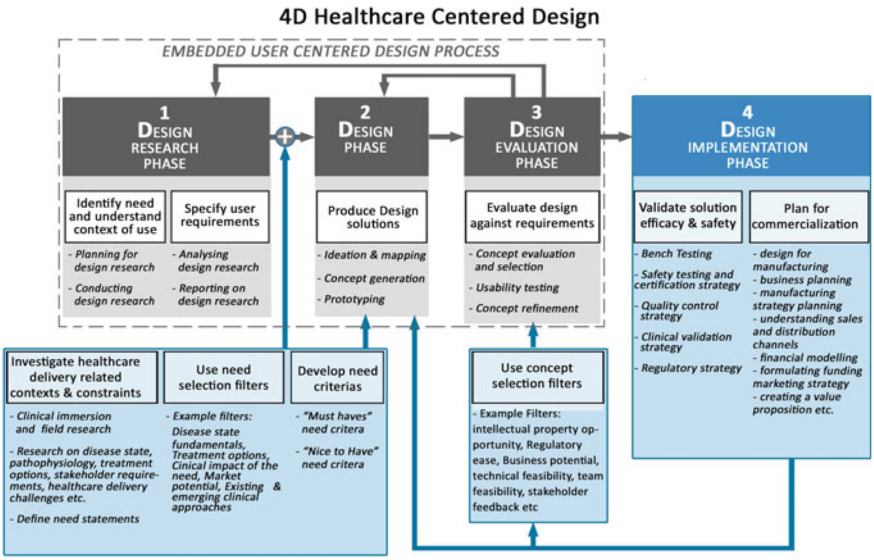

Fig. 55.4 Healthcare-centered design (HCD) framework

delineate the overall design and development process which is beyond the scope of standard UCD practice.

For user-centered designers, design for healthcare innovation without knowledge of biodesign process is a challenging task. The above comparative analysis helps us in understanding where the two processes corroborate and where the biodesign process extends the UCD process. Based on this theoretical critical analysis, additional contexts and stages can be considered by a UCD practitioner as an easy adaptation for healthcare design projects. Figure 55.4 depicts a *"Healthcare-Centered Design (HCD)"* framework which is an easy adaptation over standard UCD process flow for healthcare design projects having additional activities and phases to be considered by a UCD practitioner. These additional activities and phases are formulated based on shortfalls of the UCD process found in the comparative analysis done in this paper. As shown in Fig. 55.4, an UCD framework is well embedded within the proposed HCD framework. Additional activities related to healthcare delivery related contextual research, need selection and need criteria development is proposed after the "*Design Research*" phase of UCD process, i.e., after user or stakeholder enquiry. Execution of these activities will also have influence in the "*Design*" phase of UCD process. Again, concept selection filters specific to healthcare design is proposed at the "*Design Evaluation*" phase apart from usability study. A completely new phase "*Design Implementation*" phase is proposed to ensure solution validation and commercialization planning-related activities.

Similar to biodesign process this framework is optimized to address challenges and constraints of health technology innovation and implementation as an easy adaptation over the UCD framework.

55.6 Conclusion

User-centered design is a widely accepted framework based on which industrial designers practice design and innovation. Unfortunately, in specific situations like healthcare innovation, UCD approach fails to address some of the complexities and contexts of health technology innovation and as such the biodesign process developed by Stanford University is often adopted by innovators. In order to analyze this issue, this paper makes a comparative analysis between UCD and biodesign process and proposes a modified framework named "*Healthcare-Centered Design*" which is an extension of UCD but with additional factors catering to address challenges and constraints in health technology innovation and implementation. This new framework proposed in this paper can be adopted by practicing industrial designers and design students easily without going through the journey of learning biodesign framework. Thus, adopting the new framework would ensure addressing of critical factors of healthcare innovation which UCD failed to cater and thereby would ensure success of UC designers in healthcare innovation. The "*Healthcare-Centered Design (HCD)*" framework proposed here has been an outcome of a theoretical critical analysis of research literatures. It would be interesting to observe an experimental validation of the two processes—UCD versus HCD when used by practicing designers. It is envisaged that the proposed framework would go a long way in addressing projects specifically in the area healthcare innovation by industrial designers trained in UCD approach.

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Chapter 56
Design of a Heart Perfusion Device for Extending Preservation Time: A Case Study of Risk Management for a High-Risk Medical Device

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Abstract An estimated 50,000 people in India need a heart transplant annually. Today, one of the biggest challenges is practical: moving organs from one hospital to another. LifeBox is a device that addresses this problem with a system that extends preservation time of the heart, specifically to allow for increased travel time and distances. It utilizes non-recirculating, intermittent perfusion of non-oxygenated, cardioplegic solution in hypothermic conditions. Preservation conditions of the donor heart directly affect heart health and patient survival. Consequently, the design of the device presents a unique set of risks that must be adequately identified and addressed. This work presents a case study, using LifeBox that captures the adopted risk management approach. Emphasis has been laid on the pathway to derive requirements that attempt to manage the identified risks. The authors hope that this study will serve as a practical guide for designers, practitioners and innovators in the medical device industry.

56.1 Introduction

India has seen a steady increase in the number of transplants undertaken annually, (300 since 2016—a tenfold increase compared to pre-2015) [11]. Despite this, a staggering 50,000 people are in need each year [11]. Institutional factors aside, the inability to move hearts from the donor to recipient is a major hindrance to bridging this gap [11]. Extending ex-vivo viable time of the heart is key to addressing this. Commercially viable preservation devices have been developed that attempt to do

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A. Chakrabarti et al. (eds.), *Design for Tomorrow–Volume 3*,
Smart Innovation, Systems and Technologies 223,
https://doi.org/10.1007/978-981-16-0084-5_56

so, using different techniques [14]. LifeBox utilizes non-recirculating, intermittent perfusion of non-oxygenated, cardioplegic solution in hypothermic conditions to extend ex-vivo viable time [3–17]. Additional efforts have been invested on minimization of power consumption and weight, to allow for an eventual vision of UAV-based transport. This presents a complex engineering challenge.

Even so, as with any medical device, it is important to adopt a patient safety-centric approach, as opposed to a technology-driven one. This puts risk management at the fore [6]. While a risk-free device is not deemed possible, performing systemic analysis of possible risks associated with device use significantly reduces probable harm to the user [9].

56.2 Research Background and Objective

Prior literature has shown that the global frequency of errors pertaining to medical devices remains high [8, 3]. Proactive identification and management of risks via prospective hazard analysis (PHA) methods are a key pathway of addressing this [7]. Several PHA methods, including failure mode effect analysis (FMEA), systematic human error reduction and prediction approach (SHERPA) and structured what-if technique (SWIFT), have been explored in the literature [18]. Potts et al. [19] have showed overlap between requirements generated by SWIFT and FMEA, concluding that a comprehensive approach with multiple data sources is needed to obtain a comprehensive view of risk within the system. Healthcare settings, in contrast, have been very slow and staggered in their adoption of PHA methods [12]. Such settings have traditionally relied on a reactive approach, comprising of error and incident reporting [18, 8]. However, there is very little evidence of a significant reduction in probable patient harm via this strategy [19]. Simsekler et al. [12] have proposed a risk identification framework (RID) which attempts to leverage the strengths of different reactive and proactive inputs, to evolve a comprehensive risk view within a systems approach.

While there has been a significant increase in the number of studies to accelerate improvement in patient safety since the seminal report 'To Err is Human: Building a Safer Health System' [2], there has not been a corresponding improvement in the availability of practical guidelines to do so, specifically with regard to identification and management of risks. Much of the literature focuses on new analysis frameworks, with insufficient resources pertaining to their implementation [16].

The objective of this paper is to address this gap by presenting a case study, wherein the RID framework put forth by Simsekler et al. [12] has been adopted to identify risks, which are then managed and assessed for the design of a high-risk medical device, specifically a heart preservation device.

56.3 Methodology and Approach

An overview of the adopted approach is provided in Fig. 56.1. It begins with an intake of input from multiple sources which are then collated and subsequently managed by deriving requirements that either negate or reduce the probability of occurrence/impact of the risk. There are four broad categories of input which familiarize the designer with the system, allowing him/her to subsequently identify risks: system description, possible sources of risk, nature of the hazard and the time of hazard occurrence. The identification is then done via brainstorming, safety walkabouts. Such workplace walkabouts are typically beneficial when undertaken by stakeholders within the system, who are familiar with existing settings and processes. Clinical immersion, wherein designers delve into a specific clinical area by direct immersion in relevant inpatient, outpatient settings has been shown to be vital and immensely helpful in needs finding [4]. We extend the scope of this immersion to risk identification. As part of this immersion exercise, designers observed clinical settings and spoke with specialists, clinicians within the field.

Each identified risk is then logged as shown in Tables 56.4, 56.5, 56.6 and 56.7 within the Appendix. Subsequently, management pathways for these risks were brainstormed, and requirements of these pathways were derived. Outcomes of the identification and management activities were then assessed and consolidated into a risk management report.

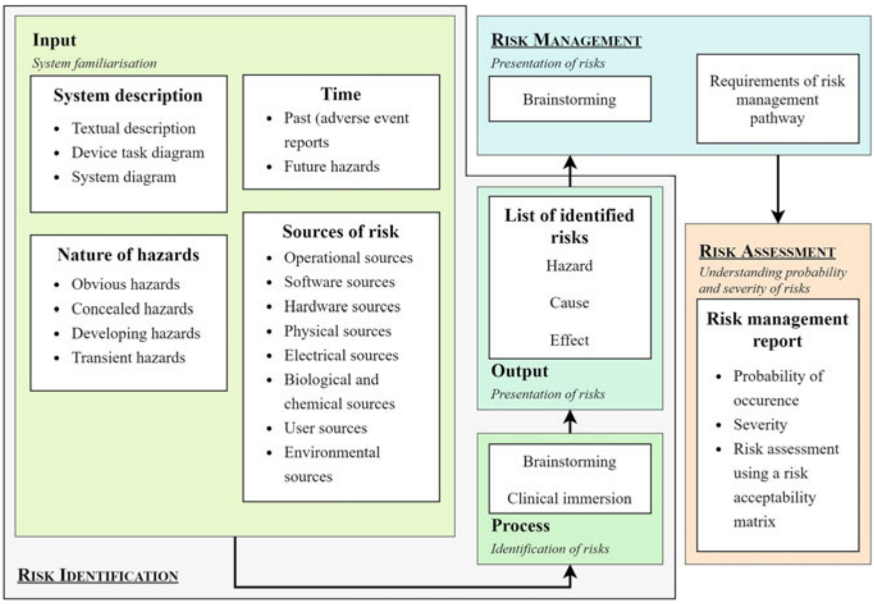

Fig. 56.1 Adopted risk identification, management and assessment approach. RID framework adopted from Simsekler et al. [12]

The identification exercise is expected to be undertaken when the top-level device concept and scope have been defined. Requirements derived from risk management allow designers to detail out the concept and serve as an input to the embodiment design stage. The risk management report is a live document which is periodically updated by designers as the concept/embodiment is further developed.

A system scope and subsystem descriptions were generated via literature study and an analysis of existing devices. The following is a sample description:

> The perfusion, cooling subsystems and other peripherals form the core set and are controlled by the primary controller. This is connected to the human–machine interface (HMI) controller and the datalogger over a communication bus. The HMI controller manages user interfacing tasks and networking requirements, whereas the primary controller executes tasks pertaining the core set.

A system diagram comprising of major subsystems which address key functionalities expected of the system was drawn up. Example risks identified (and the corresponding management pathway) via these inputs are given in Table 56.4.

A device task diagram which lists key device activities and the corresponding user interactions served as an input to brainstorming of potential risks. These activities and interactions were defined as part of the clinical immersion process. Sample outcomes from this exercise are listed in Table 56.4.

Identification of risks based on their source was undertaken using the categorization used by Zhang [15], as opposed to the one used by Simsekler [12] since it was found to be relevant and suitable for this particular device. Probable hazardous situations and their primary cause were first identified, followed by any contributing factors that could lead to occurrence of the primary cause. Requirements to manage/address these contributing factors were then brainstormed. Excerpts of the outcome are listed in Table 56.5, with some of the hazardous situations listed in Table 56.1.

Monitoring a heart transport for transplant is a logistical challenge and can potentially be an impediment/distraction for the clinician when external parties are present during such a time-critical activity. In lieu of this, clinical immersion was limited to interaction with a transplant surgeon and other auxiliary clinicians. The output of this activity was an in depth understanding of the current protocols and processes, which was then used to brainstorm potential risks which were of a different nature (obvious/concealed/developing/transient). Excerpts of the outcome are listed in Table 56.6.

Risks with a time component were looked at from two points of views: past (what has gone wrong before?) and future (what can go wrong due to change?). A study

Table 56.1 Hazardous situations

Hazard ID	Potential hazard
1.2	Underdose: the heart receives less perfusion fluid than stipulated
2.2	Temperature of heart is above the designated value
3.1	Sterility of the heart/heart chamber is not maintained

of existing commercial heart preservation devices approved by regulatory agencies revealed no field safety notices or medical device alerts had been issued [20]. In lieu of this, medical device reports (MDRs) from the FDA MAUDE (manufacturer and user facility device experience) database [10], for an analogous ex-vivo kidney preservation device was looked up. Management pathways were then brainstormed to address the adverse event reported in the MDR, and any other potential future risks that may arise. Sample outcomes from this exercise are listed in Table 56.7.

56.4 Results

The outcomes of risk identification and management exercises were then collated into a risk management report (RMR) as shown in Table 56.3. The RMR consolidates identified risks from different inputs and their corresponding probability of occurrence and severity. Each risk was then assessed based on a risk acceptability matrix as shown in Table 56.2, and a corresponding risk management strategy was also identified (avoidance/mitigation/transfer/acceptance/contingency). The outcomes of preceding risk identification and management steps have been provided in Tables 56.4, 56.5, 56.6 and 56.7.

Table 56.2 Simplified risk acceptability matrix

Probability / Severity	**Negligible**	**Serious**	**Critical**
Improbable			
Occasional			
Frequent			

Table 56.3 Risk management report

HS source category	Risk Description			CF risk impact	Probability of occurrence	Risk assessment	Risk response strategy	Requirement(s) of risk management pathway	Current status
	Primary cause	Hazardous Situation	Contributing factor (CF)						
Textual description	Corrupted data communication between hardware controller and processor	1.2, 2.2	Communication error	Serious	Occasional		Contingency	The communication protocol shall discard the data and request it again in case there is a mismatch in checksum	
			Insufficient insulation in device	Serious	Improbable		Mitigation	The box shall be insulated to retain temperature for an external variation of x degree Celsius	
Operational	Condensation on electronics	1.2, 2.2, 3.1	High relative humidity	Serious	Occasional		Mitigation	A pod containing x quantity of desiccant shall be used to passively absorb excess moisture within the device	
							Contingency	The device shall notify the user if humidity inside the device goes out of the range x - y%	

56.5 Discussions and Conclusion

The adopted RID framework was used to identify risks from multiple sources and obtain a comprehensive risk view [12]. While a substantive set of risks were identified, it cannot be claimed that all possible risks have been taken into account. As has been pointed out in literature [12], risk identification is a never-ending process and designers must decide to appropriately balance identification, management and assessment activities.

The RMR consolidates identified risks from different inputs, and their corresponding probability of occurrence and severity. The outcome of the RMR exercise provides the designer with a rundown of potential risks and allows identification of risks which have the maximum impact on device safety. Designers may choose to brainstorm additional management pathways for such risks. It must be pointed out that organizations/designers often adopt different approaches to risk assessment and management catering to their specific needs, and the RMR approach/format provided here is one of many ways this can be undertaken. The outcomes listed in Tables 56.4, 56.5, 56.6 and 56.7 are excerpts from the actual exercise, and no claims are made with regard to them being exhaustive/novel. It is important to view them with this consideration. The authors hope this study will serve as a practical guide for designers, practitioners and innovators in the medical device industry, particularly novice users.

Acknowledgements The authors would like to thank Mrs. Aseema Padhi for her review of the risk management report and other relevant items.

Appendix

See Tables 56.4, 56.5, 56.6 and 56.7.

Table 56.4 Outcome of risk identification and management based on system description

No	Source type	Hazardous situation	Potential cause	Potential effect	Requirement(s) of risk management pathway
1	Device task diagram	1.2, 2.2	User touches the input units of the device accidentally	Unintentional changes on device settings or device states	Key device settings shall be protected by a PIN to prevent unauthorized or accidental changes

(continued)

Table 56.4 (continued)

No	Source type	Hazardous situation	Potential cause	Potential effect	Requirement(s) of risk management pathway
					The touch screen shall be automatically shut off after x min of inactivity to prevent accidental touch events
2	Textual description	1.2, 2.2	Random noise or loose contact	Communication error	The communication packet format shall have a checksum value to verify integrity
					In case of a mismatch in checksum, the data is discarded and requested again

Table 56.5 Outcome of risk identification and management based on sources of risk

No	Source	Primary cause	Hazardous situation	Contributing factor	Requirement(s) of risk management pathway
1	Operational	Perfusion fluid reservoir becomes empty during fluid delivery	1.2	Leak in fluid reservoir or tubing [15]	The connections of the tubing shall withstand a pressure of at least x Pa
					The device shall notify the user of an issue, if the tubing pressure drops by more than x mm Hg
					Any unwarranted change in perfusion fluid volume shall be detected, and the user shall be alerted of the same

(continued)

Table 56.5 (continued)

No	Source	Primary cause	Hazardous situation	Contributing factor	Requirement(s) of risk management pathway
2	Operational	Condensation on electronics	1.2, 2.2	Insufficient insulation in device	The box shall be insulated to retain temperature for an external variation of *x* degree Celsius
				High relative humidity	A pod containing *x* quantity of desiccant shall be used to passively absorb excess moisture within the device
					The device shall notify the user if humidity inside the device goes out of the range *x*–*y*%
3	Software	Overshoot or undershoot of organ temperature	2.2	Communication error with blower driver	When a blower suspension command is issued, the encoder feedback shall be checked within x milliseconds to verify that the blower has stopped
					When the blower has not stopped after a suspend command has been issued, power to the blower shall be interrupted via redundant circuitry and an alarm will be raised
4	Software	Wrong value set for perfusion	1.2	User entered wrong value [15]	The value entered by the user is checked to be within a pre-defined range, if not, values are discarded, and the user is prompted to re-enter the correct value

(continued)

Table 56.5 (continued)

No	Source	Primary cause	Hazardous situation	Contributing factor	Requirement(s) of risk management pathway
					The software shall have provision for affirmation, confirmation and acceptance by the user to clear, change or reset any device setting
				User input not received [15]	If the user has not interacted with the device for *x* minutes during setup, the device shall signal a notification and discard all parameters the user has entered
				Memory device failure or error	Error correcting code (ECC) memory shall be used to detect and correct single bit errors
5	Hardware	Broken perfusion fluid reservoir	1.2, 3.1	Damage from stress	The perfusion fluid reservoir shall be protected with an enclosure
6	Physical	Fluid/humidity ingress into the device	1.2	High humidity inside the box	A pod containing at least *x* grams of desiccant shall be used to passively absorb excess moisture in the air
					The electronic systems shall be protected from fluids with a conformal coating
					The device shall notify the user if humidity inside the device goes beyond *x*%

(continued)

Table 56.5 (continued)

No	Source	Primary cause	Hazardous situation	Contributing factor	Requirement(s) of risk management pathway
				Perfusion fluid leakage	The tubing shall be chosen to withstand a pressure of at least x mm Hg
					The electronic systems shall be protected from fluids with a conformal coating
					The device shall notify the user of an issue, if the tubing pressure drops by more than x mm Hg
7	Electrical	Blower develops excessive static charge or experiences ESD	2.2	Blower blades rubbing against surrounding surfaces or articles	The blower shall be mounted with an enclosure of thickness at least x mm
8	Biological	Fluid delivery path contaminated with pathogens	3.1	Pathogen build-up on device due to improper sterilization method	User manual shall detail out sterilization protocols for each transport
				Pump is connected to non-sterile perfusion tubing	All components that need to be biologically sterile for transport shall be biocompatible, and designated single use and disposable
9	Biological	Heart perfusion site infection	3.1	User fails to correctly connect the tubing to the heart	Components shall be mounted with quick-mount mechanisms, selected/designed to minimize time
					User manual shall detail out connection protocols

(continued)

Table 56.5 (continued)

No	Source	Primary cause	Hazardous situation	Contributing factor	Requirement(s) of risk management pathway
				Improper seal of heart container allows pathogens to enter	All components that need to be biologically sterile for transport shall be biocompatible, and designated single use and disposable
10	User	User is incapable of using the device or configuring	1.2, 2.2	User is not sufficiently trained to operate the device	The user interface shall have a simple intuitive design, validated by stakeholders
11	User	User fills the perfusion fluid reservoir with wrong fluid	3.1	User is not sufficiently trained to operate the device	The device shall identify the perfusion fluid reservoir through an RFID tag, and inform the user if an incorrect reservoir is used
					The user manual shall detail out the procedure to mount the perfusion fluid reservoir
12	Electrical	Electromagnetic interference	1.1, 1.2	Physical damage to the device or its subassemblies	The device, subassemblies, mounting of components shall be designed to allow it to withstand a drop test of at least 1 m
				Improper manufacturing process	Device manufacturing processes are standardized, and manufacturing undertaken at facilities with GMP certification

(continued)

Table 56.5 (continued)

No	Source	Primary cause	Hazardous situation	Contributing factor	Requirement(s) of risk management pathway
				Failure to reinstall electromagnetic compatibility (EMC) components after service or reinstalling EMC components incorrectly	Device service manual shall detail out all standard operating procedures (SOPs) to be followed by the service personnel
					Service SOPs shall mandate only trained; authorized personnel shall be allowed to undertake service of the device

Table 56.6 Outcome of risk identification and management based on the nature of hazard

No	Nature of hazard	Hazardous situation	Potential cause	Potential effect	Requirement(s) of risk management pathway
1	Obvious hazard	3.1	Improper seal of heart container allows pathogens to enter	Heart perfusion site infection	All components that need to be biologically sterile for transport shall be biocompatible, and designated single use and disposable
2	Obvious hazard	2.2	Dust or small pebbles in the surrounding get trapped in the air path or in the blower	Air path blocked, cooling system failure	The air intake and outlet shall contain appropriate filter(s)
3	Developing hazard	3.1	Components fatigued over time	Leak in heart chamber	Mechanical components shall be designed to function for at least x usage cycles

(continued)

Table 56.6 (continued)

No	Nature of hazard	Hazardous situation	Potential cause	Potential effect	Requirement(s) of risk management pathway
4	Developing hazard	1.2	Device timekeeping drifts gradually [15]	Wrong timing in perfusion interval	RTC shall be chosen with temperature compensation and a drift of less than x second per year
5	Concealed hazard	2.2, 3.1	Excessive vibration from transport	Battery disconnected causing device reset	The system shall have a redundant power supply, with a shift to the redundant power supply in case primary supply has any issues, followed by a user alert

Table 56.7 Outcome of risk identification and management based on time of occurrence

No	Source type	Potential cause	Potential effect	Requirement(s) of risk management pathway
1	Future hazard	Components used become obsolete over time	Difficulty in maintenance and service	Components shall be selected with long term support (at least x years from present time)
3	Past hazard	Unavailable	Perfusion fluid leak causing failure of perfusion system [10]	The connections of the tubing shall withstand a pressure of x Pa
				The device shall notify the user of an issue, if the tubing pressure drops by more than x mm Hg

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Chapter 57
Design and Development of Fiber-Reinforced Polymer Seat Base for Two-Wheelers

Raghu V. Prakash and Monalisha Maharana

Abstract The recent decade has witnessed a tremendous increase of fiber-reinforced polymers as candidate materials for structural applications in automobiles, aimed at reducing the weight of structural components and improving the fuel efficiency. In this study, the seat base of a scooter was selected as a candidate component for weight reduction through replacement of existing material, following a systematic approach based on Ashby's (Materials selection in mechanical design, 4th edn (2011) [1]) material selection chart. A combination of synthetic fibers and natural fibers has been used in developing a seat base of a scooter. In order to arrive at a desirable mechanical performance, hybrid natural fiber composites were chosen as replacement material. The results of the mechanical characterization formed the input to the stress analysis on the component; a non-interactive failure criterion was used to estimate the failure stress of the material. This was further used to arrive at the optimum thickness of the seat base. To verify the proof of concept, a prototype of the seat was made after incorporating design for manufacture principles using the hand layup technique. The fitment check, repeatability of composition as well as stiffness test was also conducted on the prototype sample. This study has provided a weight savings of 40% through the use of hybrid polymer composites.

57.1 Introduction

57.1.1 Background

Automotive sector faces challenges due to the rapidly evolving emission norms and the need to fulfill the customer's expectation of better mileage. One of the methods is to reduce the weight of the components through weight optimization; this however

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A. Chakrabarti et al. (eds.), *Design for Tomorrow–Volume 3*,
Smart Innovation, Systems and Technologies 223,
https://doi.org/10.1007/978-981-16-0084-5_57

has its own limitations. This has prompted Research and Development on the use of alternate lightweight materials. Fiber-reinforced composites, offer the potential solution in view of the higher specific strength and stiffness (per unit density). This study presents the development of a seat base of a scooter using fiber-reinforced hybrid polymer composites, by following a structured approach of identifying the candidate materials based on Michael Ashby's [1] charts.

57.1.2 Challenges

Seat bases are a part of the seat assembly in a vehicle which supports the foam, over which the rider sits on. Seat bases were originally made of sheet metal stampings. Later, with the advent in injection molding technology, they were changed to homogeneous polymers. While this offers considerable weight reduction, there is scope for further weight optimization using engineered materials such as fiber-reinforced composites. Any effort to replace an existing material with a new material requires considerations of stress analysis, design optimization, design for manufacture and assembly. Toward this, identification of a suitable polymer composite material comprising of load bearing fibers (natural as well as synthetic fibers) and the epoxy system that meets the design stress, stiffness requirements is the first step. Mechanical property evaluation of the material under the expected load configuration (such as tension, compression, flexure, fatigue etc.) forms one of the various steps.

Seat assembly in a vehicle is intended not only for supporting the rider's weight, but also contributes to the comfort of the rider. The contour of a seat base is driven by such comfort requirements. Thus, designers have arrived at the allowable parameters, like deflection or nominal stress level by providing ribs/stiffeners on an otherwise mechanically weak polymer seat base. This results in a complicated part shape. This becomes a critical factor in the design of composites as the design for manufacturing of such a complicated shape has to be addressed. Thus, it is evident that the composites cannot be a one-to-one direct replacement for polymer components; it requires a relook into design, manufacturing and mechanical aspects.

This study aims at weight reduction of a scooter seat base through the use of high-performance fiber-reinforced composites. This study presents the method of identifying candidate FRP materials through the use of M. F. Ashby's charts by defining the material indices. Details of geometric modeling, stress analysis of the component with polymer composite material is discussed. Development of a prototype seat-based and its performance evaluation is discussed in the later sections.

57.2 Methodology

57.2.1 Existing Design of Seat Base

The typical seat bases are made up of homogeneous polypropylene (PP) material with an average density of 950 kg/m^3. The current weight of the seat base under consideration is 1170 g. It may be noted that the seat base comprises of several stiffeners to meet the structural requirements, as, polymers have lower strength.

57.2.2 Selection of Candidate Materials

The design requirement for a certain structural component is associated with certain attributes of the materials, such as, density, strength, and cost. Ashby [1] highlights the strategy of material selection into four main groups: (a) Translation of the design requirements, (b) screening of the materials using constraints, (c) ranking of the materials using the objective, and (d) seeking the supporting information. In the chosen problem, both strength and stiffness are important parameters for materials selection.

Figure 57.1 presents the loads acting on the seat and support (load reaction) points of a seat base in a scooter. In order to simplify the approach to select materials, the seat base can be conveniently considered as a flat panel subjected primarily to bending load (Refer Fig. 57.2), which can further be simplified as a beam bending in 1-D. Thus, the design requirements translate into the parameters as explained in Table 57.1.

As thickness of the beam has been considered as the free variable in this case of loading, one could re-arrange Eqs. 57.2 and 57.3 to arrive at the expression for thickness as:

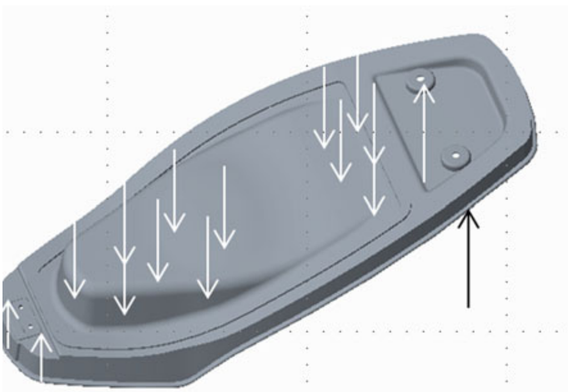


Fig. 57.1 Seat base loading and support points

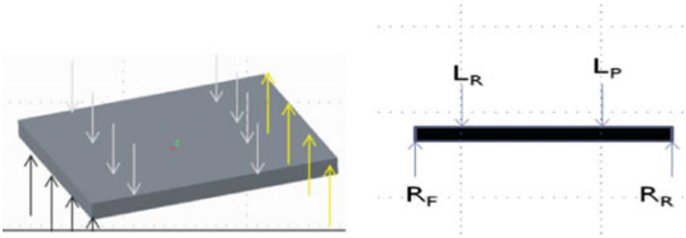


Fig. 57.2 Approximation of seat base as a plate subjected to bending loads and the equivalent schematic load and support L_R = Rider load; L_P = Pillion load, R_R = Reaction by metal support at the front, R_P = Reaction by interfacing part on the rear side

Table 57.1 Parameters for deriving performance indices

Function	Beam bending
Objective	Reduce mass Mass of the beam, $m = A * l * \rho = b * t * L * \rho$ (57.1)
Constraint	Stiffness of the beam, $S = \frac{F}{\delta} = \frac{\mathrm{CEI}}{L^3} = \frac{CEbt^3}{12L^3}$ (57.2) Strength of the beam, $\sigma_f = \frac{6FL}{bt^2}$ (57.3)
Free variable	Thickness of the beam, t

where A is the cross-sectional area of the beam, L is the length of the beam, t is the thickness of the beam, ρ is the density of the beam material, F is the load acting on the beam, b is the width of the beam, δ is the deflection in the beam, C is a constant which depends on the nature of loading (3-point or 4-point), E is Young's modulus of the beam material, and I is the area moment of inertia $\left(I = \frac{bt^3}{12}\right)$

$$t = \left(\frac{12SL^3}{CEb}\right)^{1/3} \quad \langle\text{Stiffness based}\rangle \tag{57.4}$$

$$t = \left(\frac{6FL}{b\sigma_f}\right)^{1/2} \quad \langle\text{Strength based}\rangle \tag{57.5}$$

Thus, substituting the value of thickness of the beam, t in Eq. 57.1, the performance index of the beam, i.e., mass as:

$$m = \left(\frac{12Sb^2}{C}\right)^{1/3} \cdot L^2 \cdot \left(\frac{\rho}{E^{\frac{1}{3}}}\right) \quad \langle\text{Stiffness based}\rangle \tag{57.6}$$

$$m = \left(6Fb^2\right)^{1/2} \cdot L^{3/2} \cdot \left(\frac{\rho}{\sigma_f^{1/2}}\right) \quad \langle\text{Strength based}\rangle \tag{57.7}$$

Thus, for the minimum mass design, one needs to look for materials with maximum value of the following material indices:

$$M1 = \frac{E^{1/3}}{\rho} \quad \langle \text{Stiffness} \rangle \tag{57.8}$$

$$M2 = \frac{\sigma^{1/2}}{\rho} \langle \text{Strength} \rangle \tag{57.9}$$

Material Selection Charts: Ashby's material selection charts present the properties that form the maximizing factors. From the stiffness versus density chart and strength versus density charts [1], it can be inferred that composites have outstanding properties compared to the existing material. Considering other factors, such as impact on environment and cost, hybrid natural fiber composites have been considered as candidate materials.

57.2.3 Selection of Composition of Materials

From the view point of the structural requirements, two classes of fibers were considered for this study: synthetic fibers and natural fibers. The most widely used primary fibers comprise of synthetic fibers such as Glass fiber, Carbon fiber, Aramid® fibers. Synthetic fibers have high strength and stiffness (characteristic of a monolithic polymer), apart from improved the fatigue life, an important criteria to meet the durability requirements of any component design. However, they have certain drawbacks such as high cost, poor recyclability, and non-biodegradability. This has prompted research on the usage of natural fibers, which are potential candidates for secondary structures as they possess low strength. Based on above considerations, hybrid fiber composites comprising of natural fibers and synthetic fibers were considered as the viable option for tailor making to best meet the requirements and eliminating their drawbacks.

57.2.4 Development of Laminate to Arrive at Mechanical Properties

Data on mechanical properties is required to perform finite element analysis of seat base using composite materials. For this purpose, four laminates were developed with various hybrid configurations. Hand layup technique was followed by compression molding to prepare the laminates. Four combinations of fibers were considered for the laminates that included three natural fibers (Sunhemp, Kenaf, and Flax fiber) and two synthetic fibers (carbon fiber and glass fiber mats). The volume fraction of the laminates was estimated from the weight of the fiber, resin, and density of the fiber, resin. It was observed that Carbon + Flax + Epoxy exhibited superior properties compared to other laminates. The tensile properties were estimated both along and across the lay direction of natural fibers. Details of the mechanical properties of the laminates are available in Refs. [2] and [3].

57.2.5 FEA Model

The geometric model of the seat base was exported to ABAQUS® for finite element analysis. As the existing seat base has a contoured profile, it is prone to surface defects while exporting the files from CAD software (Fig. 57.3a). Geometric diagnostics tools were used to identify any imprecise geometry. The topology of the component was checked for smooth meshing of the component using four different criteria: free edges, solid shells, shell faces, and wire edges. As a standard guideline, smaller geometries (edges shorter than 0.1 mm and faces with areas smaller than 1 mm^2) were merged with adjacent faces. Geometry edit tools were used to rectify/eliminate the imprecise geometry in the component. Figure 57.3b presents the model after clean-up using edit tools.

The isotropic model approach was chosen to assign the resultant laminate properties such as Young's modulus and Poisson's ratio obtained from the experiments. A global seed size of 5 mm (Fig. 57.4a) was used for the rider seating region of the component, and seed size of 3 mm was used for rubber cushion mounting holes and the guide for rubber cushion (Fig. 57.4b). This seed size was varied depending on the thickness of the component.

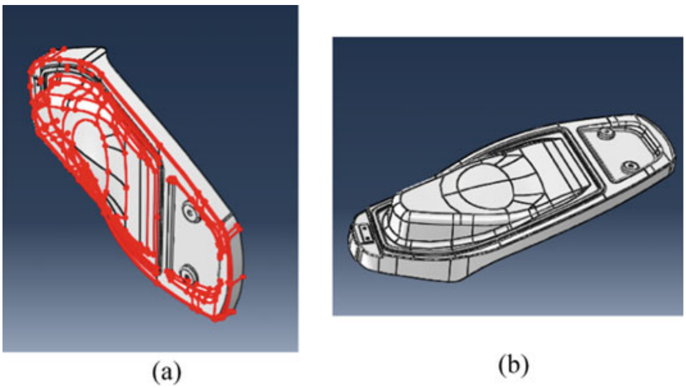
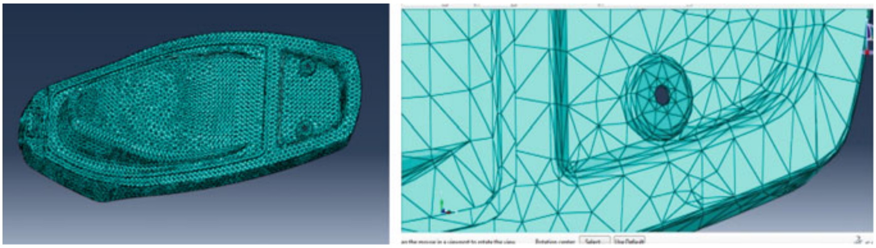


Fig. 57.3 Geometry Import and Clean-up, **a** Imprecise Geometry highlighted using the Geometric Diagnostics tools; **b** Rectification of imprecise geometry using the Geometry Edit tools



(a) (b)

Fig. 57.4 Meshing of the component, **a** Using a seed size of 5 mm throughout, **b** Finer meshing detailing at the cushion mounting regions

57.2.6 Boundary Conditions and Loads

In order to arrive at the boundary conditions, a seat load impression test was carried out using blue print method on existing seat base under the load conditions of: no-passenger, solo passenger, and twin passenger configurations. The boundary conditions were applied at the initial step in the CAD model (Fig. 57.5). The seat base bottom rubber cushion mounting and the rear rubber grommet mounting region were constrained along the vertical direction. A uniform pressure distribution of 18.5 kPa (corresponding to 2600 N of distributed load) was applied over the rider and the pillion seating area in the vertical direction (Fig. 57.6).

The failure criteria used for homogeneous materials are not sufficient for predicting failure in composite lamina. This is because the planes along which the lamina may be possibly be the weakest need not be the direction of principal stresses in a lamina. Thus, alternate failure theories have been developed to predict the failure of composite lamina. A non-interactive failure criteria were used as the interactions between the stresses/strains in the lamina is not necessary. The failure modes are predicted by comparing the individual stresses/strains with respect to their ultimate

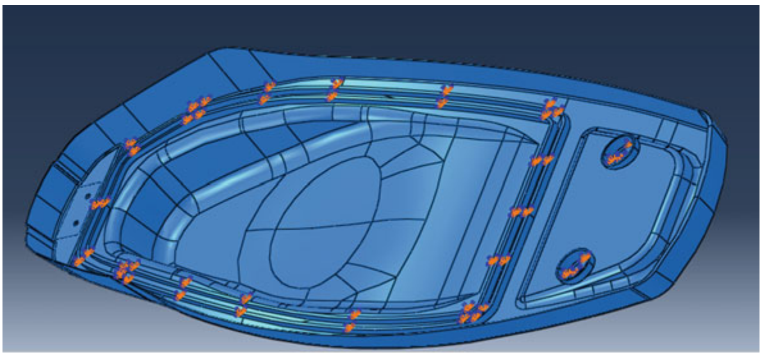


Fig. 57.5 Boundary conditions in FEA model

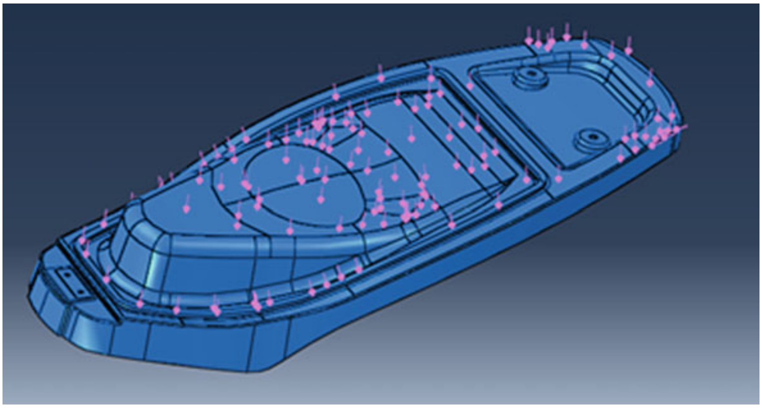


Fig. 57.6 Loading in FEA model

stresses/strains. One of the widely accepted non-interactive failure criteria is the maximum shear stress theory. According to this, failure occurs when any stress in the principal material directions is equal to or greater than the corresponding ultimate strength.

57.2.7 FEA Simulation

A linear elastic static analysis was carried out on the seat base model, for two different thicknesses of 2 mm and 2.8 mm and the corresponding maximum stress and maximum vertical displacement was extracted, as shown in Fig. 57.7. The Factor of Safety of 1.2 was applied to determine failure stresses for each of the laminate. Maximum stress criteria were used to indicate the failure of component. The results of the finite element analysis indicate that there is a possibility to reduce the thickness of the component to as low as 1 mm to meet the desired strength requirements using carbon fiber and glass fiber in hybrid configuration. Figure 57.8 presents

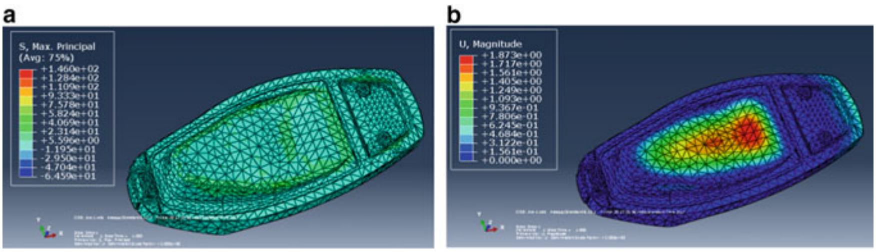
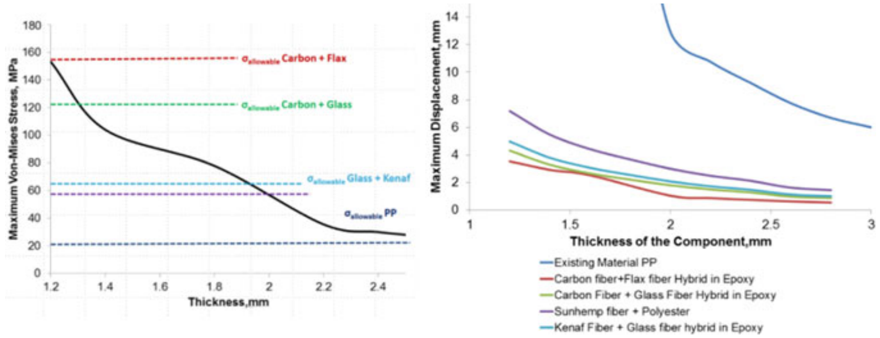


Fig. 57.7 FEA Simulation Results: **a** Maximum von Mises Stress Distribution (MPa), **b** Maximum vertical displacement (mm)



(a) (b)

Fig. 57.8 **a** Maximum von Mises stress (in MPa) and **b** maximum displacement (in mm) variation with thickness of the component

the maximum von Mises stress values and maximum displacement variation with thickness of the component for different material properties.

57.2.8 Development of Prototype Seat Base

The seat base of an existing scooter was used as the base for prototype tool preparation. The top surface of the existing seat base had stiffeners which would have led to complex tool geometry. To overcome this, the bottom surface of the tool was smoothened by trimming off the anti-theft flange. The minimum draft angle of 3° was maintained in the tool, for the ease of extraction of the component. Guide for the rubber cushion routing as well as seat frame bracket and foam-breather holes were covered using a cellophane tape. As natural fiber mats were not readily available one layer each of the synthetic glass fiber and carbon fiber which has equivalent strength of Carbon + Flax fiber laminate, was laid up. One layer each of the 220 GSM glass fiber mat and 480 GSM carbon fiber mat was laid onto the tool and resin was applied using a brush. The required dimensions of glass fiber mat and carbon fiber mat was cut. Additional layers of carbon fiber mats were applied at the rear portion to prevent cracking due to contour change. To uniformly spread the resin at contoured regions, metal rollers of smaller width (~20 mm) were used. Two prototypes were developed with the same configuration as shown in Fig. 57.9a–d, which presents the different stages of layup.

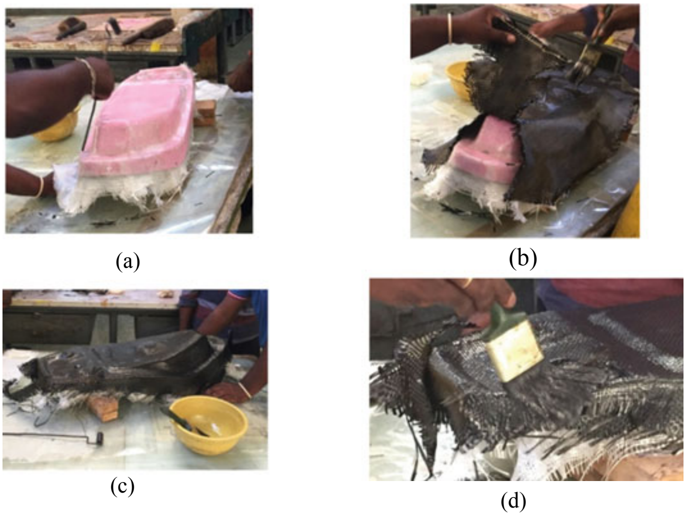


Fig. 57.9 **a** Glass fiber mat layer placed on the tool and resin applied; **b** Carbon fiber mat layer placed over the Glass fiber mat and resin applied; **c** Application of resin coat on the entire mat region over the tool; **d** Additional layer of Carbon fiber mats at the rear portion

57.2.9 Testing of Composite Seat Base

The seat base was mounted onto the utility box of a scooter using the metal bracket. The rear rubber cushions were mounted on the seat base, and the rider seat cushion was pasted onto the utility box, before mounting the seat base. The stiffness test was carried out on the newly developed seat base using a load–deflection testing machine. The sub-assembly comprising of the utility box and the seat base was mounted on the bottom plate (Fig. 57.10a), and the load was applied in steps of 5 kg. A rectangular loading plate having dimensions of 4 cm × 2 cm was used for

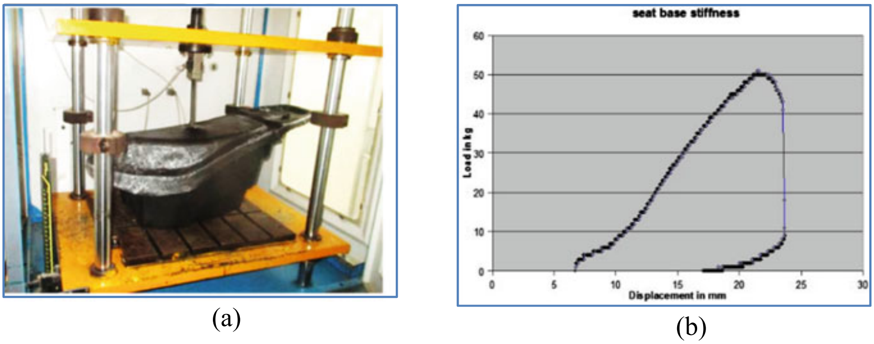


Fig. 57.10 **a** Test setup for the stiffness test; **b** Load–displacement response of composite seat base

loading. Figure 57.10b presents the load–deflection response from the stiffness test. The displacement obtained for a load of 500 N at the rider H-point was 22 mm. FEA simulation was done in ABAQUS for the same load at rider H-point, and the deflection was found to be 16.1 mm. The overall stiffness of the component was estimated to be 4.12 N/mm. The stiffness of the existing model of the seat base is 5.8 N/mm. Thus, the new design requires iteration with additional material layup to arrive at similar stiffness values.

However, other structural tests are also required at assembled condition such as vibration test and drop tests. Moreover, other comfort factors (fatigue, foam bottoming, spinal cord concerns in long-term field users, etc.) also play a major role in overall performance of the seat assembly as a whole—and these are ongoing.

57.3 Results and Discussion

The theoretical CAD weight of composite seat base was 554 g, whereas the actual weight of the component was 660 g; when compared with weight of the existing component of 1130 g, there is a weight reduction of 470 g (or 41.2%) with respect to existing design of the seat base.

The stiffness of the composite seat base is found to be less than that of the existing seat base by about 25%. This can be improved by adding extra layers of the fiber mat at the region susceptible to failure. The variation of the FEA results with respect to the experimental results was found to be ~20%. However, the failure region predicted by the simulation result is identical to the region which failed during the experiment. Though the ply drop had occurred during the stiffness test, the component had retained its shape; thus suggesting that the component could take more loads. The present failure mode is a desirable failure mode from the viewpoint of component inspection during usage of the product.

57.4 Summary and Conclusion

This study was aimed at weight reduction in secondary structures, such as a seat base of a two-wheeler through the use of advanced composite materials. Material replacement study as well as subsequent design validation was carried out by static stress analysis of the component; material properties obtained from the laminate tests were used as input for stress analysis. The study suggested that through the use of suitable composite material, one could achieve a part of thickness as low as 1 mm (similar to sheet metal) for meeting the strength requirements.

A prototype seat base was developed by hand lay-up technique for a polypropylene seat base of a scooter using a synthetic fiber hybrid configuration. Tooling required for the seat base molding was prepared, and all design for manufacture considerations relating to use of polymer composites was incorporated during the tooling and part extraction stages. The stiffness test suggested a marginal reduction in stiffness values compared to existing seat base, which could be suitably corrected through stiffening layers. A weight reduction of ~41% was achieved, which fulfills the objective of this study. Through the use of appropriate manufacturing technique for batch production, one could achieve parts with uniform thickness and reduced weight. Natural fiber mats can be developed as an independent activity, and the same used for building the prototype.

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Chapter 58
A Design Approach on Transmission Architecture Fashioned from Merge Gear Shifting Strategy for Improving Driving Comfort in Conventional Passenger Vehicle

Manish Chandra and Pranab K. Dan

Abstract This paper presents a design approach in improving driving comfort for passenger vehicles, focused on the conventional type being the largest category. Out of several aspects to driving comfort, one is the effort required in gear shifting action. The aim of this work is to achieve this design objective by reducing driver's involvement and is realized through a two-stage methodology; first, to devise an expedient gear shifting strategy and then to reconfigure the transmission gearbox with a compatible multi-clutch layout by modifying the architecture of the existing dual-clutch based one. A new shifting strategy, based on merging of speed ratio ranges, is brought about by rearranging the connection of gear trains of the existing reference model, and hence, the term merge is used to underscore the strategy and is purposed to address the start-and-stop imposed frequent shifting needs in driving. Functional requirement, imposed by the *Merge* shifting strategy, needs compliance of certain constraints; one such is mounting of designated gear members on a particular shaft, and the other, torque carrying capacity, provide information on input and controlling parameters, respectively, for design planning based on reverse engineering approach. For this purpose, stick diagrams, depicting power flow, are generated and those complying the criteria are screened out. The proposed and reference models are computationally tested using standard HWFET driving cycle to ascertain shifting instances, and it reflects that the former needs nearly sixty percent less effort to drive, providing improved driving comfort. Therefore, the new design exhibits a sound prospect in the category's market segment.

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A. Chakrabarti et al. (eds.), *Design for Tomorrow–Volume 3*,
Smart Innovation, Systems and Technologies 223,
https://doi.org/10.1007/978-981-16-0084-5_58

58.1 Introduction

The gearbox is an essential part of a vehicle, powered with an internal combustion engine (IC engine), to ensure the availability of required torque in driving wheels. Gearboxes can be classified as a parallel shaft gearbox, planetary gearbox, or gearbox with a belt pulley arrangement. This paper focuses on the first one in which automated manual transmission (AMT) system as well as the manual transmission (MT) system use gear pair arrangements and operate on engagement and disengagement processes referred to as gear shifting. These parallel shaft gearboxes are developed aiming at certain specified design goals following suitable approaches. One of the design approaches, as observed [1–3], is based on gear shifting characteristics. The design objectives for all types of gearboxes are based on planned gear shifting features. For a better comprehension of the shifting issue in parallel shaft gearboxes, it is convenient to begin with the illustration on the sliding mesh type since it is the initial version, where gears shift either on right or left on the main shaft for meshing with matching gears on the countershaft to achieve different speeds. This gearbox derives its name from the fact that the gears are meshed by sliding. Driving effort and skill requirement are an issue in this type of gearbox. It may be noted here that both the constant mesh and synchromesh gearboxes have been evolved by redeveloping and improving the operational features of the sliding mesh. Both in constant mesh and synchromesh, the driving and the driven gears are constantly in the mesh; with the exception that the latter has a synchronizer arrangement while the former uses a dog clutch. Although epicyclic gearbox has not been dealt within this paper, it may not be out of place to only mention that unlike the earlier ones, gear speeds are achieved in this type by tightening brake bands on gear drums. Constant and synchromesh gearboxes are two variants, in passenger cars, of both the MT and AMT that use manual shifting. It is observed in the literature [4, 5] that the transmission control system along with vehicle parameters such as the speed of the vehicle, throttle position, and accelerator forms a closed loop and helps the system to effectuate gear shifting. In this proposed method, the improvement resulted from the reduction in shifting frequency is comparable with a gearbox in automatic transmission (AT) as the benchmark reference for this purpose, as the shifting operation functionally is moving toward the effort level required in AT. However, in AT this decision is affected by the transmission controller, whereas, for AMT and MT, it relies on the driver's skill [6].

Several researchers [7] suggested feedback control strategies to attain high transmission performance and driving control but hardly stressed on alteration in the configuration. Concerning driving comfort, Sagberg et al. [8] related the effect of driving behavior along with road conditions on vehicle performance and driver fatigue and also explicated that the driving performance of vehicles decreased particularly in 'stop and go' situations generally occurs in heavy traffic, expressing reliance on improvement in driving behavior as solution. Galvagno et al. [9] proposed a torque-assisted automated manual transmission to improve the shift quality, whereas Awadallah et al. [10] aimed to achieve the same with a strategy of reducing torque holes during gear shifts, nevertheless in a different setting; on a mild hybrid powertrain system, comprised of a manual transmission gearbox, IC engine, and electric motor as secondary power source driving the transmission output shaft. The studies referred above focus on the localized solution, that is, at the component or sub-assembly levels without any exploration of architectural modification or such possibilities. The studies referred above focus on the localized solution, that is, at the component or sub-assembly levels without any exploration of architectural modification or such possibilities. This work attempts to fill this gap by developing a gear shifting strategy and compatible parallel shaft gearbox architecture. The methodology proposed in this work, to address and provide a solution to the aforementioned research gap, involves reverse engineering, design planning, computational software, and data resources from advance vehicle simulator (ADVISOR). Results obtained from the computational experiment, using the proposed strategy, exhibit a significant improvement in driving comfort, while tested on standard HWFET driving cycle.

58.2 Problem Statement

Frequent gear shifting is a major transmission system problem, particularly when human intervention is needed to perform shifting operations as required by driving conditions. The driver's decision to shift the gear, generally, dictates the performance of the vehicle, and also, the frequent gear shifting causes fatigue to the driver. To avoid such manual transmission problems, AMT and AT were introduced where the gear shift can occur either independently or with minimal human interference. Though both AMT and AT are more user-friendly as compared to MT but possess cost and efficiency limitations. Huang et al. [11] identified that in a parallel shaft transmission, to achieve the best gear shifting operation, the current and target gear position should be on odd and even gear shaft, or vice versa. During upshift motion, incremental motion with step size '1' is observed and the current gear and target gear mounted on different shafts to achieve smooth gear shifting. But in downshifting, generally, the stepwise motion with varying step size involves that often cause torque interruption and power loss. Further, study [12] revealed that the use of the first three gears in a vehicle is much less compared to the last two (in case of five forward speed transmission) or three (in case of six forward speed transmission). Also further breaking the first three gears into the classical 1st, 2nd, and 3rd gears, the engagement time for each one of them falls further and is much less than the use of 5th gear alone. However, nonetheless, the initial gears are important as they help in starting a vehicle from a neutral position.

58.3 Proposed Solution

Power flow and the shifting mechanism of the gearbox are major considerations in the design of the transmission systems whether it is MT, AMT, or AT. To derive the new gearbox configuration, the existing gearbox model of DCT is considered and further modified and reconfigured to achieve a newer configuration. Figure 58.3 shows a simple stick diagram (not showing synchronizers and reverse gear) of the proposed model. Conventional DCT has two different shafts, one dedicated to odd gears (1, 3, and 5), while other shaft carries even gears (2, 4, and 6). The first gear transmits the highest torque, followed by the second gear and so on. It has been established in different articles that the weight and torque transmitting capacity of gears and gearbox layshaft complement each other [16], which is considered for the screening of design along with the *Merge* gear shifting strategy. The primary argument of gearbox design derivation lies in the fact to redefine the power flow and gear shift logic to improve the driving comfort without compromising other performance indices.

58.4 Development of Gearbox Architecture: Methodology

58.4.1 Design Planning

One of the most basic requirements for any design or physical product to serve the desired purpose which sets the limit of execution parameters which include input, output, and controlling parameters and govern the design. The structured way of design development is utilized to characterize system ideas and procedures for idea realization [7, 13]. Further, the ideas evolved are examined against the system specifications before treated as the output. Steps involved in gearbox design planning are shown in Fig. 58.1 and discussed afterward.

Functional requirements, initial existing configuration, and design objective are three inputs to design planning. Functional requirements include the proposed solution, and in Sect. 58.3, the design objective is to improve the driving comfort and the

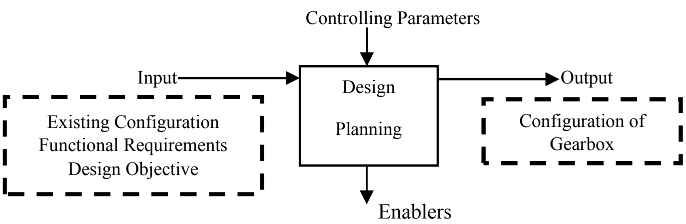

Fig. 58.1 Design planning [7]

dual-clutch transmission model is considered as the initial configuration. Controlling parameters are the number of gear shifting of the gearbox in a standard driving cycle. Different configurations of gearbox designs are considered as enablers. The development of the design configuration of the gearbox is accomplished by modifying the existing configuration of DCT. A part of the reverse engineering technique, as discussed in the next subsection, is adopted to redesign the entire arrangement at the composition level. Finally, the output of the design planning comprises configurations of the gearbox which carried out up to the design level rather than the complete physical model of the proposed architecture.

A novel shifting strategy, based on merging of speed ratio ranges, is developed by rearranging the connection of gear trains of the existing reference model, and hence, the term *merge* is implied to underscore the strategy and is planned to address the start-and-stop imposed shifting needs. Functional requirement, thrust by the *Merge* shifting strategy, requires compliance of certain specific constraints; one such is mounting of designated gear members on a particular shaft, and the other is the torque carrying capacity, providing information on input and controlling parameters, respectively, for design planning based on reverse engineering approach.

58.4.2 Reverse Engineering

The product development process carried out either by forward engineering or reverse engineering [14]. Product development when starts with a basic sketch design and developed to a final product is called forward engineering, and the process that starts with an existing product is called reverse engineering, as shown in Fig. 58.2.

Reverse engineering process has been adopted here for the exploration of different architecture developed in this work to comply with the necessity for benchmarking and comparison with a reference design. For this purpose, the reference design has been retrieved in the form of gear layout and stick diagram from the literature [17] on which reverse engineering is performed to examine the suitability of the proposed design. Also, the adoption of reverse engineering approach enhances the likelihood of easier adaptability, since it is based on an established dominant design.

58.4.3 Transmission Design

Power transmission in DCT is currently designed to follow odd and even gearing, placed on two different co-axial shafts. As suggested in the proposed architecture, odd and even shafts are replaced by three co-axial shafts and each mounted with two gears. The total number of possible combinations gearbox architectures is 48, out of which 10 are given in Table 58.1, where H1 and H2 represent hollow shaft 1 and hollow shaft 2, respectively.

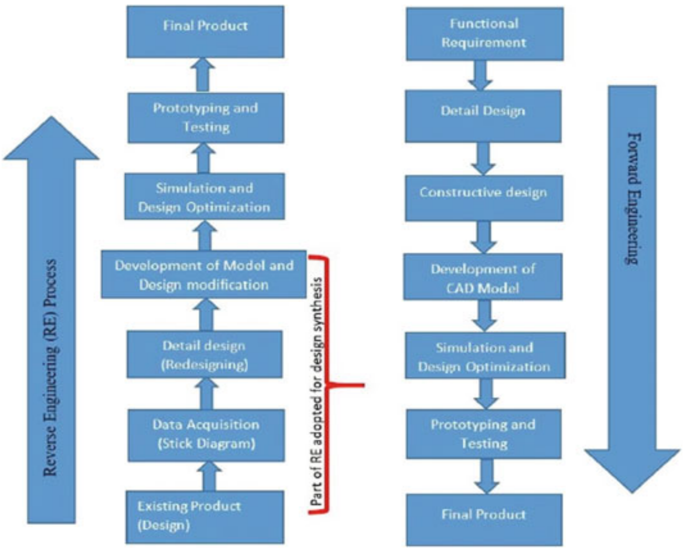

Fig. 58.2 Reverse engineering versus forward engineering [15]

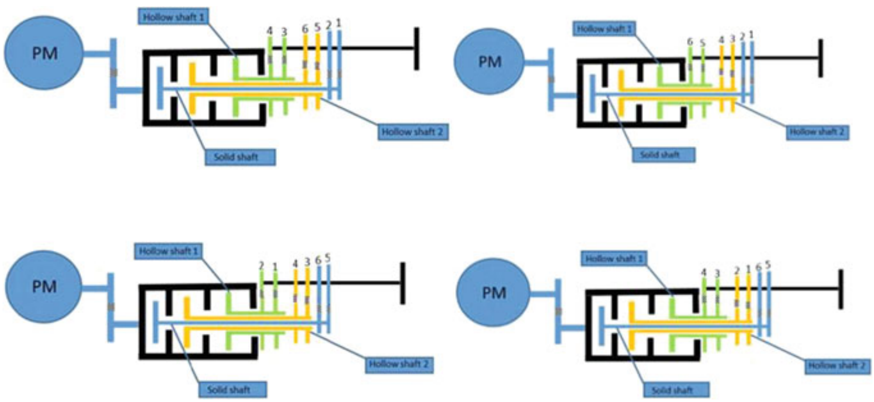

Fig. 58.3 Schematic Representation of different combinations

Table 58.1 Different Combinations

S. No.	Solid	H1	H2	S. No.	Solid	H1	H2
1	1,2	3,4	5,6	6	5,6	3,4	1,2
2	1,2	5,6	3,4	7	5,6	4,3	2,1
3	3,4	5,6	1,2	8	2,1	4,3	5,6
4	3,4	1,2	5,6	9	4,3	5,6	2,1
5	5,6	1,2	3,4	10	6,5	2,1	4,3

Schematic representation of some variations is shown in Fig. 58.3 and the shifting strategy for gearbox architecture discussed in the next section. Uniqueness in the proposed merge shifting strategy allows drivers to have better vehicle control, especially in unpredictable circumstances that are experienced regularly in different driving conditions.

58.5 Transmission Shifting Strategy

The novelty of this system is to incorporate human intelligence with machine capability, where drivers need to provide the input for gearbox when and how long to act automatically or independently. When the vehicle is idle or gearstick is in neutral position, no clutch is activated or engaged. When the driver shifted to first gear, clutch one is engaged, and based on the vehicle input either of the gear is selected. When the driver shifts to 2nd gear, clutch two is engaging and based on the vehicle input either 3rd or 4th gear is selected and similarly for the 3rd clutch. The shifting algorithm of the proposed gearbox is provided ahead. Range of the speed thresholds has been indicated in literatures [10, 11]. ADVISOR, the software that has been used for simulation experimentation indicated speed threshold value according to its database. Such threshold values of advisor conform to the values as cited from the literature (Fig. 58.4).

Merge Gear shifting strategy of the gearbox is designed in such a way that it enables the driver to have control over the shifting of gears. But in each gear, there is an auto-selection mechanism that ensures correct gear in speed range as provided by the driver itself. This mechanism improves the shifting time as well as reduces the torque interruption as found in conventional DCT.

- Step 1: Start the engine and press gas pedal
- Step 2: Engage 1st cluster [1st gear as visible to driver, range 8–24 kmph]
  - Speed is less than 8 kmph 1st gear will be engaged else 2nd gear
- Step 3: If the vehicle speed goes beyond 24 kmph, engage 2nd cluster of gears [2nd gear as visible to driver, range 24–72kmph]

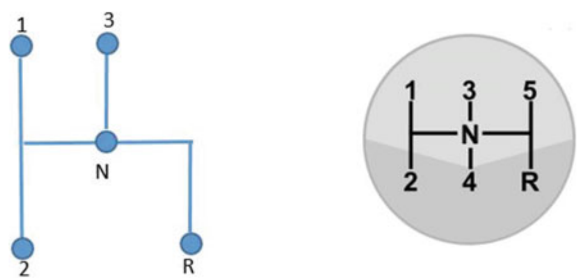

Fig. 58.4 Arrangement of shifting layout for MCT versus Conventional Manual Gearbox

  - Speed is less than 48 kmph 3rd gear to be engaged else 4th gear
- Step 4: if the vehicle speed goes beyond 71 kmph, engage 3rd gear cluster
  - Speed is less than 96 kmph 5th gear to be engaged else 6th gear.

  Shifting Strategy of the existing model.

- Step 1: Switch on the engine and press gas pedal
- Step 3: Engage 1st gear [1st gear as visible to driver] on starting
- Step 4: Engage 2nd gear, if the speed goes beyond 8 kmph
- Step 5: Engage 3rd gear, if the speed goes beyond 24 kmph
- Step 6: Engage 4th gear, if the speed goes beyond 48 kmph
- Step 7: Engage 5th gear, if the speed goes beyond 72 kmph
- Step 8: Engage 6th gear, if the speed goes beyond 72 kmph.

58.6 Screening of Architectures

Three clusters, containing two gears, are mounted on three different co-axial shafts as discussed in Sect. 4.2. As discussed in Sect. 58.5, i.e., *Merge* shifting strategy, there is automatic gear selection for 1st and 2nd gear, 3rd and 4th gear and 5th and 6th gear; therefore, to prepare possible gear arrangements of proposed gearbox architecture combination of gears other than clusters (1st, 2nd), (3rd, 4th) and (5th, 6th) are not considered. Further, arrangements (1, 2) and (2, 1) and (3, 4) and (4, 3) and (5, 6) and (6, 5) are the same; therefore, arrangements will reduce as shown in Table 58.2.

Corresponding schematic stick diagrams of the gear arrangement of Table 58.2 are shown in Fig. 58.2. The first and second gears involve maximum torque transfer from the driving shaft to the driven shaft, and also, the size is smaller as compared to other gears. This limits the nominal shaft diameter of the 1st and 2nd gears, and therefore, these gears should have been mounted on the shaft with the smallest diameter, which is the solid shaft. Thus, combinations of Table 58.2a further reduced and shown in Table 58.2b. Again hollow shaft 1 possesses the maximum diameter, and therefore, gears with maximum size should have to be mounted on this shaft. This condition

Table 58.2 Different combinations: **a** first level, **b** after 1st screening, **c** final design

S.No.	Solid	H1	H2
1	1, 2	4, 3	5, 6
2	1, 2	5, 6	4, 3
3	5, 6	1, 2	4, 3
4	5, 6	4, 3	1, 2
5	4, 3	1, 2	5, 6
6	4, 3	5, 6	1, 2

(a)

Screening 1

S.No.	Solid	H1	H2
1	1, 2	4, 3	5, 6
2	1, 2	5, 6	4, 3

(b)

Screening 2

S.No.	Solid	H1	H2
1	1, 2	5, 6	4, 3

(c)

fixes the shaft for 5th and 6th gear, and Table 58.2 further reduced to Table 58.2c and gives the gear arrangement for all the shafts. The final configuration thus obtained further analyzed in a standard high fuel efficiency test (HWFET) cycle in Microsoft excel for driving comfort, discussed in the next section.

A cost analysis has also been carried out to assess the economic suitability of proposed design. In order to implement this design, the cost involvement of mechanical parts comprising of gear, shaft, bearings, and clutch plate increases by 70 to 80 USD, while the cost for sensor is getting lessened and is in the range from 65 to 85 USD. Therefore, on the whole it is quite apparent that the increase in the cost of mechanical parts is more or less getting neutralized by the reduction in the cost of sensor, and therefore, in effect there practically is no change in terms of cost.

58.7 Results and Discussion

Based on the simulation data available for a conventional vehicle in ADVISOR, the number of gear shifting events is obtained as thirteen, whereas for the derived multi-clutch transmission system (MCTS) architecture, gear shifting is computed as five. Desired speed, as shown in Table 58.3, is speed input coming from standard HWFET driving cycle for gear shifting process whereas the actual speed depicts the speed at which actually gear shifting is taking place during simulation. Selected gear shifting event data for both the architectures are given in Table 58.3.

Under MCTS column '0' indicates the manual input given to the vehicle to shift the gears, whereas, under gear selection (actual) column 0.5, 1.5, 2.5, 3.5, 4.5, and 5.5 indicates the gear shifting action in a conventional vehicle. Comparing the data

Table 58.3 Shifting events comparison

Time	Desired speed	Actual speed	Throttle (%)	Gear selection (actual)	MCTS
4.5	7.9838	7.7080	0.2011	0.5	0
7	21.2903	20.4628	0.6837	1.5	1
9.5	33.8709	33.4609	0.3265	2.5	0
12	41.6129	41.0725	0.5135	3.5	2
25.5	29.9193	29.9581	0	3.5	2
34	49.1935	48.2541	0.7893	3.5	2
36	58.3870	56.7336	0.8016	4.5	0
39	65.3225	64.7517	0.5192	5.5	3
155.5	50.0806	50.0965	0	5.5	3
161	40	40.1406	0	4.5	0
164.5	30.3225	30.3194	0	3.5	2
169	17.4193	17.3328	0.1151	2.5	0
171.5	4.9193	5.0355	0	1.5	1

points of conventional vehicle gear shifting and derived gearbox architecture gear shifting, more than 60% of shifting effort reduced. Mathematically,

Number of gear shifts in existing architecture (HWFET Cycle) = 13
Number of gear shifts in derived architecture (HWFET Cycle) = 5
Reduction in driving effort (%) = (13 −5) * 100/13 = 61.53%.

58.8 Conclusion

Architectural modification of parallel shaft gearbox, planned in this study, proves to be highly beneficial as the results demonstrate a significant reduction which is to the tune of sixty percent (60%) in the occurrence in gear shifting, which has been based on standard HWFET driving cycle. This reduction in shift frequency translates in the lessened effort and constant attention of the driver, which improves the driving experience and comfort. Also, the assessment of cost analysis shows that there is almost no change in such respect on account of the modifications and hence, for the proposed design.

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Chapter 59
Conceptual Design of a Robot for Cleaning Narrow Spaces

Apala Chakrabarti

Abstract Markets for both cleaning services and cleaning robots are growing fast, globally as well as in Asia. Markets in emerging economies are, however, highly cost-sensitive where most cleaning is currently carried out manually. Cleaning robots reported in literature as well as available commercially focus primarily on cleaning of wide surfaces; access to and cleaning of narrow spaces are not adequately addressed. Further, the cost of current robots is at least twice that of the competition. Using the IISC Design Thinking Approach, this paper focuses on developing near-term solutions to these problems: affordable surface cleaning robots for narrow spaces for Indian middle-class domestic markets. The paper proposes conceptual solutions for three such robots all of which meet these criteria. It then compares these with one another using three criteria, area-cleaning efficiency, time efficiency and cost, to select the most promising solution. The work is meant to not only propose novel, potentially affordable and useful solutions for a long standing, unaddressed problem, but also provide a demonstration of the power of a structured design process, supported by design methods such as requirement analysis, brainstorming, morphological chart and weighted objectives method, in developing such solutions.

59.1 Introduction

According to a market study [1] the global cleaning services market is expected to grow at a compound annual growth rate (CAGR) of 6.2% during 2016–2022 to reach $74,299 million, with Asia-Pacific exhibiting the highest growth at 7.0%. Among the various cleaning services, which include maid services, window cleaning, floor cleaning, carpet and upholstery cleaning, etc., floor cleaning, particularly vacuuming, holds the dominant share. The major factors driving the growth are increased disposable incomes in households, increased sensitivity to hygiene, growth in construction activities and growth in the number of working women.

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A. Chakrabarti et al. (eds.), *Design for Tomorrow–Volume 3*,
Smart Innovation, Systems and Technologies 223,
https://doi.org/10.1007/978-981-16-0084-5_59

The market for cleaning robots [2] should grow at a CAGR of 16% during 2020—2025. Technological innovation and changing lifestyle of people are the major factors for this growth. Increased adoption of smart home devices is particularly driving the growth of cleaning robotics for domestic and industrial uses. The above predictions are consistent with [3] that forecasts a similar figure for the growth of cleaning-robots market, from USD 2.1 billion (2018) to USD 4.4 billion (2023), at a CAGR of 16.2% during this period. The major drivers are increased penetration of automation in household appliances, rise in labour costs and increasing safety concerns.

This paper explores opportunities for robots in addressing domestic cleaning needs of Indian middle-class families, especially in the cleaning of spaces of narrow widths and heights. It generates a variety of ideas inspired from both engineering and biological domains, proposes several conceptual solutions and selects the most appropriate as a potential, near-term solution for emerging markets. The research approach follows the IISC Design Thinking Process [4], with the following stages: *identify* problems and opportunities, *ideate* solutions, *consolidate* solutions and *select* the most appropriate. Sections 59.2 and 59.3 focus on identify; Sect. 59.4 on ideate; Sect. 59.5 on consolidate; and Sect. 59.6 on select. Section 59.7 contains discussion, conclusions and future work.

59.2 Review of Literature on Cleaning Robots: Current Limitations

Robots aid humans in a variety of tasks including cleaning. Automatic cleaning robots are used in several places [5]. Roomba has revolutionised surface cleaning robots with efficiency and effectiveness [6]. Robots, e.g., iLife A4, Roborock S6, etc., [7] provided relief to cleaning personnel and ensured a healthier environment. The literature below provides a review of relevant work, to identify the gaps in the current state of the art.

An RC car robot-inspired, autonomous, cleaner mobile robot that can clean without continuous human guidance is proposed in [8]. The robot consumes low power (54 W) and has a cyclonic-type filtration system. It is battery powered (3.6 h) and uses a vacuum motor of 20,000 RPM to enable high suction power. However, it is bulky (0.14 m^2) and cannot clean spaces smaller than 0.2 m $\times$ 0.7 m and areas beyond an obstacle.

A design for a manually operated floor-cleaning machine is proposed in [9] to replace ineffective, manual cleaning. During manual cleaning, the transfer of dust particles from one surface to another prevents desired level of cleaning and increases manual effort. The proposed design can clean both wet and dry surfaces, using a moisture cotton mop, swiping brushes, wipers and a vacuum cleaner. Advantages include low operating time and simultaneous cleaning and polishing. However, it is noisy, bulky due to the presence of water tanks and SMPS; unable to reach and clean narrow, smaller spaces and needs regular maintenance of the moisture mop.

CLEANER—a smart automatic floor-cleaning robot [10] has both manual and automatic modes, with features, e.g., scheduling run-time, and a bag-less dirt container with an auto-dirt disposal mechanism. In the manual mode, it is controlled with a laptop using GUI with Bluetooth connectivity. Its advantages include having a precautionary safety circuit and the dual mode of operation. Another robot for a similar function is proposed in [11]; it also has dual modes of operation, suction for cleaning and control using a remote or a cellular phone. However, these cannot clean wet surfaces, have a short-range and cannot reach and clean narrow, smaller spaces.

Vahid et al. [11] proposed a deep-learning-based robot for automatically detecting garbage (with 95% accuracy) using odometers, cameras, ultra-sonic sensors and CNN. Advantages include the use of a manipulator for handling large pieces of garbage. Disadvantages include restriction on garbage cleaning to a 60-degree visual field; garbage can fall out of its open storage; and due to its flat cylindrical shape, it cannot pick garbage from corners. While it can reach spaces with narrow heights, it cannot negotiate spaces with narrow width.

A design of a solar-powered, Bluetooth-IoT based guided robot is reported [12] for vacuum cleaning and mopping flat surfaces. However, the design is not implemented. While use of IoT for remote control is potentially useful, its range is limited due to Bluetooth. Further, the path algorithm does not ensure coverage of entire area.

A voice-operated floor-cleaning robot is proposed in [13]. The advantage is its simple user interface. Apart from the low range of Bluetooth, its disadvantage includes the low accuracy of speech recognition, especially in the presence of ambient audio-noise. Also, the size of the robot does not permit navigation through narrow spaces.

Overall, surface cleaning robots have several common, unresolved limitations:

- Cleaning large, open spaces as well as narrow, small spaces. This is difficult to achieve in a single robot due to the need for different principles for achieving maximum results in both cases.
- Narrow spaces, such as cleaning of narrow areas like the area behind beds, between bookshelves, cleaning of corners and edges with precision; cleaning of spaces which have minimal height like under a bed or a sofa, are currently out of bounds for most cleaning robots.
- Commercial cleaning robots are expensive (entry level ones are at US$90 which is about INR 7000; advanced ones are US$300–1000, or INR 23,000–75,000) and do not access small spaces.
- Reaching under or over obstacles to clean a surface.
- Many automatic robotic surface cleaners have low battery life (<2 h).

This paper focuses on two essential, unresolved issues: how to enable access to narrow spaces and how to enable cleaning at a price that is compatible with the market of focus: Indian middle-class domestic floor cleaning. The other issues: life, obstacles and cleaning of large spaces are taken as desirables.

59.3 Assessment of the Indian Market: Opportunities

According to Wikipedia [14], average income in an Indian family was US$6671 in 2011 and had an average population of 4.8 per family; 67% of households have electricity, 63% have landline or mobile telephone service; 43% have a television; 26% have either a two- or four-wheel motor vehicle [15]. According to Bijapurkar [16], at least 75 million households in India in 2006 had owned bulk of branded consumer goods as well as 70% of the two-wheelers and washing machines; and 6 million households were rich that owned most of the cars. Even if we focus only on this market, the market size is for 81 million households (as early as in 2006).

Assessment of the cleaning scenario in Indian urban, middle-class households reveals the following. Most such households have regular maid servants for carrying out cleaning and other activities. Vacuum cleaners are a rare commodity in Indian households. Typically, maids spend an hour per day for these activities and charge INR 3000 per month, which is about INR 100 per hour. Narrow spaces including the spaces under or behind almirahs, cots, tables, etc., are rarely cleaned (once in three months or less) due to the difficult ergonomic postures these require to be assumed and the difficulty of reaching far corners while retaining such posture. Further, often materials are stored in such spaces, which require moving out before such activities can be undertaken. Normally, external agencies are commissioned for such activities, who charge about INR 1000 per hour for cleaning these spaces.

A typical middle-class household in India has the following items with narrow under-spaces and spaces-behind that are difficult to reach: 3 cots ($7'$ by $6'$), 3 almirahs with gaps behind ($3'$ by $0.67'$), 3 tables with narrow space underneath ($4'$ by $3'$), 2 medium ($3'$ by $3'$) and one large sofa ($6'$ y $3'$), one showcase with gap behind ($6'$ by $0.67'$) and one TV set with gap behind ($3'$ by $0.67'$). These have a combined area of 18 m^2 to be cleaned. Based on multiple observations of the typical cleaning speed of maids in Indian households, as well as speaking to Indian housewives, it was estimated that a representative speed of work for cleaning narrow spaces is about 2.5 min/m^2. At this speed, it would take 45 min to clean the above spaces. Assuming that such spaces should be possible to be cleaned once a week (due to availability of the proposed robot), the total cleaning time needed is 45 min * 52 weeks/year; the total cost for this activity, if done by maids would be INR (100/60 min) * 45 min * 52 weeks/year = INR 3,900/Year. If professionals are employed as frequently as now, i.e., once every three months, the cost would be INR (1000/60 min) * 45 min * 4 times/Year = INR 3000/year.

The above, along with the analysis in the previous section that the minimal price of current robots in this space is INR 7000, indicates that a robot that is priced at INR 3000 or less would be able to compete with all current solutions and recovers the expenses within a year, even at the sparse four times a year activity, while providing a much better frequency of cleaning even in competition with the extremely inexpensive maids as long as cleaning is carried out once a week for these spaces. INR 3000 is therefore taken as the ideal price for such a robot; INR 2250, which is 75% of the above price, is taken as the target cost for the robot and used as the benchmark for evaluation purposes. Even in conservative terms with numbers from 2006, the potential market size for the proposed robot in monetary terms can be estimated to be 81 million * INR 3000 = INR 243 billion.

59.4 Ideation

To address the need as discussed in the last sections, the following major functions need to be fulfilled:

- Often the area to be cleaned is not directly accessible due to presence of intermediate obstacles that must be reached over or under. How to overcome obstacles to reach the area to be cleaned?
- Often spaces have very narrow width (e.g., 15 cm). How can the robot reach such spaces?
- Spaces may have narrow head-heights (e.g., 6 cm). How can the robot reach these areas?
- Once the space is reached, one needs to detect the areas that have dust or dirt to be cleaned, so that process becomes efficient. What strategy should be used for this?
- The entire area needs to be reached in order to inspect and clean. How can this be ensured?
- How to clean the areas so reached and transport the material back if necessary?

The search for ideas led to exploration of numerous natural phenomena:

- Shedding of snakeskin [17];
- Materials that absorb dust to reduce pollution;
- Methods of navigation used by animals [18]: magnetic; chemicals; visual cues; solar navigation, etc.
- Alternative methods for cleaning, e.g., sodium hypochloride to clean [19]; gill cleaning [20, 21].

Based on individual mind mapping by the author, initial directions for search of ideas were identified (see Table 59.1); the rows have the above six functions; columns include ideas to fulfil these. After studying these ideas and a brainstorming session with others, the following ideas were added (see Table 59.2):

- The robot can be remote-controlled with a camera or left on its own to navigate the space.
- It can have a long pipe that can curl and become a circular or quadrilateral brush. When uncoiled, this can become like an elephant's trunk with an opening of small diameter to suck finer dust particles from edges.
- The pipe can change its diameter depending on the dimensions of the area to be cleaned.

Table 59.1 Initial ideas

Main functions	Alternative ideas				
Go under or over obstacles to access cleaning area	Elephant trunk	Snake	Frog	Climb (Gecko)	Fly
Reach spaces of narrow width	Flexible nozzle	Snake	Mechanically change orientation -bird	Monkey/cat squeeze thru windows	Compressing or becoming small-panda rolling
Reach spaces of narrow heights	Flexible nozzle	Snake	Mechanically change orientation -bird	Monkey/cat squeeze thru windows	Compressing or becoming small-panda rolling
Detect areas to be cleaned	Blind	Camera	Dust detector		
Traverse entire cleaning area	Expand cleaning interface in bird		Eyes- wiper	Gills-brushing	Anaconda eating by stretching
Clean area and transport dirt	Lick with a rough interface	Suction			

- Image processing can be used to sense dirt. Various path algorithms may also be explored.
- A dust sensor or light reflecting from the surface can be used to detect dirt.
- A microcontroller and a Wi-Fi module, e.g., a NodeMCU, can be used for long-range connectivity.
- Brushes can be used in two ways: circular or straight, oscillatory motion.

A morphological chart [22] summarises the ideas triggered by the above processes (Table 59.1). Each row in the chart is for one major function to be fulfilled; each column enlists an idea for each function.

59.5 Consolidation of Concepts

Based on various combinations of the above ideas across the six functions, many combinatorial solutions were first generated. From these, three concepts have been developed based on their relatively near-term feasibility, see discussed below. All solution concepts are based on the following assumptions:

- Covering of small as well as large spaces can be resolved by either making the robot very small, or by enabling it to have multiple configurations, some are suitable more for narrow and some for wide spaces.

Table 59.2 Feasible ideas

Main functions	Alternative ideas				
Go under or over obstacles to access cleaning area	Manual				
Reach spaces of narrow width	Compression and expansion	Reconfigure (Caterpillar inspired)	Reconfigure three-point structure (e.g., foldable paper plane)	Reconfigure (change of axis of rotation)	Reconfigurable thread (e.g., hand fan)
Reach spaces of narrow heights	Manual	Caterpillar climbing	Track wheels	Adhesion (Leech inspired)	
Detect areas to be cleaned	Camera feed	Blind search	Random search	Sensors	
Traverse entire cleaning area	Compression and expansion	Reconfiguration			
Clean area and transport dirt	Moving brushes and suction	Suction	Moving and static brushes and suction	Static brushes and suction	

- Automated navigation over/under obstacles as a general problem is too complex to be solved in near-term; currently, this would be a manual process: someone to put the robot at/near space to be cleaned.
- The solutions should clean using a combination of suction and brushing.
- It should be possible for the robot be used also, as an attachment to an existing vacuum cleaner; in that case, need for separate vacuum generator could be eliminated, and material could be disposed to dust chamber of the main cleaner.
- Need for batteries could be eliminated using direct powering, power from main vacuum cleaner, etc.
- Reaching the space is attained using a combination of sensors and a path algorithm.

Concept 1: The foldable aircraft or three-point support structure

The proposed design is of a reconfigurable robot which could be used for cleaning flat surfaces. The robot can be operated in two configurations (Fig. 59.1 left): the expanded configuration and the contracted configuration. The basic components

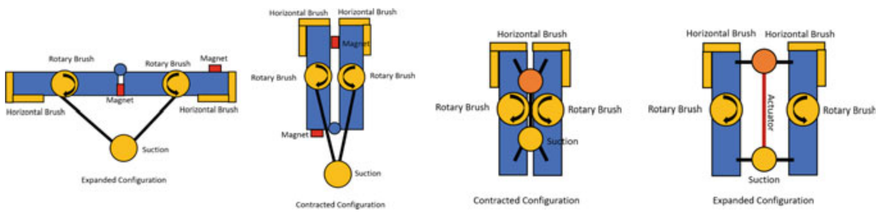


Fig. 59.1 Concept 1 (left) and Concept 2 (right)

include two cuboidal structures connected to a vacuum. Each cuboidal structure will host its basic circuitry as well as a straight and a rotary brush. The straight brushes will push the dust towards the rotary brushes thereby enabling the rotary brushes to sweep the dust towards the suction. The vacuum will use suction to clean the area and transport it into a dirt bag.

i. *The Expanded configuration:* Useful for cleaning larger areas. The two cuboidal structures connect to each other along the width. The structures are connected to the suction to ensure stability and cleaning.
ii. *The Contracted configuration:* Useful for cleaning narrow areas. The two cuboidal structures align along their length using a magnet. As the two structures come together, the tubes connecting them to the suction come closer and the suction moves farther away from the structure to ensure stability.

Looking at the problems we sought to solve, this robot can access narrow spaces using its contracted configuration. Depending on the boundaries of the area to be cleaned, it can reach the entire area either by expanding or by contracting. Reconfigurability of the robot ensures faster coverage of the area to be cleaned. Addition of a camera to send in live feed to the user or automated image processing could help detect the area to be cleaned. The use of straight and vertical brush as well as suction ensures deep cleaning of the surfaces.

Concept 2. The worm-inspired reconfigurable design

This design (Fig. 59.1 right) also proposes a reconfigurable robot. It has two configurations: the expanded configuration and the contracted configuration. The basic structure consists of three components: two cuboidal structures hosting internal circuitry and an actuator-suction component connected via tubes. It is integrated with a straight brush and a vertical or rotary brush for effective cleaning. The straight brushes are added specifically to clean edges. The dust brushed off is pushed towards the suction by the rotary brushed. The suction cleans the area and transports the collected dirt to the dirt bag through the attached tubes.

i. *The Expanded configuration:* For larger areas, the expanded configuration should be used. The two cuboidal structures, connected to the suction and the actuator, move apart from each other horizontally. The tubes connecting the structures create a 90° angle with the cuboids. This ensures both stability and cleaning.

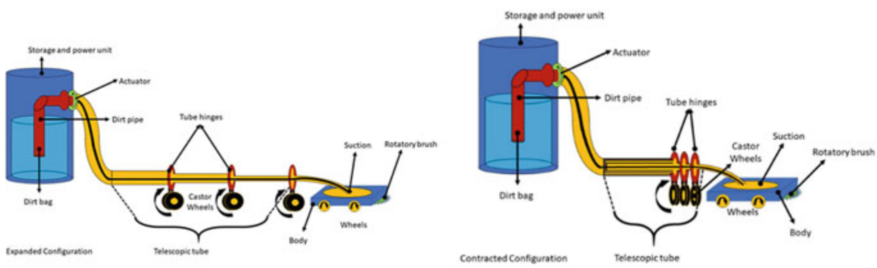


Fig. 59.2 Concept 3 in expanded and contracted configurations

ii. *The Contracted configuration:* For cleaning narrow areas, the contracted configuration should be used. The two cuboidal structures come towards each other and align along their length, as the tubes connect them to the actuator and the suction from an acute angle, thereby, compressing the structure. Through this mechanism, a contracted configuration is achieved which is stable and can be used for cleaning purposes.

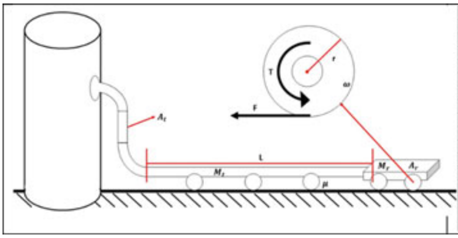
Among the problems we sought to solve, the contracted configuration can be used to reach narrow spaces. Use of a dust detection sensor could help the device detect the areas needed to be cleaned. The two configurations of the robot would enable the user to reach the entire area to be covered irrespective of its narrowness. The use of straight brushes, rotary brushes and suction is intended to provide deep cleaning of the surface.

Concept 3: The elephant trunk inspired detachable nozzle design

The proposed design is that of an extension that can be attached to a normal vacuum cleaner or that can be used independently to clean a small surface. In the attachment version, it comprises a flexible waste connector tube attached to an actuator on the cleaner body. The cleaner body hosts the internal circuitry, a rotary brush as well as suction. Its cleaning mechanism is described below; for overall design, see Fig. 59.2.

A wire passing along the outside of a compressible tube connects to a winch near an actuator. To attain the expanded configuration, the winch uncoils the wire, and the robot moves forward. This expands the tube to the length it needs to attain and can be used to clean long, narrow spaces. The contracted configuration is used to clean shorter areas. This entire mechanism can be replaced with the normal extension of a vacuum cleaner. In the independent version, the cleaner robot is simply a smaller robot with its own, on-board vacuum generator.

Turning to the problems of our focus, the robot can reach narrow spaces and under obstacles but must be placed manually over obstacles, if needed. In its manually controlled version, the user detects the area to be cleaned and manoeuvres the robot. The extendable tube allows cleaning of narrow areas. Detachability ensures ease of use whenever needed. The use of suction as well as a rotary brush ensures cleaning of the surfaces.



Mass of the robot	M_r	$1Kg$
Mass of the tube	M_t	$5kg$
Acceleration due to gravity	g	$10m/s^2$
Friction force due to suction	F_s	
Friction force due to the weight of the tube	F_t	
Friction force due to the weight of the robot	F_r	
Coefficient of friction between the wheels and the surface	μ	$0 \cdot 4$
Radius of the wheels	r	$0.025m$
Suction pressure	p	$550000\ Pa$
Power of the drive motors required	P	
Velocity of the robot	V_r	$0.083m/s$
Torque to be provided by the wheels	T	
Angular speed of the wheels	ω	
Surface area of the robot	A_r	$15 \times 10^{-3}m^2$
Surface area of the tube	A_t	$3 \times 10^{-4}m^2$
Length of the tube	l	$3m$
Highlighted parameters have variable values		

Fig. 59.3 Computation of major parameters for consolidation of Concept 3

Each concept is consolidated further by identifying the main components required for its embodiment. For example, the calculations and estimations of motor power, etc., for Concept 3 are given below, see Fig. 59.3.

The following are taken as the governing equations for Concept 3:

$$F = F_s + F_t + F_r \tag{59.1}$$

$$F_t = (M_t)(g)(\mu) \tag{59.2}$$

$$F_s = (p)(A_t) \tag{59.3}$$

$$F_r = (M_r)(\mu) \tag{59.4}$$

$$T = (F)(r) \tag{59.5}$$

$$P = (T)(\omega) = (V_r)(F) \tag{59.6}$$

Typical suction power for robotic vacuum cleaners starts at 8 AW. With some factor of safety for losses due to tube-length, leakage, etc., using an indicative vacuum pump (suction power = 14 AW; flow rate = 1.5 LPM; suction area = 3 cm^2; suction pressure = 5.5 bar) for calculation gives a maximum permissible robot velocity of 8.32 cm/s.

$F_t = (5)(10)(0.4) = 20$ N; $F_s = (550000)(0.0003) = 165$ N; $F_r = (1)(10)(0.4) = 4$ N

$F = 20 + 165 + 4 = 189N \approx 200$ N; $T = (F)(r) = (200)(0.025) = 5$ Nm

$\omega = \frac{(F)(V_r)}{T} = \frac{(200)(8.3)\left(10^{-2}\right)}{5} = 3.32$ rad/s; $P = (5) * (3.32) = 16.6$ W

So, the minimum power of the motors required for movement is 16.6 W, which is approximated to 20 W to have further factor of safety against losses. Adding to this the power needed for the indicative vacuum pump and the power required for brushes and driver motors, the total power required is estimated to be 40 W.

59.6 Evaluation and Selection

For each concept, a bill of materials is estimated (Table 59.3), and the overall dimensions is assessed (Fig. 59.4).

Feasibility of the robots was assessed by asking if all major parts needed for each robot was available and if any major uncertainties existed about their integration. Based on the fact that each robot could be constructed using available components, e.g., Bo-motors, vacuum generators, standard sensors, etc., it was felt that all three concepts are feasible and therefore not a distinguishing criterion for selection of the most promising concept.

Table 59.3 Bill of materials

Item	Unit cost	Concept 1		Concept 2		Concept 3	
		No	Cost	No	Cost	No	Cost
Wheels	INR 075	3	INR 225	4	INR 300	4	INR 300
Motors for wheels	INR 130	3	INR 390	4	INR 520	4	INR 520
Motors for rotary brush	INR 057	2	INR 114	2	INR 114	1	INR 057
Vacuum generator	INR 800	1	INR 800	1	INR 800	1	INR 800
Motor driver	INR 125	2	INR 250	2	INR 250	1	INR 125
Dust pipe	INR 045	1	INR 045	1	INR 045	1	INR 045
Actuator motor	INR 057	1	INR 057	2	INR 114	1	INR 057
Castor wheel	INR 050	–	–	–	–	3	INR 150
Ultrasound sensors	INR 200	4	INR 800	4	INR 800	4	INR 800
Magnets	INR 038	2	INR 076	–	–	–	–
Straight brush	INR 040	4	INR 160	4	INR 160	–	–
Rotary brush	INR 150	2	INR 300	2	INR 300	1	INR 150
Microcontroller + Wi-Fi	INR 380	1	INR 380	1	INR 380	1	INR 380
			INR 3597		INR 3783		INR 3384

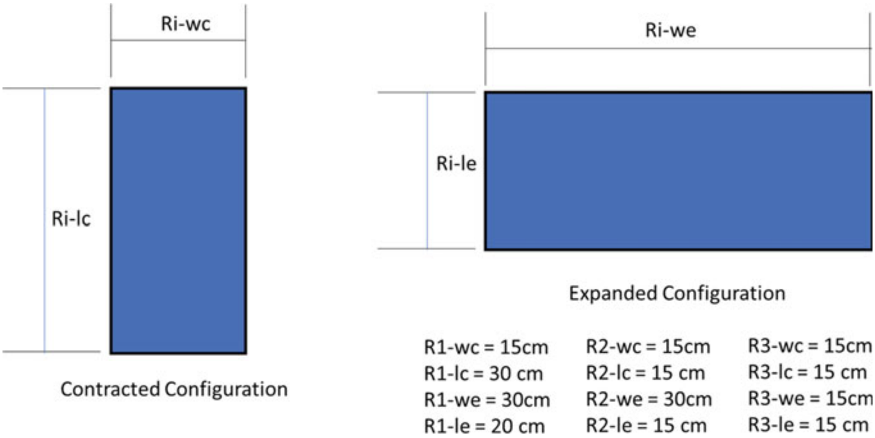
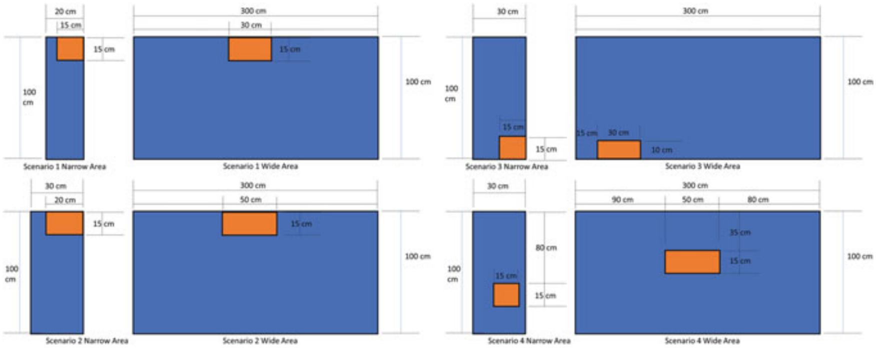


Fig. 59.4 Dimensions of robot concepts R1, R2 and R3 in expanded and contracted configurations



Legend: Blue is the space to be cleaned; Orange is the obstacle within the space to be cleaned

Fig. 59.5 Four scenarios for estimation of area and time efficiency of the three robot concepts

Three criteria were used for comparative evaluation of the concepts for selection of the most promising one:

- **Area efficiency of cleaning**: measured by average % area cleaned in four representative scenarios.
- **Time efficiency of cleaning**: measured by the average time taken to clean the areas in the four scenarios
- **Cost**: measured by the aggregated cost of the components in the bill of major materials to be purchased

Using the robot dimensions and making assumptions about the speed of the robots (uniform across the robots at 8.32 cm/s), the four representative scenarios, the (same) algorithm to be used for traversing the areas to be cleaned and the values of the above three parameters for the robot concepts were estimated. Estimated area and time efficiency of the robot concepts for narrow and wide areas in each scenario are given in Figs. 59.6, 59.7, 59.8 and 59.9.

The values of the three parameters for the three robot concepts are given in Tables 59.4, 59.5 and 59.6, along with their mapping into a scale of evaluation score 1–10, where 1 signifies worst possible performance. Applying weighted objectives method for aggregating the scores against the three criteria, where the weights (relative importance) given to efficiency of cleaning, time to clean and to cost are varied across the tables. The variation in the aggregated scores for the concepts are captured

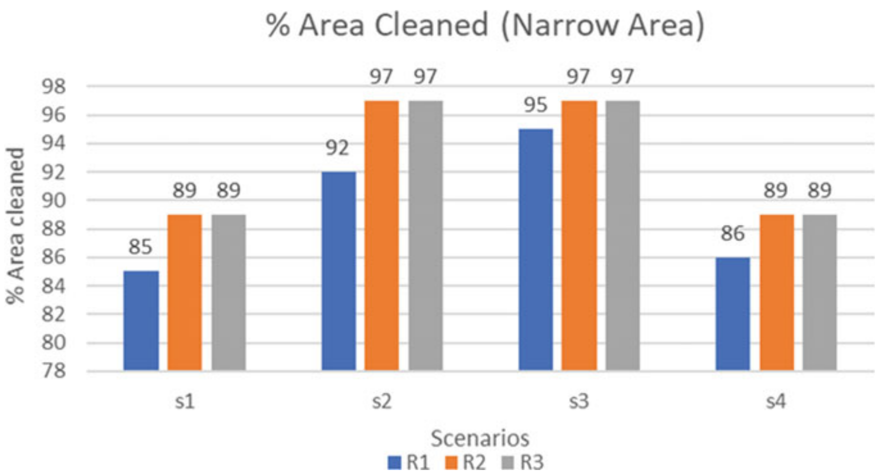


Fig. 59.6 % areas cleaned for narrow areas for the four scenarios

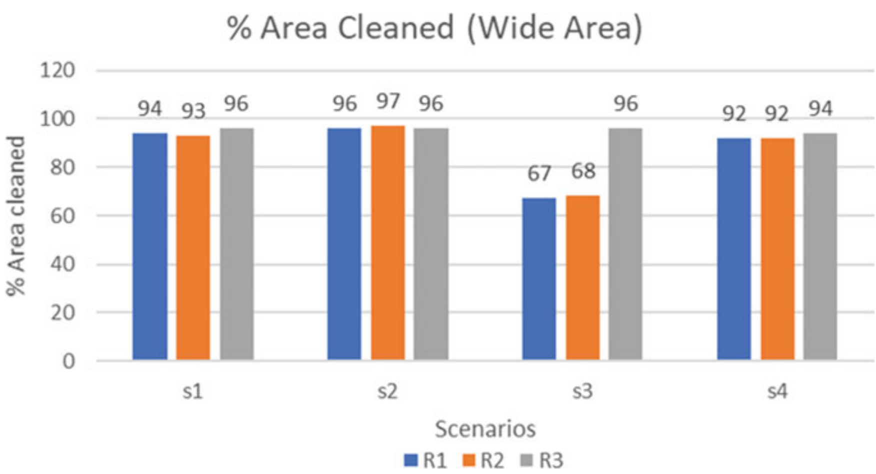


Fig. 59.7 % areas cleaned for wide areas for the four scenarios

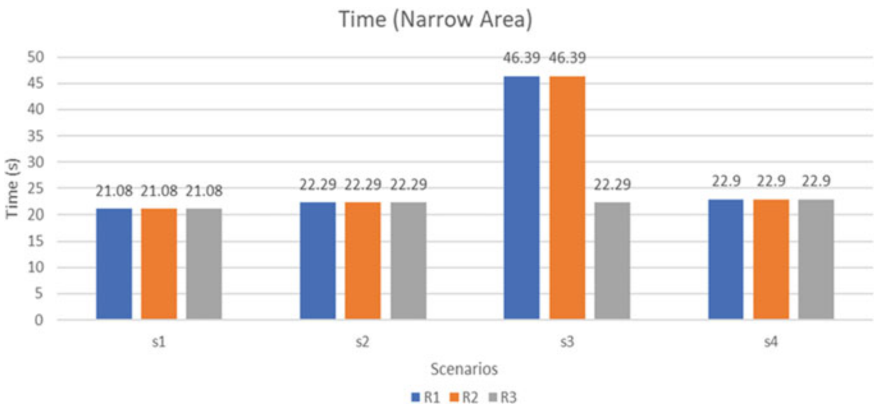


Fig. 59.8 Time efficiencies for narrow areas for the four scenarios

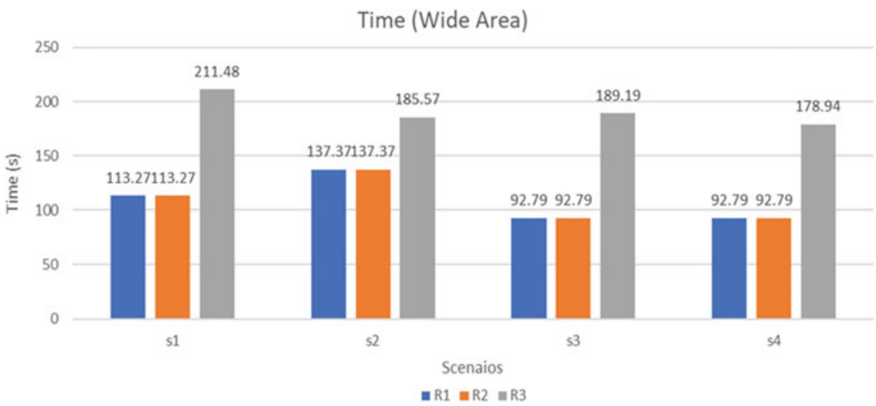


Fig. 59.9 Time efficiencies for wide areas for the four scenarios

Table 59.4 Overall comparison of the three robot concepts with area highest, cost second and time least priority

Criteria	Relative weight	S1 (Actual)	S1 (Score)	S2 (Actual)	S2 (Score)	S3 (Actual)	S3 (Score)
Cost	3	INR 3597	6	INR 3783	4	INR 3384	8
Area	5	88%	6	90%	7	94%	9
Time	2	69 s	6	57 s	9	78 s	4
Overall score 1			60		65		77

Table 59.5 Overall comparison of the three robot concepts with same area and cost and less time priority

Overall score 2	Relative weight	S1 (Actual)	S1 (Score)	S2 (Actual)	S2 (Score)	S3 (Actual)	S3 (Score)
Cost	4	INR 3597	6	INR 3783	4	INR 3384	8
Area	4	88%	6	90%	7	94%	9
Time	2	69 s	6	57 s	9	78 s	4
			60		62		76

Table 59.6 Overall comparison of the three robot concepts with area time and cost same priority

Overall score 3	Relative weight	S1 (Actual)	S1 (Score)	S2 (Actual)	S2 (Score)	S3 (Actual)	S3 (Score)
Cost	3.33	INR 3597	6	INR 3783	4	INR 3384	8
Area	3.33	88%	6	90%	7	94%	9
Time	3.33	69 s	6	57 s	9	78 s	4
			60		67		70

in Tables 59.4, 59.5 and 59.6, for the following cases: Table 59.4: area of cleaning has the highest importance, followed by cost, followed by time (time is least important as a robot is used for cleaning); Table 59.5: cost and area have the same weight, followed by time; Table 59.6: all criteria have the same weight.

As can be seen from all three evaluations, Robot Concept 3 is consistently on the top, indicating its promise.

59.7 Discussions, Conclusions and Future Work

While the finalised robot is yet to be fully validated, the results obtained so far indicate the following: The work reported in this paper has identified a major gap in literature (affordable cleaning of narrow spaces for emerging markets such as India). It has proposed three novel and potentially useful solutions and selected one for further development. The work also demonstrated the power of 'IISC Design Thinking' for supporting the design process. The novelty of the selected concept is as follows. While foldable robots exist, it is not yet applied for robotic cleaning. While detachable nozzles are present in vacuum cleaners, the combination of robot reconfigurability and detachability to facilitate cleaning of narrow spaces is new. This enables multiples modes of cleaning as well as affordability and convenience of use to anyone who owns a vacuum cleaner. Further, novelty lies also in the specific way reconfigurability is achieved. However, the work reported is far from complete as validation of the concept, via development and testing, is still to be carried out. This constitutes immediate, further work.

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Chapter 60
Requirements Capture and Validation: Adopting the Lean Approach for Task Clarification

Komal Shah and Manish Arora

Abstract Requirements capture is an important activity in the development of any product, as it contributes to the understanding of the problem, and the solution of any problem can only be as sound as the understanding that it is based on. The consequences of poorly captured requirements can be significant, leading to wasted resources and missed market opportunities. These issues can be addressed by using a market-oriented method for systematically validating the captured requirements, making informed decisions about their alignment with the market opportunity, and consequently, refining the requirements, before they are used in the subsequent stages of product development. This paper outlines a lean-based approach to task clarification stage of engineering design process, for capture, validation and refinement of requirements. The approach is further demonstrated by its application to design of a urinary incontinence care device. The proposed approach will be valuable to design engineers for efficiently capturing, validating, and refining requirements for new product development.

60.1 Introduction

Requirements capture, for the design of a proposed product, refers to the process of identifying and understanding the needs and expectations of all relevant stakeholders, in order to define and elaborate the goals and objectives, that the system must be designed to fulfill, under specified circumstances [1]. The output data of this process are broadly classified as design, technical, market, and regulatory requirements [2, 3]. They are compiled in a requirements specification, with details pertaining to the functional behavior of the proposed system, the non-functional aspects, the various interrelationships, the constraints and the operational environment. Once compiled,

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A. Chakrabarti et al. (eds.), *Design for Tomorrow–Volume 3*,
Smart Innovation, Systems and Technologies 223,
https://doi.org/10.1007/978-981-16-0084-5_60

the requirements specification acts as the primary source of knowledge about the characteristics of the product and can be used to continuously inform and monitor the design and development process [1]. Thus, well-captured requirements strengthen the understanding of the problem and form a solid base to design and develop the solution.

Poorly captured requirements, such as "conflicting," "missing," and "incorrect requirements" [2], can result in significant business loss due to wasted resources and missed opportunities. Consequently, a repetition of several activities of the product development cycle is required to fill the market gaps. With each repetition, escalating time to market, development costs, and product price lead to further losses [2, 3]. The higher the amount of time elapsed in the development process, the larger the impact of these losses. Yet another common reason for failure and resultant losses associated with requirements capture is development of a product with no demand in market [3].

These issues highlight the importance of starting requirements capture early in the development process, to ensure risk reduction [2, 3]. They also highlight the need of using a market-oriented method for systematically validating captured requirements, making informed decisions about their alignment with a market opportunity, and consequently refining them, before use in subsequent stages of product development.

60.2 Related Work and Research Gaps

The engineering design (ED) process uses an iterative approach to develop a product in four stages, of which "Task Clarification," the first stage, largely uses stakeholder research for requirements capture [1]. The lean methodology (LM) presents an efficient approach to innovation; its first stage of "Customer Development" [4] begins with an initial business idea [5], around which hypotheses are formulated and tested through customer interview and data analysis, to learn if a problem is worth solving [6]. Both ED and LM support the innovation process, prioritize customer needs, and depend on extensive user or customer input for continuous improvement of the output. Both approaches provide for successive refinement of requirements or value propositions; while this is achieved through iterations in ED, the same is achieved by means of iterative hypotheses testing and possible business idea pivots in the LM.

While LM starts with an initial business idea and carries out iterative testing and refining of hypotheses, the ED process adopts various methods to capture requirements, which become the basis of ideation in the conceptual design stage. While ED uses product testing, typically on a prototype, in the late stages of the process, the LM also tests hypotheses in the early stages, making it possible to pivot early, if necessary. The ED process uses various tools for interpreting the information gathered from stakeholders, and for assigning weightage to requirements [1]. The LM uses the Business Model Canvas (BMC) as a tool, for enabling a meaningful transformation of the initial idea. Overall, both ED and LM have similar goals, but employ different techniques to achieve them, suggesting that their combination may be a complementary one. The ED process may particularly benefit from the methods of LM that validate intuitively defined hypotheses and convert them into market-derived facts, for timely identification and appropriate course correction of the path for product development.

The complementarity of ED and the LM is analogous to that of design thinking and lean start-up, which has been described in the literature. Methodologies that combine them argue that there is high value in their collective implementation [5, 7, 8]. However, they do not elaborate on (i) the potential interactions of the two processes, and (ii) the specific contribution of their combination, both in the context of capture, validation, and refinement of requirements in the development process of a product.

The objective of this paper is to (i) outline a lean-based approach, for use in the first stage of ED, for efficient capture, validation and refinement of requirements, such that the customer-centric and iterative nature of both parent models are maintained; (ii) demonstrate its application in the case of design of a urinary incontinence care device.

60.3 The Lean Approach for Task Clarification

To develop a lean-based approach for task clarification, the authors reviewed and analyzed the methodologies of both ED and LM. The key activities identified in the task clarification stage of ED process were streamlined and placed in an LM framework where hypotheses for each stage were framed, tested, and refined successively. Combining the two approaches resulted in the "Lean Approach for Task Clarification" consisting of five stages as shown in Fig. 60.1.

In Fig. 60.1, stages marked in blue indicate the intervention of the LM. The arrows within the stages indicate the iterative nature of the stage itself. Each stage is described briefly as follows:

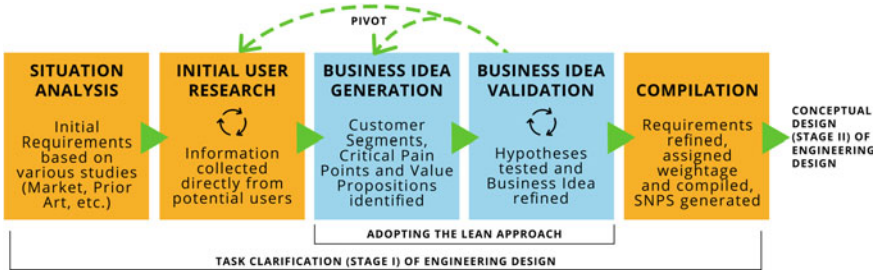

Fig. 60.1 Five stages of Lean approach for Task Clarification

Stage I—Situation Analysis: It involves investigation of the literature, patents, standards, guidelines, competitor analysis, and other relevant sources of information. Gathered information is converted into requirements and systematically recorded.

Stage II—Initial User Research: It involves iterative gathering of information directly from users, and continuous refinement and extension of requirements to satisfactorily understand the most important goals and objectives of the intended solution, the desired characteristics and the implicit wishes involved. Interview transcripts are studied, affinity patterns are identified, and existing and desired situations are outlined. Market opportunity with the maximum potential for successful commercialization, within the available resources is identified.

Stage III—Business Idea Generation: It primarily involves the identification of the customer segments (CS), their most critical pain points and value propositions, based on the understanding gained so far. Elements of the various other sections of the BMC may be identified and filled as well. Thereby a business idea is generated.

Stage IV—Business Idea Validation: It involves iterative formulation and testing of falsifiable hypotheses, primarily about who the potential customer is, what the proposed benefits are and why the customer will choose them, based on the business idea. Data collection is planned with experiment design, systematic sampling of individuals who can best represent the larger CS, etc. Data collection may involve a "get out of the building" approach [6], to conduct a "problem interview," where focus is on the way potential customers rank the top problems identified by the business idea, how they currently solve them and whether they are a viable CS [9]. Empirical evidence is used to continuously prove or disprove hypotheses and refine the business idea until it satisfactorily serves early adopters—customers who are not only looking for an alternate solution but are displaying the strength of their need by engaging in, often self-discovered, makeshift ways of addressing the same [4]. At the end of this stage, an invalidated idea may lead a team to pivot or abandon the project. Depending on scale of pivot, they may go back to stage II or stage III to pursue a different opportunity.

Stage V—Compilation: It involves the use of updated business idea for refinement of requirements, which are then assigned weightage and compiled. Once the team concludes that requirements have adequate clarity and are attainable, a "Solution Neutral Problem Statement" [1] is generated and the way is clear for the next step of ED.

60.4 Results

Described approach was applied in the design of a urinary incontinence care device:

Stage I—Situation Analysis: An extensive study of various relevant sources of information was done. The understanding was used to focus the area of work to "treatment of urinary incontinence in women." Some outputs achieved are listed below.

Literature Study—The background literature is studied, particularly covering topics of physiology, types of urinary incontinence, causes, symptoms, impact on social, work and personal life, diagnosis and management, technology status, patents, governmental support schemes, relevant standards, regulations, and associated problems.

Urinary incontinence (UI) refers to the involuntary flow of urine. It is described by lower urinary tract symptoms that can be present with the impairment of storage or voiding [10]. More than 20% women in India [11, 12] are affected by UI due to several reasons—childbirth, aging, to name a few [13], and the availability of only one urologist for a population of more than half a million people [14] makes the situation worse. Women affected by UI suffer from a diminished quality of life [10]. Their daily routine involves the adoption of strategies such as voiding schedules and reduced fluid intake, and the pain of dealing with the various consequences of insufficient sleep, unexpected leakage and foul odor. To avoid embarrassment at their workplace, many adults choose to rely on pads, diapers, and frequent clothing changes [15]. These only aid management of the condition and can lead to diaper dermatitis—a source of additional pain and cost [16, 17]. Research has documented depression, anxiety, and other difficulties as consequences of UI, that lead these women to start isolating themselves—an adverse effect on their personal, professional and social life [18]. Given the extent of the spread of this condition, the problem accounts for a significant impact on the entire community.

Available Treatment Solutions—Currently employed workflow pertaining to available treatment solutions, and associated problems are understood. Pelvic floor muscle exercise (PFME) is known as one of the first-line treatments for UI [19], but it is difficult to isolate pelvic floor muscles and perform the exercise correctly. For patients who can identify the muscles, the prescribed routine is taxing. The primary disadvantage of PFME and alternate therapies, such as electrical stimulation and vaginal cones is the lack of long-term patient compliance [20, 21]. Pharmacological options, such as anticholinergics, are associated with high rates of discontinuation due to debilitating side effects [22]. Surgical treatments, like sling procedure and injections, are associated with complications like back pain, infections, and blood clots [23].

Market Study—A preliminary understanding of the market trends and aspects pertaining to UI devices is obtained. Both global and Indian markets for such devices were expecting to see a significant growth in the recent future; however, low affordability was identified as a factor restricting the demand in India.

Competitor Analysis—The primary benefits generated, and the competitive advantage held by key players in the market is understood, leading to the identification of gaps in existing products. The need for a portable solution was particularly noted.

Stage I: A list of initial requirements was generated from the gained understanding.

Stage II—Initial User Research: It involved a clinical immersion including interactions with and observation of patients, their caregivers and their clinicians (urologists, urogynecologists, gynecologists, and physiotherapists). Further interactions were held with other stakeholders, like family members and UI-related product manufacturers.

Multiple interactions and observations led to insightful information related to the burden of following the pelvic floor exercise routine, frequent visits to the clinic, having to wear wet absorbent pads, worrying about urine leakage and embarrassment, and not being able to travel by bus, to mention a few. The strong association of the condition of UI with societal stigma in India was found to lead to various kinds of fears in the mind of a patient. Essentially, patients had the wish to feel free.

In-depth discussions were held to interpret the collected information and transform it into requirements. Overall, strong indicators led to strengthening of the initially identified need of "portable, wearable, pelvic floor muscle exerciser, for treatment of UI in women." It would especially help those women with UI, who are unable to identify and isolate the pelvic floor muscles, to perform the exercise in the right way. It would allow them to use it in their daily routine, without having to make frequent visits to the clinic, thereby fitting their lifestyle and improving long-term compliance.

A detailed analysis led to the identification of six customer segments whose pain could be addressed by addressing the identified opportunity. Segmentation was based on their most critical pain point, and the context in which it was to be addressed: *The Working Woman* (spends a typical day at work, has no time to exercise), *The New Mother* (UI due to childbirth, unable to exercise due to post-partum weakness), *The Travelling Woman* (struggles to find a private place to exercise during a journey), *The Older Woman* (unable to exercise due to physical weakness), *The Dependent Woman* (not physically fit to exercise, embarrassed to take help for cleaning urine or changing the absorbent pad), and *The Caretaker* (pain of cleaning urine repeatedly).

User personas and journey maps were created for each customer segment. To understand the potential impact of various interventions, corresponding envisaged journey maps were created. Total 15 requirements were formed into 8 clusters, classified as demands–wishes, allotted 26 technical measures, classified into broad categories of functional, software, etc., and compiled. Top 5 user requirements are shown in Table 60.1.

Stage III—Business Idea Generation: Numerous design discussions were held, and for each customer segment, the archetype was identified, attributes were listed, and jobs-pains-gains charts were prepared. For addressing each of their most critical pain points, value propositions of the envisaged product were identified: Treatment anytime anywhere, Concealed Use, Side-effect free, Easy to use, and Custom fit (see Table 60.2). Based on the understanding gained, other sections of the BMC were filled.

Stage IV—Business Idea Validation: Core assumptions of the business idea were identified: (i) Women having UI consider it to be a problem that can be solved, (ii) Women having UI are not happy with the currently available solutions, (iii) Women

Table 60.1 List of the top five user requirements

	User requirements
1	The device must be lightweight and easy to carry throughout the day
2	The operation of the device must not depend on any form of support from the external environment
3	The user must be able to wear the device under other clothing and use it in a concealed manner
4	The device must comply with high standards of hygiene, as per medical requirements
5	The device must provide comfortable fit for different users with different body types

Table 60.2 Customer segments and value propositions, at the end of Stage III

Customer segments (down) and value propositions (right)		Treat any time any where	Conceal when in use	Free of side effects	Easy to use	Customised fit
1	The Working Woman	Y		Y		Y
2	The New Mother	Y		Y	Y	
3	The Travelling Woman	Y	Y	Y		Y
4	The Older Woman	Y		Y	Y	Y
5	The Dependent Woman	Y		Y		
6	The Caretaker				Y	

having UI are looking for an alternative to current solutions. Several hypotheses were generated and tested in 102 problem interviews (broadly 47 end users, 55 clinicians).

On collating data from interviews, it was seen that women who work from home, and new mothers who stay at home, do not worry about public embarrassment, and manage their condition with a voiding schedule. Travelling women who have the freedom to travel in their own car, make convenient stops, and dependent women would rather depend on one person, than fail at handling themselves and become a burden on all family members. These women considered UI to be a problem. But they were neither happy with the available solutions, nor were they actively looking for an alternative. Older women often had other conditions, such as diabetes, which had caused UI. Caretakers wanted an immediate solution to their pain of repeated smelling and cleaning of urine. Neither of them could be helped by the envisaged output.

On the other hand, there were travelling women who took the public transport, or new mothers who were office goers and working women with a busy and non-flexible routine—all of who were severely affected and actively looking for an alternate solution for UI. Therefore, it did not matter what their most critical pain point was, women would look for a solution only when UI started coming in the way of their lifestyle. Moreover, even women looking for an alternative to existing solutions had the tendency to lose hope after multiple failures and eventually learn to live with UI. Of all patients interviewed, 85% of those who were within 3 years of being diagnosed were actively looking for a new solution, as compared to 54% of those who were not in the same timeframe, suggesting that the product must reach women in early stages of UI.

Thus, the target market was identified and sub-segmented: women leading a busy lifestyle—young women pursuing their career/work (Young and Busy), or women with a tight schedule in post-partum period (The Busy Mother), or socially active older women (Active Senior Citizens)—within 3 years of being diagnosed with UI.

About 80% of women interviewed from the Young and Busy sub-segment were using medication, despite severe side effects, because it was convenient and gave them an uninterrupted routine. Of all interviewed potential customers who were on medication, 93% were dissatisfied, and 67% were actively supplementing it with other methods, like exercising whenever possible, in the hope that they could stop medication sooner. Young & Busy women who were actively supplementing medication were identified as potential early adopters, and medicine supply companies, as the top competitors. Although the value proposition "free of side effects" had an advantage over medication, it was imperative to ensure the benefits: "cost comparable to medicinal treatment" and "as easy to use as taking a pill." Subsequent interviews were directed at collecting data particularly related to the target market (see Table 60.3). Among other patterns, such as buying preferences, it was found that 86% of

Table 60.3 Updated customer segments and value propositions after Stage IV

Sub-segments (down) and value propositions (right)		Treat anytime & any where	Conceal product when in use	Free of side effects	Easy to use	Custom fit	No interruption in routine	Cost less than or similar to current choice
1	Young and Busy	Y	Y	Y	Y		Y	Y
2	The Busy Mother	Y		Y	Y			
3	Active Senior Citizens	Y	Y	Y	Y			Y

such women chose a solution recommended by their clinician. Thus, the role of a clinician as a recommender was important in the ecosystem. Business idea validation was performed in several iterations, continuously updating the BMC, generating, testing, and refining hypotheses, and revising user personas, journey maps, jobs—pains—gains charts, channel, and petal diagrams.

Stage V—Compilation: The updated business idea was examined for interconnections with previously defined requirements and used to refine those requirements, their technical measures, and their relative weightage. The requirements were further analyzed and modified, and the Solution Neutral Problem Statement was developed.

60.5 Discussion and Conclusion

Requirements capture is an important activity in the development of any product, as it contributes to the understanding of the problem, and the solution of any problem can only be as sound as the understanding that it is based on. Our intention is to bring to this activity, the strengths of both ED and LM, by outlining an approach that combines the two, for use in the early stages of the process. The stages of Situation Analysis (Stage I) and Initial User Research (Stage II) use ED methods and allow one to explore and contemplate all the many aspects of a problem. The largely open-ended nature of information gathering in these stages gives one the freedom to investigate several opportunities in the market space and understand different facets of potential stakeholders. On the contrary, data collection in Business Idea Validation (Stage IV) is relatively supervised in the sense that various activities such as interview discussions and observation of behavior are focused on testing of well-defined hypotheses. For instance, interviewers may use the likes of open-ended and follow up questions, to direct the conversation for obtaining empirical evidence to prove or disprove hypotheses. Overall, the first two stages are used to capture requirements by gathering information, interpreting it, generating and systematically compiling requirements; following stages are used to validate and refine them, for market alignment.

By adopting the outlined approach for the design of a UI care device, the team recognized unanticipated opportunities. One of their biggest learning was that potential end users with a problem do not necessarily convert into customers looking for a solution. Further, potential customers looking for a solution do not necessarily convert into early adopters with a burning need and the ability to pay for its solution. Without having taken the outlined approach, the team would have possibly spent time and resources on developing a UI care device for various CSs that were classified based on their pain point and were assigned value propositions accordingly. They would have considered various medical device companies, physiotherapists, etc., as competitors. The outlined approach helped them to narrow their CS, identify value propositions for their benefit, and consequently, to validate the business idea. Further, it helped them to identify their potential early adopters and adapt the requirements around them. They identified their place in an existing market with pharmaceutical companies as their top competitor and captured critical requirements related to the cost and ease of use of the envisaged solution, as compared to pharmacological options. Adoption of the outlined approach in the earliest stage of ED was helpful for the team to focus the direction of future activities.

Therefore, by adopting the outlined approach, as demonstrated, one is able to build an understanding of the whole market, explore and assess various opportunities, determine the opportunity with maximum potential; and then use lean methods to validate assumptions. This is used to build a business model based on market-derived facts, which is further used as a basis for mapping out the right path for pursuing the opportunity, pivoting or abandoning the project in the early stage itself, if needed.

It is possible to arrive at the same outputs by iteratively using several tools such as the ethnographic studies and journey mapping in accordance with the ED process alone. However, in this paper we demonstrate that the market-focused approach of the lean methodology has the potential to contribute to the efficient, systematic validation, and consequent refinement of requirements. The relatively supervised nature of the lean methods adds further structure to the task clarification stage of ED and increases its overall effectiveness and efficiency. The lean approach to task clarification proposed in this paper is useful to capture, validate, and refine requirements in an organized manner, with reduced time and reduced risks. This benefit is attributed to prompt recognition of flaws and early, iterative revisions of the output. This approach particularly helps one to address the business aspect of their product and thereby increase its market viability. Although the updating and refining of requirements continues throughout the development process, the outlined approach is useful to build a strong base for the successful development and commercialization of the product.

To the best of our knowledge, no clear guidelines exist, pertaining to the ethics of conducting interviews of potential stakeholders for the purpose of capturing and validating requirements, as illustrated in this paper. Given that a strong societal stigma and embarrassment are associated with the condition of UI in India, a possibility of obtaining potentially biased results was anticipated with the method of obtaining a written consent from interviewees. However, at the beginning of each interview, the interviewee was verbally given the option to maintain anonymity and asked for permission for digital recording of interview. Their choice was strictly adhered to throughout the process, and steps were taken for future safe keeping of collected data.

The work presented in this paper may contribute to a better understanding of the role of both, ED and LM, in the context of requirements capture, validation, and refinement for product development. However, it may have some limitations. Even though the outlined approach and following demonstration use the translation of requirements into a business idea and vice versa, the method for doing so has not been fully described. Further, the possibility of inadequate maintenance of traceability, completeness, and consistency of requirements, in the process of such a translation, has not been directly addressed. These issues, along with those related to long-term benefits of the outlined approach, in actual practice, will be addressed in future work.

Acknowledgements Authors would like to thank Gopalakrishnan-Deshpande Centre for Innovation and Entrepreneurship, IIT Madras, and Malavika Harita for their invaluable guidance and support during the I-NCUBATE Program; Sruthi Sasikumar, Ashish Tomar, Chinmayi Narasimha, Sunandan Paul, and Nishita Anand for their contribution in the various stages of design of the UI care device.

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Chapter 61
Introducing Visual Literacy Activities for Primary School Children in India

Swati Mittal, Satyaki Roy, Mritunjay Kumar, and Ahmed Sameer

Abstract Visual literacy is an essential skill to comprehend and interpret visual meaning efficiently. Previous research has claimed visual literacy to be necessary for thinking, communication, and learning. Several researchers have realized the importance of visual awareness in children, which does not only benefit their visual skills but also their verbal skills, motivation, engagement, independence, and confidence. Despite having multiple advantages of introducing visual literacy in the school curriculum, scant attention has been paid to introduce visual literacy for school children in India. This study is an intervention to introduce visual literacy through VL activity book and scaffolding for primary school children. Several visual literacy tasks were developed and tested with primary school children in Kanpur (Uttar Pradesh, India). Results show significant improvement in children's visual literacy skills after our VL activity-based learning program's intervention. We argue for the design and implementation of such visual literacy activities as a part of the curriculum for Indian children to develop an eye for it and understand visuals in a better way.

61.1 Introduction

Dondis [1] forecasted the ubiquitousness of visual images 46 years ago. Since then, visuals have evolved with more pervasive user involvement. To name a few, icons, logos, user interfaces, infographics, Internet images, etc., have bombarded today's civilization with complex visuals. This has increased the demand for visuals over text. Several career options have emerged in recent years, e.g., design, film, media, etc.,

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A. Chakrabarti et al. (eds.), *Design for Tomorrow–Volume 3*,
Smart Innovation, Systems and Technologies 223,
https://doi.org/10.1007/978-981-16-0084-5_61

to name a few that require an individual to be visually literate. Visual literacy (VL) is not the same as it was a hundred years ago. Visual meanings should be interpreted for effective communication, and often, this ability requires heuristics and awareness [2]. These skills develop automatically and independently, based on various experiences, environment, etc., without any external support. This does not mean that people who are better in VL develop these skills without paying attention and thinking; e.g., somebody cannot be a musician only by listening to music casually. These skills can also be trained [3] for effective communication. Thus, there is a need to introduce VL training programs during the early stages of life. The way any verbal language has its own components such as letters, syllables, and protocols to form a sentence, and visual languages also have its own foundational elements. However, these forms have their intrinsic complexities as they demand attention, creativity, observation, and awareness from the user, making it an important subject matter of study.

61.2 Visual Literacy and Its Components

Debes, in 1969 [4], coined the term *Visual Literacy* and broadly described it to be a mutable concept and stated that "*Visual Literacy is a group of vision competencies possessed by a human being to make meaning out of the visuals by integrating other sensory experiences. These competencies are fundamental to the development of human learning. When developed, these enable a visually literate person to critically analyze, discriminate visible actions, symbols, objects in their surroundings.*" Since then, several theories have been proposed [4–9]. Despite these theories, the complexity of VL and its coexistence in multiple disciplines have made it challenging to define it.

Different researchers have also identified several conceptual components of VL theory. For example, Burbank and Pett [10] divided the parameters of VL into theoretical and practical constructs. Seels [6] proposed three theoretical constructs of the VL phenomenon, i.e., visual thinking, visual communication, and visual learning. Avgerinou and Pettersson [11] proposed that the VL should be rooted in 5 theoretical constructs, i.e., visual language, visual thinking, visual learning, visual communication, and visual Perception. Vermeersch [12] proposed a framework to support the VL skills to be taught in the school curriculum. Based on the literature, VL skills were broadly divided into four categories, *visual perception, visual imagination, visual conceptualization,* and *visual analysis.* Due to the limitations of the paper's length, we suggest the readers referring to these theories and prepositions in detail.

61.3 Visual Literacy in the School Curriculum

Much research in the past has suggested introducing visual training during the early period of life [13]. Most schools' education system focuses on visual arts knowledge (drawing and painting) concerning VL [14–16]. They should expand their paradigm to visual knowledge transfer. However, teaching for VL in a school setting has still not been well researched. The mistaken belief toward VL skill—a self-taught process that develops based on direct experiences—has led it to be not recognized by the education system [17].

Several researchers have suggested having visual literacy awareness programs/workshops to develop visual awareness among individuals [18]. Different researchers have proposed some of the programs; e.g., Lopatovska et al. introduced children of 4–6 years of age to artworks through a visual literacy program [19]. Some schools promote film-viewing as a medium to improve children's learning, talking, and writing [20].

The divide between several parameters of the school context has created different classes of schools privileged over the others [21]. Medium-resource schools have basic infrastructure facilities; low-resource schools have poor infrastructure, less experienced teachers; and high-resource schools have the almost perfect setting of the infrastructure with highly experienced and qualified teachers. Despite various initiatives by the Indian government to provide primary education to the masses, common issues like quality and access to education remain persistent in India's rural schools [22]. Children in the low and medium bucket hardly have exposure to different literacy concepts like visuals and media literacy. Many researchers from India have also asserted to explore the use of visual tools in the Indian curriculum [23, 24]. Based on the literature review and the author's own experience with the children present education system, the following research aims and hypotheses were proposed.

61.4 Research Aims and Hypotheses

The aim of this research is to introduce and inculcate visual literacy skills in underprivileged primary school children in India to interpret/create better visuals for effective communication. We propose a VL activity-based book integrated with the "teaching experiment methodology" [25], using a scaffold, a one to one teaching experiment, supporting students to learn VL skills. Scaffolding has been proven effective over the work alone condition [26, 27].

61.4.1 Hypotheses

4.1.1. Students will have no difference in their pre-post VL scores after the intervention of a VL support system.

4.1.2. Students will not differ in pre-post VL scores, considering their schools and backgrounds.

61.5 Visual Literacy Support System Design

Based on the anecdotes and proposed literature, four operational and conceptual VL skill constructs were identified as a framework to develop a VL support system for the Indian school children between the age groups of 7–11 years of age. The cognitive-developmental theory categorizes this age to the concrete operational stage [28]. By this time, individuals start recognizing the images, categorize them, organize them into meaningful constructs [29]. Cooper [30] demonstrated the significance of introducing VL as early as, at this stage, for a better effect on the individuals. To understand and design a VL support system, the following VL conceptual constructs were operationally defined:

(1) **Visual Perception**—Visual perception is the way images whhich are perceived to make sense of them and deals with the visual elements and their relationships [17]. Color, form, shapes, foreground and background, textures, rhythm, emotions, etc. constitute the main component of any visual image.
(2) **Visual creativity and imagination**—Skills refer to the ability to imagine and the creative use of images [10].
(3) **Critical viewing, association, and discrimination**—Critical viewing is a common term associated with media literacy and refers to applying critical thinking skills to visuals [31]. Visual association and discrimination utilize critical thinking skills to associate and discriminate visuals with unifying/disparate concepts.
(4) **Visual Reasoning**—Avgerinou [31] explained it as logical thinking carried out primarily by means of images.

Several mediums were considered for developing a support system that could work with major schools' resource settings. We chose to develop an activity workbook for school children. Activity doodle books are considered to stimulate creativity and imagination [32, 33] and have several advantages over the other mediums (such as low cost and ease of use). Several existing books were looked at, and we thought to develop a VL activity book with the following goals:

(1) The illustrations should be familiar with distinct visual forms and less text to maintain prolonged interest in the workbook.
(2) The book should encompass VL tasks related to the operationally defined framework.
(3) To augment the heuristic approach of children while solving VL tasks.

The illustrations were developed using a Cintiq 24 HD system.

Table 61.1 Participants details

School	Grade	Male	Mean_ age	SD	Female	Mean_age	SD
1	5th	13	9.4615	0.776	9	9.55	1.01
2	4th	9	8.88	0.781	9	9	1
3	5th	10	9.9	0.737	6	9.833	0.752
4	Mixed (4th, 5th, and 6th)	17	9.823	0.727	14	9.714	1.069

61.6 Method

61.6.1 Participants

Eighty-seven participants volunteered for the study with the following details in Table 61.1. Informed consent was taken from the school authorities and parents before conducting the experiments and tests. The study was approved by the institute ethics committee of IIT Kanpur.

61.6.2 Materials and Setting

A VL Activity book The book consisted of 37 tasks related to the VL skills based on the framework proposed in this paper. These tasks have not been included in this paper, considering the limitations of the pages. However, they can be referred to here [34].

A battery of pre–post-tests 16 tests based on the proposed framework was printed and was given to the participants (see Appendix 1). These tasks were chosen based on our four conceptual constructs framework presented in Sect. 61.5.

61.6.3 Procedure

The study was conducted in two phases. In the first phase, 76 school children (7–12 years of age) participated from different parts of India remotely. Children were asked to complete two worksheets within a week's timeline. These worksheets were either parceled via physical mail or emails for printouts. Parents were asked to send back the scanned responses and parcels directly to the author. Worksheet 1 (an A4 blank sheet) and worksheet 2 (with 12 blank squares) were given, and children were asked to draw anything with their imagination without consulting any help from their parents and books. This was done to understand the preferences and existing knowledge of children's visuals before the intervention of any VL support system. Some of the responses are shown in Fig. 61.1.

Based on the observations and findings, 47 tasks were designed, out of which 37 tasks were selected based on visual design expert's feedback at IIT Kanpur. The ratings were taken from the judges on a 5-point Likert scale (1 = least relevant and 5 = most relevant). We used intraclass correlation (ICC), Hallgren, 2012 [35] to judge the suitability of the tasks for the VL activity book based on ratings by three judges (see Table 61.2). For all the tasks, ICC was computed using the "psych" packages in R statistical software. All correlations were high, ranging from 0.96 to 0.99, as well as significant.

The maximum possible score for the suitability of the task was 20. If it was found to be less than ten, the task was rejected.

In phase two, 56 children were recruited from 3 different schools (two low-resource schools and one high-resource school), and 31 children from a low- and medium-resource school from the Nankari locality in Kanpur. Phase 2 aimed to understand the VL activity book's efficiency on the children's VL skills using an existing battery of pre–post-test tasks (see Annexure A). First, a pre-test was

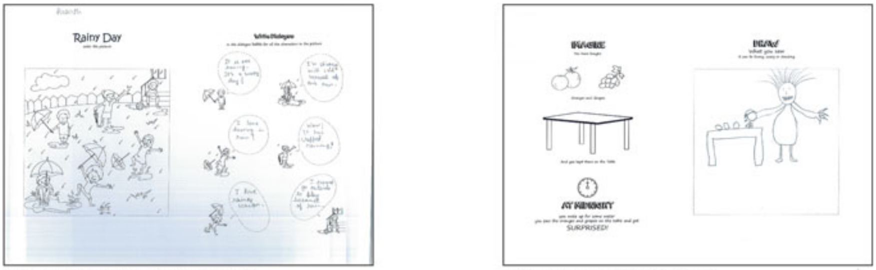
Fig. 61.1 Some of the initial responses gathered from the children in phase 1

Table 61.2 Intraclass correlation coefficients

	Type	ICC	F	df 1	df 2	p	Lower bound	Upper bound
Single_raters_absolute	ICC1	0.96	77	46	94	7.4e−58	0.94	0.98
Single_random_raters	ICC2	0.96	80	46	92	1.3e−57	0.94	0.98
Single_fixed_raters	ICC3	0.96	80	46	92	1.3e−57	0.95	0.98
Average_raters-absolute	ICC1k	0.99	77	46	94	7.4e−58	0.98	0.99
Average_random_raters	ICC2k	0.99	80	46	92	1.3e−57	0.98	0.99
Average_fixed-raters	ICC3k	0.99	80	46	92	1.3e−57	0.98	0.99

No. of subjects = 47 and no. of Judges = 3 conducted with children during the second halves of the school day with prior consent and permission from the school authorities and parents. The total administration time was approximately 20–30 min for the pre-test.

After the pre-test, children were introduced to the VL activity program using scaffolding during weekends at their respective schools. Children below five years of age were accompanied by their parents. Each school group consumed approximately 8–10 h to complete all the 37 tasks over the weekends. Half of the tasks were introduced on Saturday and the rest on Sunday for all the four groups. During the experiment, every child was provided with printed tasks one by one. Each child was asked to solve the tasks and was guided throughout the process. Average time spent to solve each task was approximately 15 min. Certain tasks were more time consuming than others. The main objective was not to judge the outcome of these tasks based on their complexities; instead, we aimed that children would understand the VL concepts when solving those tasks. Figure 61.3 shows the experimental setup at different places with different groups. A ten-minute break was given for every hour of the session. Some of the results are shown in Fig. 61.2. After the VL activity program intervention, a post-test was conducted with similar protocols followed during the pre-test.



(2a) - Responses generated by a child from opportunity school for one of the VL task from the VL activity book.

(2b) - Responses generated by a Nankari locality child for one of the VL tasks from the VL activity book.

Fig. 61.2 Responses generated by the children during phase 2

Fig. 61.3 Nankari society children *(left)* and opportunity school children *(right)* working on the VL workbook

61.7 Results

A two-way ANOVA was conducted that examined the effect of schools (1/2/3/4) and condition (Pre/Post) as independent variables, whereas combined score for each individual of tasks as the dependent variables. Statistically significant improvement in the VL test scores was found at all the four VL categories regardless of children's school background following the VL activity-based learning. Tables 61.3, 61.4, 61.5, 61.6 and 61.7 summarize the results.

Table 61.3 Descriptive summary of the results for each school for pre–post-tests

	n	C1-Pre	C1 -Post	C2 -Pre	C2-Post	C3 - Pre	C3 -Post	C4 -Pre	C4 - Post
School 1	22	3.73	6.14	4.86	6.77	11.1	16.5	2.86	3.23
School 2	18	4	5.83	4.67	5.72	11	12.8	2.5	3.11
School 3	16	4.62	5.38	5.38	5.75	13.3	14.4	2.62	3.62
School 4	31	3.97	5.13	4.84	6.26	11.9	14.3	2.74	3.16
	Mean	4.08	5.62	4.937	6.125	11.82	14.5	2.68	3.28
	SD	0.379	0.451	0.307	0.496	1.062	1.52	0.154	0.231

C1 = Visual elements and relationships, C2 = Visual creativity and imagination, C3 = Visual conceptualization, and C4 = Visual reasoning and analysis

Table 61.4 Visual elements and relationships

	df	Sum sq	Mean sq	F value	Pr(>F)
Condition	1	103.2	103.2	71.11	7.02e−13***
School	1	3.843	3.843	2.929	0.0906

Table 61.5 Visual creativity and imagination

	df	Sum sq	Mean sq	*F* value	Pr (>*F*)
Condition	1	70.81	70.81	56.55	4.9e−11***
School	1	0.49	0.4935	0.259	0.0612

Table 61.6 Visual conceptualization

	df	Sum sq	Mean sq	*F* value	Pr (>*F*)
Condition	1	339.4	339.4	45.31	1.79e−09***
School	1	1.5	1.535	0.123	0.726

Table 61.7 Visual reasoning and analysis

	df	Sum sq	Mean sq	*F* value	Pr (>*F*)
Condition	1	13.24	13.241	9.923	0.00225***
School	1	0.01	0.0081	0.008	0.93

61.8 Discussion

In the current preliminary study, we investigated the effectiveness of the VL activity workbook on the VL skills of the children. This research aimed to demonstrate the introduction of VL programs in the school curriculum. Although there is no single correct answer about introducing VL skills in the school curriculum, we proposed a VL activity book integrated with scaffolding for the children up to 7–11 years of age based on our literature study and study done in phase 1. These tasks were designed broadly on our four conceptual constructs or framework described in Sect. 61.5. We did not aim to distribute equal weight to each conceptual construct. Instead, we wanted the categories to encompass all the major constructs provided in the VL literature. Results show significant improvement in children's visual literacy skills after our VL activity-based learning program's intervention, thus rejecting the first hypothesis. However, students' scores did not differ when considering their school and background, which was in congruence with the second hypothesis. We found that children were eager to learn and liked a new approach to look at the visuals. The majority of children expressed interest in such workshops and activity-based learning. Children were able to identify technical concepts such as warm/cool colors, perspective, salience in images. Visual imagination also significantly improved, which was evident in their post-test results. Initially, children had difficulty in comprehending gestalt images. However, after working on the VL activity book, children showed interest in solving similar kinds of problems.

Based on these findings, we recommend having several such VL skill development interventions to promote these neo-skills in children's best interests. This study identified many areas that need to be explored when developing VL support systems. The use of appropriate visuals and different mediums should be considered when designing such interventions for different age groups. Perhaps, a VL framework/constructs should be first identified that would help to design a VL support system. These constructs might vary between different age groups and the user group depending on the context. Second, visual training content, and different mediums (tools) such as virtual reality, augmented reality, etc., should be utilized to design a novel mode of interventions to introduce visual literacy.

Acknowledgements We are grateful to children, parents, and the school administration to help us facilitate the study.

Appendix 1

1. Visual elements and relationships (Pre-post)

Two paintings were chosen with the following questions for the pre–post-test [36].

(a) Pre-test painting: *Van Gogh – Terrasse des cafes*
(b) Post-test painting: *Van Gogh – The night café*

Colors

What colors do you see in this painting?

1.1 Could you please identify warm colors in the painting? (Yes or No).
1.2 Could you please identify cool colors in in this painting? (Yes or No).

Shapes

1.3 What shapes do you see in this painting? Could you point those shapes? (Yes or No).

Lines

1.4 What lines do you see in this painting? Could you point those lines? (Yes or No).

Perspective

1.5 Which things looks closer to you? Could you point them? (Yes or No).
1.6 Which things looks far away? Could you point them? (Yes or No).

Salience

1.7 Which things looks/seems important to you in this picture? Could you please point them? (Yes or No).

2. **Visual Creativity and Imagination**

2.1 **Pre-test Task**—Design a logo for a bicycle company. Please design 5 different logos which represents the company in the blank boxes given below. Two sketches are already given as example. You surely have more ideas to design additional logos.

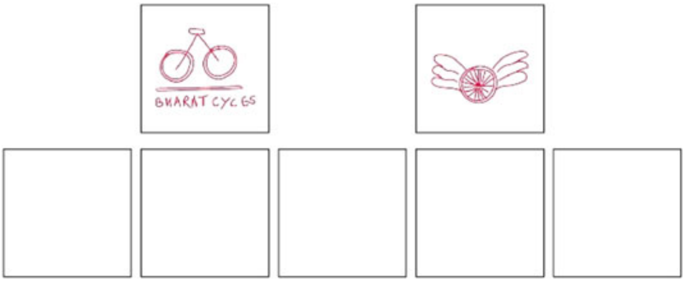


Image 1 Pre-test sample (Task 2)

2.2 **Post-test Task**—Design a logo for a shoe company. Please design 5 different logos which represents the company in the blank boxes given below. Two sketches are already given as example. You surely have more ideas to design additional logos.

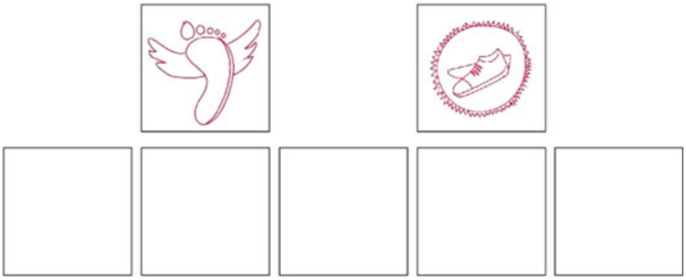


Image 2 Post-test sample (Task 2)

3. **Visual Conceptualization**

3.1 **Pre-test Task (Gestalt)**—What do you see in this picture?

Image 3 Example of a closure test stimulus: dog, from the Street Gestalt Completion Test (1931). Street, R.F. (1931). A Gestalt completion test. Teachers College Contributions to Education

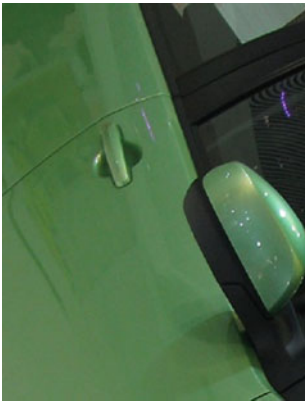


Image 4 Gestalt example of a Car

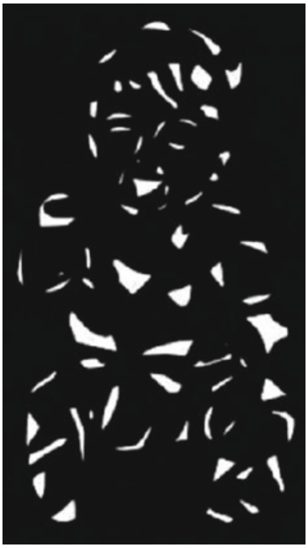
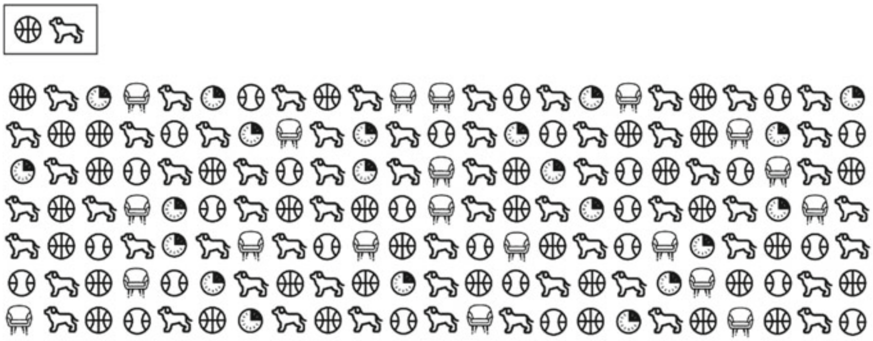


Image 5 Example of a closure test stimulus: dog, from the Street Gestalt Completion Test (1931). Street, R.F. (1931). A Gestalt completion test. Teachers College Contributions to Education

Image 6 Gestalt example of an aircraft, from Farrell (2013). Farrell, Teresa, “Measuring Visual Literacy Ability in Graduate Level Pre-Service Teachers” (2013). Graduate Student Theses, Dissertations, & Professional Papers, 4130

3.2. **Post-test Task (Gestalt)**—What do you see in this picture?

3.3. **Pre-test**—Pair cancellation test (adapted from Woodcock-Johnson III tests of cognitive abilities). This Test has 17 correct pairs *(Image 7 below)*



Braden, J. P., & Alfonso, V.C. (2003). The Woodcock-Johnson III Tests of Cognitive Abilities in Cognitive Assessment Courses. WJ III Clinical Use and Interpretation, 377–401.

3.4. **Post-test**—Pair cancellation test (adapted from Woodcock-Johnson III tests of cognitive abilities). This Test has 17 correct pairs. *(Image 8 below)*

4. **Visual Reasoning and Analysis**

4.1 **Pre-test**—Raven's progressive test (A5, A11, B3, B1 and B5)
Raven, J.C. (1990). Test de matrices progresivas. Editorial Paidos.

4.2 **Post-Test**—Raven's progressive test (A8, A12, B4, B2 and B6)
Raven, J.C. (1990). Test de matrices progresivas. Editorial Paidos.

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Chapter 62
On How to Add SALT: 'PLAYGORA'—A Real-World Case Study and Experimentation (Out of the Lab)

Robert E. Wendrich

Abstract This contribution presents a real-world case study and experimentation based on the Serendipity, Ambiguity, Laterality and Tangibility (SALT) conceptual architecture. We present early-stage design engineering processes (DEP) coupled with assisted human–machine creativity and directed towards research Out of the Lab in which we engaged public participation during a nine-day public international design event in The Netherlands. The 'Playgora' study and experiment(s) were executed and conducted (i.e. early-stage research) with hybrid design tools (HDTs) and environments (HDTEs) support systems imbued with SALT.

62.1 Introduction

62.1.1 An Early-Phase SALT Case Study

This case study is based on physical reality and tries to give tangible proof of the SALT hypothesis in a real-world setting named 'Playgora' (PLG). We present early-stage design engineering processes (DEP) coupled with assisted human–machine creativity and directed towards research Out of the Lab[1] [1], in which we engaged public participation during a nine-day public international design event in The Netherlands that brought together the work of 2,600 designers for an audience of 335,000 visitors.

The study and experiment(s) were executed and conducted with hybrid design tools (HDTs) and environments (HDTEs) including support systems for data acquisition and repository. All the interaction and generated data were acquired and mined with various observation and capture technologies and stored real time on

[1]Scientific activity is not 'about nature,' it is a fierce fight to construct reality. The '*Out of the Lab*' is the workplace and the set of productive forces, which make construction possible.

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A. Chakrabarti et al. (eds.), *Design for Tomorrow–Volume 3*,
Smart Innovation, Systems and Technologies 223,
https://doi.org/10.1007/978-981-16-0084-5_62

a data repository for analysis and evaluation. A feedback loop[2] (real time) was made available to participants synthesized from user generated content and data.

62.2 PLG and SALT in Public Space

62.2.1 *What is PLG?*

PLG is a metaphorical assemblage on the words ‘play’ as, for example, identified and addressed in Homo Ludens [2] and the Greek word ‘agora’, a public (i.e. playgoers) open space used for assemblies and markets [3]. PLG guides the development and functioning of cyber-physical systems, networks and its users to the realization of potential through emergent creative behaviour, intent and meta-cognitive knowledge. We point to Voltaire’s [4] observation that the demonstrative force of a public show is entirely entangled with the constitution and character of its public and realize that it is a surprisingly heterogeneous undertaking.

Design could be the ‘happy medium’ to link people, society and technology to improve, sustain and reframe the status-quo of contemporary mono-culture thinking, progression and doing, through meaningful communication, participation and experiential story-telling, interaction and creation of narratives (see Fig. 62.1).

Testing devices, systems and machines play a fundamental role (e.g. social media) in the formation of enlightened social practice and democratization of ‘knowledge’ (i.e. truths, ideologies and philosophy) as a means by which esoteric or natural ‘knowledge’ might be diffused pervasively through innumerate spheres and social contexts [5].

62.2.2 *Environment and Setup*

The PLG design environment entails innovative interactive software solutions and design tools to create meaningful communication, experiences, personal involvement and social inclusion within various contexts and/or domains. People cannot feel data; however, by tangibly taking advantage of touch (a simple emotional phenomenon), add ambiguity in visual stimuli, we aim to stimulate the lateral thinking capacity and capability in people (i.e. users) possibly leading to serendipitous events and novel and/or alternatives in ‘design’ outcome (See Fig. 62.2).

The placement, location and layout of the various interactive areas were in such that the HDT’s (i.e. 2 Tablets + 1 Smartphone) were mounted dead centre on the tabletop. The digital content monitor (DCM) showed a scrollable digital content with

[2] We characterize this process as a simple feedback loop of virtual content based on users’ physical, tangible and behavioral dynamics.

Fig. 62.1 Orthogonal projection of HDTs in public arena, showing test and experiment environment with various inactive tools and screens

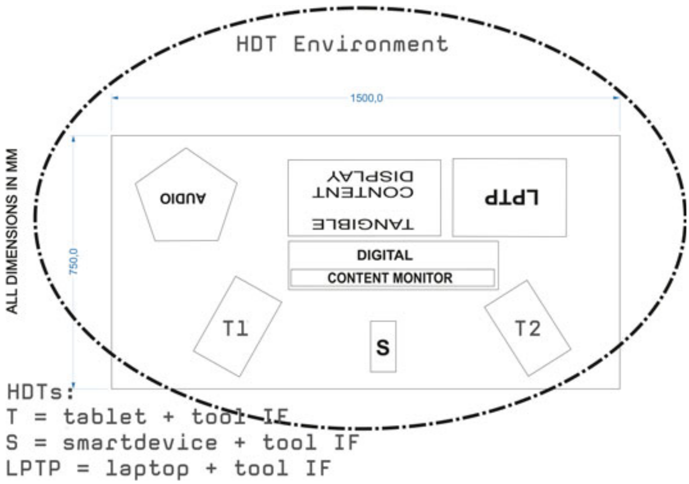
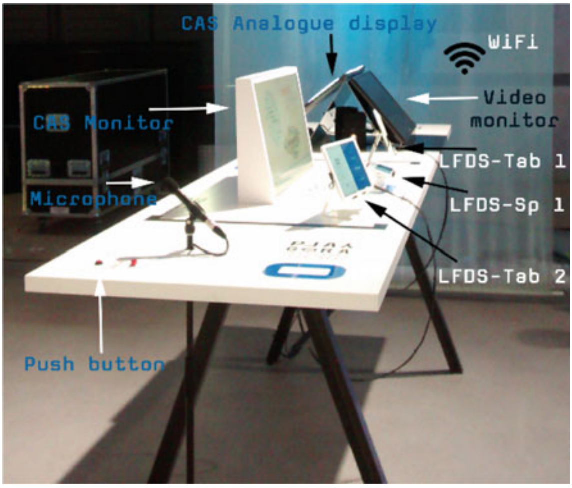


Fig. 62.2 Diagram set-up PLG HDT environment and tools

Fig. 62.3 Typical set-up PLG with HDT devices, systems and machines



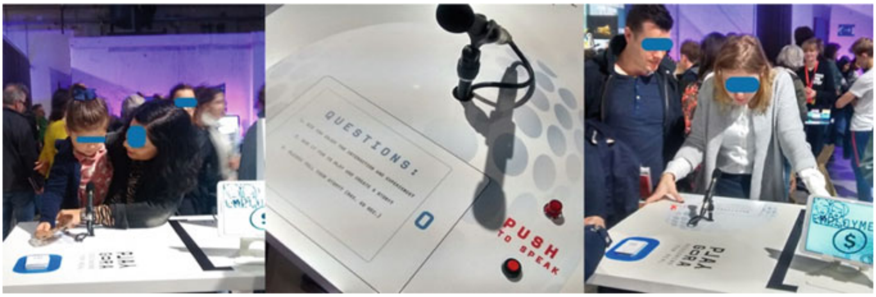


Fig. 62.4 PLG audio set-up (speakers' corner) and audience engaged in (inter)action (left/right)

generic simple and archetypical icons/themes that were selected based on the chosen 'context' (see Fig. 62.3).

A led lightbox with wide variety black-and-white depictions in archetypical icons and signs was located directly opposite of the DCM to visualize and attract users to engage in generative design activity. On the left corner of the set-up, the audio area including a high-definition microphone, push-to-speak button and red indicator light was facilitated. The audio stream was captured 24/7 by means of a strategically placed high-definition microphone. Three questions[3] were framed and placed next to the microphone to trigger story-telling, enquire verbal 'stutter' and exclamation from the participants/users (see Fig. 62.4).

In addition, we mounted an IP-Camera at 4.5 m above the PLGR set-up pointing directly downward to monitor and observe all the traffic of visitors and interactions

[3]Three questions were: (1) Did you enjoy the interaction and experience? (2) Was it fun to play and create a story? (3) Please tell your story (max. 60 s).

of the participants. We collected and acquired a total of 14 GB in video data (.mp4) and 2 GB in audio data (.wav) during the event.

Matters of concern, societal issues and challenges exist only if the concerned groups create them as such by making them visible, tangible, audible and perceptible in the public sphere [5]. People (e.g. users) should congruously and relentlessly made aware to immerse themselves in explorative iterative creative processes by use and means of intelligent interactive hybrid design tools and environments (iHDTs; iHDTEs).

62.2.3 *Approach, Context and Tasks in PLG*

The approach we take in this project is to test and experiment with a large number of users in public space. In fact, we take our research Out of the Lab environment and try to connect our framework and approach to the general public (rest of society), in this paper named users. It was stated that '…the social world cannot exist on one side and the scientific world on the other because the scientific realm is merely the end result of many other operations that are in the social realm' [5].

For instance, take the case of climate action and change, the depletion of resources, the transitional and renewable sources of energy, addressing issues in access and lack of potable drinking water or the continual increase of inequality and unemployment.

Formatting of (global) economic agency, concerted activism and achieving sustainability goals (i.e. local, national and global) coupled with these societal concerns, induced and instigated by the asymmetries and unbalances of competencies by supply and demand, need and greed and haves or have nots.

Making 'things' public through highlighting and to demonstrate the existence, organize (e.g. public) investigations on possible solutions, test and facilitate experiments designed to (re)qualify, for example, policies, laws and governance; products, systems and services; and (re)analyse and (re)evaluate their performance which helps to reduce the socio-cognitive handicaps that cripple people and society.

Visitors create their own present and near-future scripts in conjunction with the PLG set-up and hybrid design tools (HDT). Individualized and cooperative design combined with hybrid design tools has the capacity to act as the missing link between humans, society and technology (STS). The blended design environments (spaces) entail innovative interactive software solutions and design tools to create meaningful communication, experiences, personal involvement and social inclusion within various contexts and/or domains (see Fig. 62.5).

The design task to be executed voluntarily by heterogeneous users was to create user generated content by expression through narrative of experiences (e.g. associative reasoning), audiovisual representations (e.g. designing, engineering) based on a prescribed context, externalization of opinion and address meaning. The objective of the task was to nudge the user's think, feel and react on the specified context: '*On*

Fig. 62.5 Top view audience in PLG blended design environment

Societal and Cultural Issues and Challenges', spur design interaction to create visualizations of their individual perspective or story based on a selected *theme* within the specified *context.*

62.2.4 The Challenge Ahead

The challenge now is to rethink and readapt completely the processes according to the available technologies, proposing new design models, conceptual blending strategies, iterative-layered processes and/or architectures that can leverage the digital continuity in both physical (PPD), virtual (VPD) and hybrid product[4] development (HPD). Whatever meaning or intention one may have, in essence and in general, people 'shape and design' their own lives and 'form' their own perspectives on life.

Individualized design combined with collaborative dynamic activity (e.g. discussion, narration and negotiation) in conjunction with hybrid design tools has the capacity to act as the missing link between humans, society and technology (STS), thereby addressing the fundamental core issues (e.g. regional, national and international) and global challenges at hand.

62.3 Out of the Lab, Making Things Public and Context

62.3.1 Observing SALT Through Public Engagement and Externalization

Externalization through representation, by making use of diagrammatic representations, or mental diagrams in the mind's eye, which provide it with powerful inference processes [6], coupled with aid of computational and/or artificial systems therefore

[4]Product could be artefacts, systems and/or services.

seems a logical and obvious step to assist human action, communication and interaction. Although the HDTs input–output interaction modalities and virtualization system, by the standards of formal logic, are a jerry-built structure, we depict as ‘loosely fitted’.

But it gets us through the intuitive externalization process amazingly effective and addresses slow and fast thinking efficiently. Users rely on quite powerful but somewhat unreliable inference operators, so-called heuristic processes, to discover new conclusions [6]. The thought process (i.e. to think like a mountain) here is considered as a holistic view on where one stands in the entire ecosystem.

To think like a mountain [7] means that to have a complete appreciation for the profound interconnectedness of the elements in the ecosystems. Later, in the process, users subject them to careful scrutiny, using more microscopic and reliable inference rules to test the doubtful steps. In the common practice of reasoning, discovery and verification are intermingled, we may alternate between them during the whole course of our thinking [6]. The elegance of the HDTs is the immediacy and integrated activity to facilitate and allow users readily available access and congeniality with the HDT environment [8].

62.3.2 HDTs Thinking Machines as Creative Inventing Tools

HDTs are machines for thinking and inventing [9]; by interaction and intentional stance, the user is enabled through the interface and workspace (blended space) to immerse and engage in creative and design processes. The twist and/or mix between analogue interplay and digital feedback loops require very little knowledge of the system or various interaction modalities. The object of the HDT inventing machine is to facilitate a low threshold, whereby the interactive instrumentation and tool layout initially have no preset limits, constraints or boundaries for the prospective user.

To start an iterative design process, the user can either use hand-drawn sketches, images, 2D and 3D objects, snippets and any other type of content or material. The aim is to create designs or instances with the aid of a high-definition video camera and capture instances with keystrokes. The keystrokes are input (i.e. captures) for the system as separate and individual instances over time, whereby the system simultaneously generates virtual output in a blended fashion. The blended stacks consist of multiple layers of instances generated by the user(s) over the duration of process time.

Blended space is filled with numerous images (i.e. stacks), and multiple instances can be unstacked and repurposed for other stacks through simple tack, copy and paste instructions on screen. The user interface (IF) has a very simple, clean and transparent intuitive configuration to facilitate easy progress and interaction during the design process. Over the last decade, we tested and experimented many configurations, variety in embodiments and version adaptations of the HDTs with thousands of users, either laymen novice and/or experts. The primitive arrangement of the HDTs and first impression simplicity of the HDT system interface and interaction modalities

Fig. 62.6 Users' interaction, engagement and experience with devices, systems and machines

Fig. 62.7 Participatory design and collaboration of multiple users and interested audience

gives users' confidence, supports motivation and brings forth direct results in virtual outcome, enjoyment and surprise (see Figs. 62.6 and 62.7).

The HDTs support our hypothesis that computational tools could intuit, enhance and assist users in their sense-making, design and creative endeavours whilst making sure that user could rely on their individual explicit and tacit knowledge, human capabilities, personal capacities and idiosyncratic stance.

62.4 Data and Content Generation

We measured all the interactive progressions and actions in the limit over time. The keystrokes were tracked and harvested from our *imagedb_server*. In Table 62.1, we show the results of user interactions (UIs) of all the devices, measured and acquired from the system and machine databases. We differentiate between visible and invisible 'captures', this means that the visible interactions became part of the real-time feedback loop, whereas the invisible 'captures' were tagged not saved and made recurrent by the system.

Table 62.1 Statistical result content captures of total event duration

Total amount captures HDT devices from Public IA						Percentage visible captures: 74.4%—9 days					
Day Nr.:	Total/Day:	Visible:	Invisible:	Tl:	Visible Tl:	T2:	Visible T2:	S:	Visible S:	LPTP:	Visible LPTP:
1	185	163	22							–	
2	213	190	23								
3	32	19	13	–						–	
4	48	30	18								
5	43	34	9	–						–	
6	76	46	30							–	
7	56	29	27	-						–	
S	280	212	68							–	
9	147	81	66							–	
TOTALS	1080	804	276	262	188	183	148	365	254	270	214

MAC Address	
Tl:	19eb8b0a00aba3cc
T2:	56386c29479975c
S:	6c255abM1af2d5t >
LPTP:	webclient l

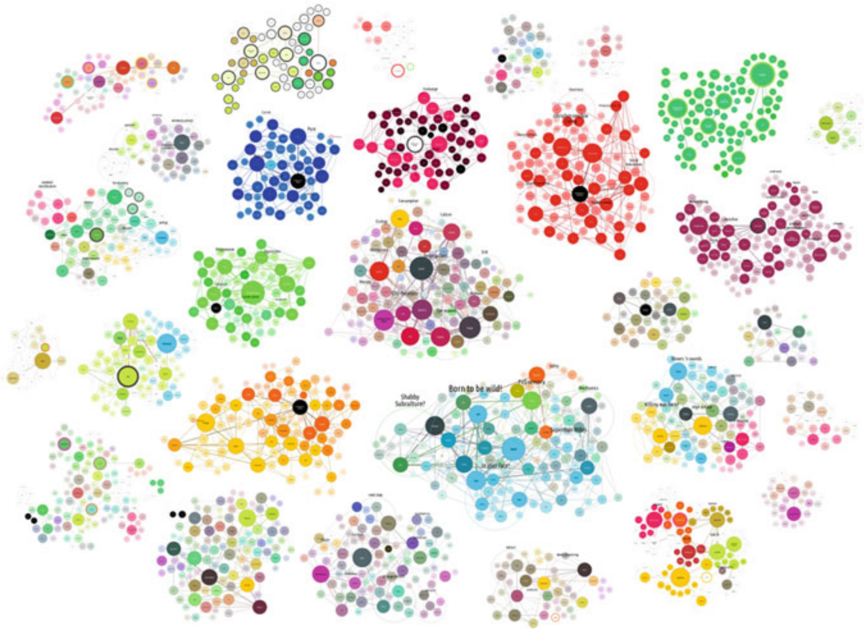


Fig. 62.8 Associative network visualization from interactive and iterative generative datasets

In addition, we collected data from the audience (i.e. users, participants) during generative and iterative design sessions over the duration of nine days. These associative reasoning and narrative tracings were captured and visualized with one of the tools and instantly connected and derived from discussion, enquiries and story-telling between the facilitator(s) and the audience or active participants (see Fig. 62.8). Participative technological evaluation (PTE) is very useful to elaborate, investigate and improve devices, systems and machines, whilst allow for more sustained and articulated forms of citizens expression. This emerges at a locus of particularly great complexity, through the interface of science and society. However, this taking into account of the impact of technological innovations (e.g. interactive technological evaluation) on society or on concerns of democracy is not new [10]. At the end of the PLG process (event), we returned to our institute's laboratory, where discussion and evaluation started on how to analyse, synthesize and present the data; based on the results, the specific audience (heterogeneity), the context of the event and the decisions the datasets might entail the available time during the testing and other relevant resources.

62.5 Evaluation

PLG was both an accident and success. People are in general very curious or at least driven with some curiosity and show interest in the overall layout and scope of the PLG setup. We observed that eighty percent of the audience do not engage themselves, participated immediately or become active in their actions or immersed in activity. Only after some nudging, giving attention and/or reach out people were willing to pick up the devices and asking: 'What to do next'? 'How does it work'? or 'Why is this relevant'?

Relations and associations between *context(s)* framed from presupposed societal issues and challenges (*content*) were often considered 'not really relevant' or 'of interest' at the start. However, after some enquiry and questions by the facilitator(s), about twenty percent of the users started to interact, connect and make representations. Some users were able to connect narrative based on a constraint challenge and create simple visuals with the tools. If asked if they had a concern or societal issue, in general, these were topical like, for example, 'plastic soup' or 'climate change'.

Younger audience (10–30 years) was faster and more spontaneous to pick up and play with the tools. A substantial number of these users were able to frame and visualize scenarios based on the design task. However, a larger number lacked attention or interest to get involved in the actual design task. One of the problems was, deduced from questions and responses, that the total event was overwhelming, and cognitive overload made most visitors to be overstimulated in their senses and concentration levels.

Older participants showed some anxiety initially to use the devices and system features. Most were afraid that 'something would happen'. Demonstration and some instructions helped to get these people interactive and worked collaboratively (i.e. friends, family and bystanders) to the creation and generating of content. Most people (audience) understood the tools and were able to formulate stories and make satisfactory visuals to go along with the storyline.

The audio area (speakers' corner) was the most spontaneously used tool of the PLG setup. Most users followed the sequence, first tool use and content creation afterwards reflection on tool interaction, experience and story-telling. However, we observed (and listened afterwards) many people to go up to the microphone and speak their minds, stutter randomly or answering the questions placed next to the microphone.

We ended up with a lot of data from the various resources and observed, received and witnessed many positive reactions and feedback from the audience. They found it novel, exciting, thought-provoking and often quite interesting to represent in multi-modalities based on context-aware societal issues and challenges.

The context of the event (*design*) and our PLG set-up created some friction in the publics' expectations, constraints in interests and trade-offs oscillating between '*fun and play*' [2] and '*serious and play*' [11].

62.6 Conclusion

To conclude, SALT as part of tools and systems to support and facilitate users in their interactions, communications and processes (e.g. design, creativity, engineering, sense-making, etc.) is argued to be beneficial for society, whilst enhance and foster democratization and helps in creating insight and understanding in (e.g. common, mutual) interests, hidden knowledge and tracing unknowns (i.e. unknown unknowns).

PLG was a prototype of an open-ended space; basically, it was a space on the edge of the unknown, perhaps even the frayed seam of societal fabric, however, a space for exploration, for probing experimental associations, meanwhile for investigating exploration in itself. It was a blended space, where the processes of knowledge (i.e. implicit/tacit to explicit) are examined and enquired into that allow the representation and visualization the production of knowledge in the entire multiplicity of its resources.

Thereby making visible, the mutually constitutive processes of translation through generative iterations that transform heterogeneous actors into seamless hybrids and hybridity networks. Automatically, a lot of bias and subjectivity occurs when tests and experiments take place as public evaluation in a synchronous or asynchronous manner in the presence of audience (i.e. users, participants) and in conjunction with various technological mediations, such as, interactive communication devices, information systems and machines.

Subjectivity is a process (not a 'thing'), which relies on two critical ingredients: the building of a *perspective (image making)* for the images in mind (*mental images*) and the accompaniment of the images of *feelings* [12]. Subjectivity is considered the first and indispensable component of consciousness. Every increment of design in the universe begins with a moment of serendipity, and the undersigned intersection of two trajectories yielding something that turns out, retrospectively, to be more than a mere collision [13]. You never can tell when SALT will strike, if given an opportunity.

Globally, collective, collaborative, networked users should be enabled to engage through democratization (e.g. communications, interactions and connections) and increasingly pose significant challenges (e.g. structures, analysis, behaviours and doctrines) that could lead to have strategic impact(s) (e.g. societal, industrial, resources, energy and environmental), experience global communal relations and pursue alternative agendas for effective change, affect and stance.

The SALT architecture and framework are discussed more in-depth in an additional article titled as: 'Why Add, SALT?' the case for tools to support Serendipity, Ambiguity, Laterality, and Tangibility (SALT). Unfortunately, this additional and supporting article was not accepted for this conference and/or proceedings.

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Chapter 63
Influence of Culture and Tradition in the Tribal Architecture of Meghalaya

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Abstract Northeast India is home to several tribes and tribal communities. In a tribal context, art, architecture and culture are intertwined into the day-to-day activities. Although most vernacular structures in the northeast use similar locally available materials like bamboo, wood, mud and thatch, they are different from each other. This factor of identity stems from their diverse cultural practices and beliefs. The paper explores the relationship between culture, art and architecture in northeast India, taking the case example of Meghalaya. It further investigates the scenario by analysing the two most important housing typologies of Meghalaya—Garo and Khasi houses.

63.1 Introduction

Meghalaya is a north-eastern state of India and part of the seven sister states (Fig. 63.1). The state tucked in a picturesque corner of India is known for its rich biodiversity as well as its tribal culture and folklore. Meghalaya's population is predominantly constituted by tribal groups. The Khasis, the Garos and the Jaintias are the largest groups. Other groups comprise of the Hajongs, the Biates, the Koches and Rajbongshis, the Boros, Dimasa, Kuki, Lakhar, Tiwa (Lalung), Karbi, Rabha and Nepali. The two dominant vernacular housing typologies in Meghalaya are Garo house and Khasi house. Garo houses are built by the Garo tribe community while the Khasi houses are the innovation of the Khasi tribe and many Jaintias. Both the housing forms utilize locally available materials such as bamboo, timber, cane, mud and thatch. However, the distinction between the two housing forms arises from their cultural practices, beliefs, tradition and their response to the physical attributes of the context.

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A. Chakrabarti et al. (eds.), *Design for Tomorrow–Volume 3*,
Smart Innovation, Systems and Technologies 223,
https://doi.org/10.1007/978-981-16-0084-5_63

Fig. 63.1 State of Meghalaya (*Source* Author)

63.2 Garo House

63.2.1 Narrative

Garo house is a housing technique devised by the Garo tribe of Meghalaya. Garo villages are situated in the dense irregular hills of the state where bamboo is available in abundance. Populated with forests and concentrated vegetation, these hills experience heavy rainfall around the year. Garo tribes have an affinity towards slopes and steep inclines and thus build their homes on such terrains with piles for protection (Fig. 63.2).

The process of building houses is a community affair for the tribe. People build their own houses with the help of family members, friends and fellow villagers. The knowledge of building these traditional tribal houses is inculcated in the youngsters at an early age by giving them hands-on training during live constructions. This step becomes crucial for the community since it is viewed as a means to pass on the art of building to the future generations. The Garos consider the active participation of youngsters and elderly alike as a mechanism to store and carry forward traditional knowledge, craftsmanship and artistry.

Garo villages are agglomerated, amorphous and semi-nuclear. The settlements form a ring of houses around an irregularly shaped common space called '*Atela*' or '*Sara*'. Granaries and storage structures are built outside the ring of main houses. Each cluster consists of a village head house *(Nokmandi)*, family houses *(Nokmong)*, a bachelors' housing structure *(Nokpante)*, granaries that are built 30–40 m away from the main house to prevent the spreading of fires *(Jamnok)* and communal meeting space *(Kachari)*. Each household has two houses, one main house and the other one in the agricultural field on the top of a tree, called a *Borang* to prevent attacks from

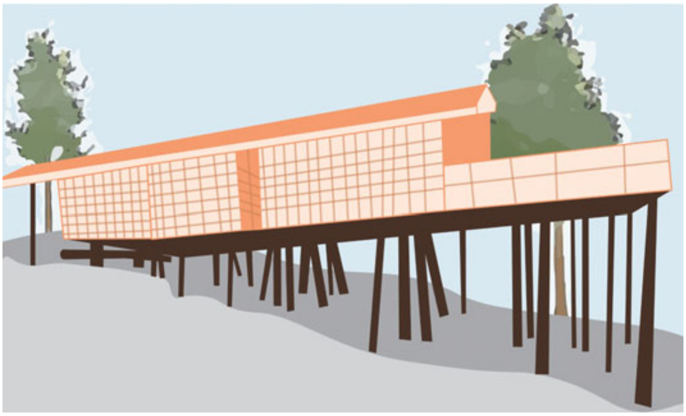


Fig. 63.2 Typical Garo House (*Source* Author)

elephants and wild animals. The presence of *Nokpante* or a bachelors' apartment stems from their belief system that teenage and unmarried boys should be separated from young women of their age. This structure also acts as a knowledge acquiring place where the art of cultivation, construction, tribal practices and life lessons are taught by the village seniors.

Generally, the Garo houses are built facing the East direction. The Garos believe that the Sun's rays entering their doorways in the morning would bring prosperity to their families. Their abode of Gods is represented by several long and upright bamboo with leaves placed in front of or near their houses. The Garo houses are constructed on an inclined platform; the front part touches the ground while the rear end is raised to house farm animals and birds. This inclination and elevation are intentionally achieved to prevent these animals and birds from entering the main houses since they are considered impure. There are two significant columns within the main room, erected for holy reasons. One, *Maljuri*, is placed near the wall of the front room and acts as a place of worship and sacrifices; the other, *Chusimra*, is placed near the fireplace and acts as a place for brewing drinks and storing large jars. Multiple white handprints patterns are a common sight in Garo houses. These symbols are imprinted on the main columns and roof beams of the houses during times of worship and are considered sacred.

63.2.2 Architecture

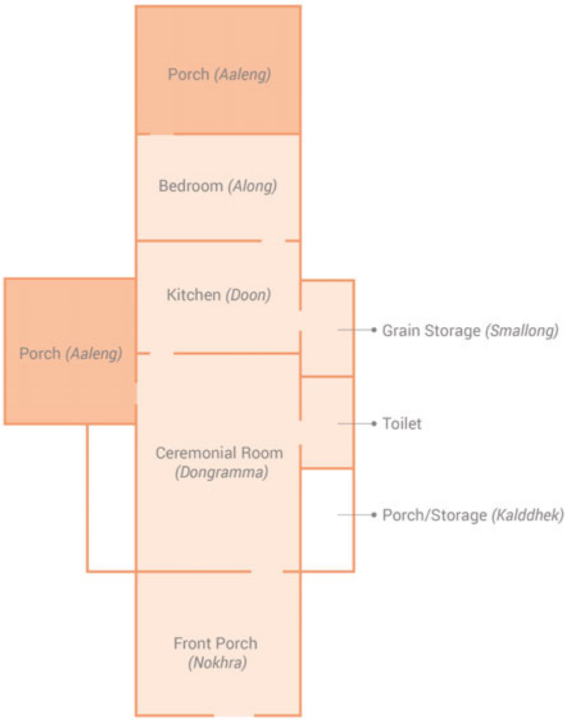
A Garo house is a linearly planned structure, about 80 feet long with an open porch and a verandah on either end [1]. The Garo chief's house is a larger version of the same model of about 260 feet by 40 feet. The house consists of a front porch where women pound rice *(Nokhra)*, a living room with a fireplace *(Dongramma)*, kitchen

(Doon), bedroom *(Along)*, toilet and a balcony/verandah *(Aaleng)*. The fireplace in the living room is built with extra caution on a mud plinth since the materials are mostly inflammable. A smoking shelf is erected above the fireplace to store baskets and keep food warm. Sanitary facilities like toilets are attached to the living room (Fig. 63.3). Rainwater harvesting in toilets is a common practice in Garo villages.

The closely-knit Garo tribe carefully selects materials locally available in the forests such as bamboo, cane, timber, palm leaves and thatch. The tribe never uses *Bambusa tulda*, a species of bamboo for construction since they are used for worshipping and considered holy. The profuse use of bamboo in every part of the house, including door frames and room dividers, makes it peculiar.

The house is constructed on wooden piles which are used to negotiate height inequalities of the ground [2]. In cases where the ground is even, large standing stones are used to erect the platform. Horizontal wooden beams are constructed, upon which the platform rests. The main structural system is made of wood. However, poles of bamboo may be used in some cases. The floors are made of bamboo mats which are reinforced with flattened bamboo boards. The walls have a brilliantly formed bamboo framework interspersed with bamboo poles over which flattened bamboo mats are placed. The roof is covered with a sizable amount of thatch, bamboo leaves or cane leaves. The front and back ends of the roof are extended over the verandah and are covered with palm leaves to direct the flow of rainwater. Bamboo rafters supported

Fig. 63.3 Garo house (*Source* Author)



over roof beams and the thatch cover are specially strengthened from the inner side with the smoke that arises from the hearth. Garo houses have sliding bamboo doors and windows that hang on bamboo rails. Due to the adversity of heavy wind and rain in the region, the number of openings is kept to a minimum. All the connections in the house are made with jute ropes and canes. This makes the construction flexible and helps dissipate pressure during seismic events.

63.3 Khasi House

63.3.1 Narrative

Famed for being earthquake resistant, the Khasi houses are crafted by the Khasi and the Jaintia tribes in Meghalaya. The house is a unique creation that is elliptical and symmetrical with an inverted boat form for the roof. There are a number of beliefs and traditions followed by the tribes while constructing a house. Steep slopes and river beds are not favoured by the people for the habitats. Constructing on a hill that is the last hill of the mountain range is also forbidden. The roofs of any two houses cannot overlap each other. Wood for construction is not procured from more than one type of tree and felling from sacred forests is prohibited. Like most Indian homes, the Khasi dwellings also face the east direction. Khasis consider the use of any metal as a taboo since they believe it may anger the Gods of thunder and lightning [3]. Hence, wooden and bamboo pegs are used for connections in place of nailing or bolting.

Site selection and construction process are elaborate events in the tribal community. The occupants build their own houses with the help of a few others. There is no monetary transaction that takes place for helping. The helpers are treated as guests and provided with food in return. People plan well in advance before constructing houses. Timber is procured in the months of winter and dried for a few months to remove the presence of moisture or termites. The construction commences during spring when people are relatively free. After the successful completion of construction, celebrations ensue through tribal dances and fowl sacrifice.

The tribes' belief system and culture are responsible for the distinctive shape of the houses. Khasis believe that a house is similar to an egg which is the key to creation and life. The elliptical shape of the dwelling is derived from the essence that just like an egg protects and nourishes the embryo, the dwelling shall protect its occupants (Fig. 63.4). The funeral pyre is square-shaped within the community. Hence, non-square conformations are preferred for a house [4]. The inverted boat-shaped roof is said to be an inspiration drawn from the shell of a turtle. The significance of traditional values is reinforced by the presence of a non-structural column called *Rishot-blei* within the house. It is considered as a means of metaphysical connection with the ancestors.

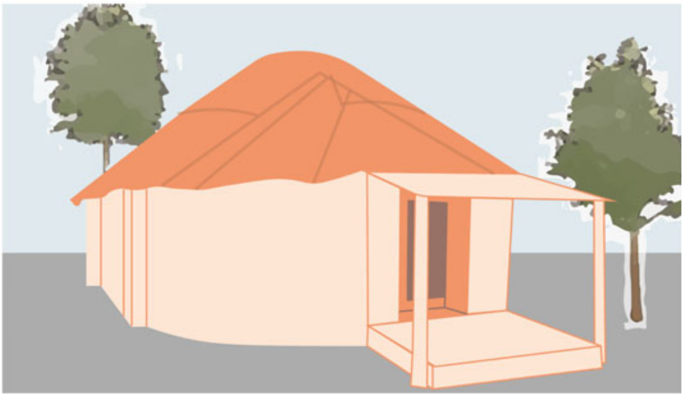


Fig. 63.4 Typical Khasi House (*Source* Author)

63.3.2 Architecture

The Khasi houses are rectangular with slightly bent side-walls or elliptical are semi-circular at the ends. The shape was originally semi-oval. However, this has evolved into more conventional shapes due to the introduction of modern building materials. The dwelling consists of an entrance porch *(Shyngkup)*, living room, hearth *(Rympei)* and private rooms [5] (Fig. 63.5). The entrance is equipped with a wooden plank at the end of the verandah to prevent animals from entering the house. The living room houses the sacred column, *Rishotblei*. The family gathers near the fire-place where the seniors or grandparents of the house narrate stories and folklore to the children. Strangers are not allowed into this section of the house. Beyond the hearth lie the storage rooms and bedrooms. Small skylights are incorporated at the top of the structure for daylighting [4]. Some houses have two doors from end to end for cross-ventilation, especially in regions where the humidity is very high.

The structure is made of stone, lime mortar, lime rendered mud walls, wood, bamboo and thatch. A two feet high plinth is constructed with mud, bricks or stone pillars. This is generally done in order to avoid insects and moisture seepage. The structural system is composed of beams and posts of timber. The flooring is supported by limestone or wooden pillars interlocked with the floor beams. Since the region experiences heavy rainfall and strong winds, the roof is extended closer to the ground with the help of additional beams that sit on a double stone wall. This strategy proves to be extra-efficient since the mainframes of the buildings are structurally independent of the walls and would be unaffected even if the walls fail during seismic events [6].

In plain regions, the walls are either made of wood or mud-plastered bamboo. In high altitude regions, the walls are made of stone. Stone blocks are also used in granaries and storage spaces to keep the contents cool. Decorations on the walls include red clay plaster up to a specific height and whitewashed surface above that. The traditional roof has properties of aerodynamics involved to tackle lashing rains and winds. The inverted boat-shaped roof is covered with layers of thatch and curved

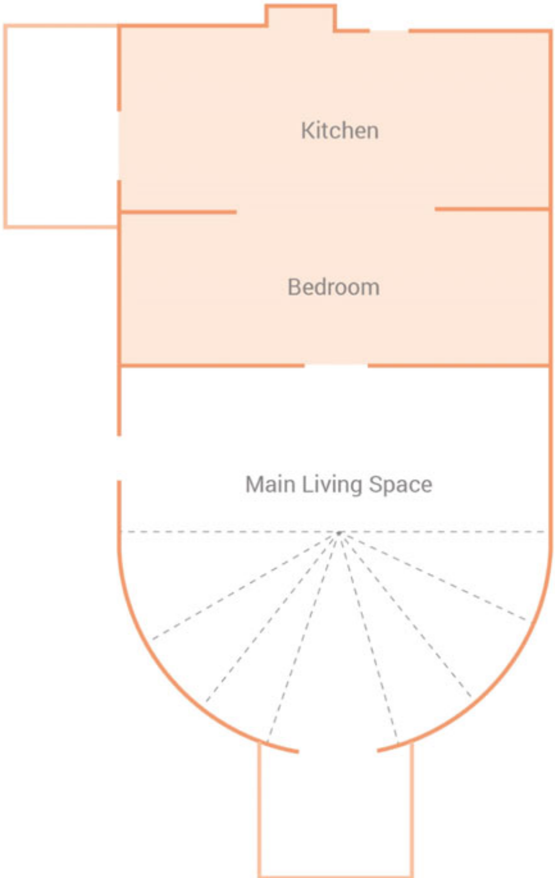


Fig. 63.5 Khasi house (*Source* Author) [1]

at the ends to minimize the impact of harsh weather. The no-metal policy is evident in the usage of wooden pins for fastening doors and windows. The connections are also non-metallic and mostly involve mortise joints which help to redistribute lateral loads on the framework.

63.4 Results

The traditional beliefs of tribes have shaped their settlement patterns and their housing structures. The aesthetics of the houses can be seen as a result of their mythology-based symbolism. Interestingly, the beliefs and taboos of the groups in construction have proven to have positive seismic, environmental and sustainable outcomes. Simple beliefs, which may seem rudimentary at the first glance, have effectively contributed to the evolution of the vernacular architecture of the region—the Garos using most types of bamboos for construction except *Bambusa tulda* because of their sacred value and the Khasis avoiding metal for connections owing to their inauspicious character are a few instances. The tribal architecture that stems from the culture mentioned above has evolved by being mindful about the harsh climate, frequent earthquakes, local resources and animism. Thus, all these characteristics, driven from culture and traditions, can be considered as the key reasons for their earthquake and weather-resistant characteristics.

63.5 Conclusion

Culture, art, symbolism and the belief systems have largely influenced the tribal architecture in terms of planning, aesthetics and semiotics, making them unique, localized and indigenous. However, their influence is gradually diminishing because of standardization and contemporary practices. With globalization, certain aspects of the tribal culture including but not limited to the practice of animism are being undermined and possibly on the verge of extinction. It is commendable that though there is increased usage of metal and modern construction materials in the form of metal roofs, bolts and brick walls, the underlying values and interior planning remain the same.

Acknowledgements This work is carried out under the research project titled 'Creating Digital Heritage of Representative Architectural Marvels from Each State of North East India', PI: Shiva Ji, IIT Hyderabad, India, funded by Department of Science and Technology, Ministry of Science and Technology, Government of India, under ICPS/IHDSR scheme 2019–22.

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Chapter 64
Image is a Tangible Element of Visual Communication: Role of the Image to Increase Social Awareness

Bappa Das and Debkumar Chakrabarti

Abstract Photographs act as an essential medium for increasing awareness among people. India is the second largest populated country and with mixed culture. Awareness and social issues is a really big mission. Proper use of imagery is crucial for raising social awareness. Consequently, one of the government's primary reform initiatives revolves around spreading awareness on various social issues. Since image or photograph has a long-lasting and significant effect on the human mind, the awareness campaigns by the government sizably depends on such a medium to reach out to a large number of audiences. In this situation, it may be specified that the visual medium, like various electronic platforms, posters, banners, hoardings plays a significant role in enabling such initiatives to develop social awareness at a larger scale across the society.

64.1 Introduction

Awareness is the key concept of a social issue. Media plays a very significant role in increasing social awareness [1]. There are two main types of visual communication, like electronic medium, and the other is print medium. Both of the media represent text and images or photographs. In India, there are many issues related to social awareness and directly linked to development for the society, like drug, alcohol, child labor, child marriage, girls education, polio, toilet-related, lack of literacy, HIV, TB, gender inequality and so on. To make aware of all such issues, to a huge diverse nature population with various religions, traditions, and cultures mix [2], the Indian government and some nonprofit organizations (NGOs) are constantly putting efforts. An image can create a lot more connection than written words and we become

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A. Chakrabarti et al. (eds.), *Design for Tomorrow–Volume 3*,
Smart Innovation, Systems and Technologies 223,
https://doi.org/10.1007/978-981-16-0084-5_64

more dependent upon visual media sharing information, education, and socialization. Visual information affects people's sense and image to convey a message. The power of a visual image is essential for emotion and influencing our conscious thoughts [3]. Photographs have been creating to help people understand they're emotional; that is, strong emotional effects seem to inspire more cognition about what an image depicts [4]. The image has an important social role. People are communicating their emotions when they watch the photograph [5]. Affective awareness through photography defined various components, which make the universal sense [5]. Photographs embedded in a message presentation always intend to convey a meaning and clears confusion when a complex message is presented with only texts. Photography is progressively popular in educational research and communication medium [6]. The realistic pictorial cautioning depictions strengthen smokers' intentions to quit smoking [7]. Photography is the most accessible medium that helps people to communicate easily and effectively. A photograph can communicate every moment of humankind [8]. Communication, which allows people to maintain social connections with their peers in a very emotional context; issues are coming how effectively this medium is being used in social message transmission in India where the population composition is highly diverse.

Photography supports new practices of social interaction [9] and helps in building identifiable brand [10]. The educational potential of photographs recommends visual information training for teachers. Increase eco-visual-scientific knowledge, outstanding properties for student education. Discussions on environmental protection increase the visual information of their target people and their communities [11]. Photography helps enriching a message presentation for particular target people experience and enhances social emotion [12]. Every individual should connect themselves with the context of photographs and to the message [13]. The poster image about the sexual abuse of girls was recognized by most of the people beyond the barrier of intended target age group and thus it became a big successful awareness campaign [14] for all. A country like India, the visual campaign for social awareness, plays one of the most significant role [15] where the scope remains on how to improve the usage of photographic image representation to enrich the communication specific to target group as well as with universal approach.

64.2 Objective of Study

The study aims at understanding the prevalent pattern of social awareness campaign using various human images in it and the perception of appropriateness to communicate the message to target people. Objectives are set to analyze the common practice and perception of representative human figure elements representing eminent personalities and target group representation to promote social messages. It assumes that a social awareness campaign has to influence people with a message that would help them to change their thinking on social issues. If the message is not clear, if it does not reach its target audience, if it does not look to apply to them, or if it just does not register at all, it can be said that the design is not reaching to destination. Use of appropriate photograph in visual campaign design is a commendable task.

64.3 Methodology

A social awareness campaign has to influence people with a message that will help them to change their thinking on social issues. To achieve the objectives of this research, a systematic review has been conducted from various research papers, journals, and the Indian government portal. The reason for this study is to reveal the current awareness on poster design for the target audience and further the need for study regarding this. All the literature review sought to observe the poster image or photograph used for design awareness poster. A survey on contemporary social awareness campaign (Indian government social awareness campaign) was conducted to understand the present scenario and to get the feedback from the target people on use of human image in the campaign. The image is truly relevant for the particular promotional awareness campaign. India is a country where many people in many religions are living together. India has a widespread culture and language. Every year Indian government spends a huge amount of money on social awareness program. In this research, we consider the only "Human Image," which is used in the Indian government awareness campaign to communicate with target people. Out of randomly chosen 12 posters commonly seen in market, 3 posters specifically have been selected for this study. All the posters (Indian government portal) have been selected by the common peoples' perception of attractiveness. Target people liked the posters and said that where all are currently running, that is, the contemporary issue or which is currently seen more often.

64.3.1 Experiment

Mostly the social messages are being put by government agencies specifically to make aware the target people. Government, as the primary communicator, advertisements on an awareness campaign were considered as study material. Mostly these were in the education sector, social equality, food and health, and family welfare. Samples were collected from the government online portal and mainstream panchayat for direct communication. Three states (Maharashtra, West Bengal, and Karnataka) were specifically visited for the survey, (1) two locations near Pune district, Shindewadi Village and Katauli Village in Maharashtra, (2) two locations in Shakharipota and Hashpukur in West Bengal, and (3) two at Peenya and Tumkur in Bangalore, Karnataka.

Table 64.1 Survey background

Number of participants and background			
	Headcount	Background of participants	Method
Students	37	Future designer and other discipline	Poster image without relevant text
Villagers/common people	54	Farmers, housewife, worker, service	
Urban people	17	Service/professionals	
	Total: 108		

64.3.2 Procedure

People very actively participate in this survey, out of 12 poster images, 3 poster images selected through the random selection process [16]. The total number of participants was 108 and the age group chosen from 18 to 58 years. 37 students, 54 villagers/common people, and 17 urban people have participated in this survey. Students have belonged to different backgrounds and groups (subject). Villagers/common people (men and women) are mostly Farmers, housewives, and workers in service. Urban people are highly educated and working in high positions in society. The participants' background is mention in Table 64.1.

64.3.3 Image Survey

Survey-1

This poster shows a little cute girl with a smiling face. This poster showed without text to the participant. Participants reacted instinctively on the poster image (Figs. 64.1 and 64.2; Table 64.2).

Most of them answered entirely another way and context. 24% of students participants answer this poster is on "Girl Equality," 24% on "Related to Health," 14% on "Save Girl," 16% on "Poor Girl," 11% on "Related to Kids" and 11% of students participants went on "Do not Know." The key point is that no one identifies the main context of this image. Everyone attempt to reach the topic of this campaign poster. However, this cute girl's image is not contextual as per the original poster with text. The image cannot communicate with the target people. Similarly, village people are also answering the same way. 6% of village participants said this poster belongs to "Save Girl," 15% on "Poor Girl," 17% on "Related to Kids," 26% of villagers said "Girls Education," 18% on "Girls Equality," and 18% of villagers think this poster is for "Related to Health." Out of 17 urban participants, 35% think this poster goes to the context of "Save Girl." Also, 23% on "Girls equality," 18% on "Girls education,"

Fig. 64.1 Survey-1 poster image (*Image source* Ministry of Health and Family Welfare)

Fig. 64.2 Survey-1 result details

Table 64.2 Outcome "Survey-1" poster image

Comments on	Number participants
Save girl	14
Don't know	6
Girls education	17
Poor girl	15
Girls equality	23
Related to kids	14
Related to Health	19

Fig. 64.3 Survey-1 poster original

6% think "Related to Kids," 6% on "poor girl," and 12% of participants consider "Do not Know." (Fig. 64.3).

Survey-2

This poster noticed that a famous personality (Amitabh Bachchan) is standing in front of the blackboard. This image itself says something or instructs to the viewer. The target audience is confused with these two elements, which is altogether looks a classroom and someone trying to say something to the students. People get confused when they see this kind of image. 34 participants out of 108 think this image for "Sarva Shiksha Abhiyan" campaign. 11 people said this is related to "Girls Education." 35% of people think this is for the "Swatch Bharat" campaign. Peoples are very much confused about using celebrity images for such type of government social campaign. They are not able to connect with the image or image could not influence the people. The celebrity image is not to sustain social awareness communication. This study result shows that clear images are not appropriate for a social awareness campaign (Figs. 64.4, 64.5 and 64.6; Table 64.3).

Survey-3

In this survey, 27 participants out of 108 participants said this poster image is associated with "Girls Reservation." 11 participants on "Save Girl," 19 on "Physical

Fig. 64.4 Survey-2 poster image (*Image source* Ministry of Health and Family Welfare)

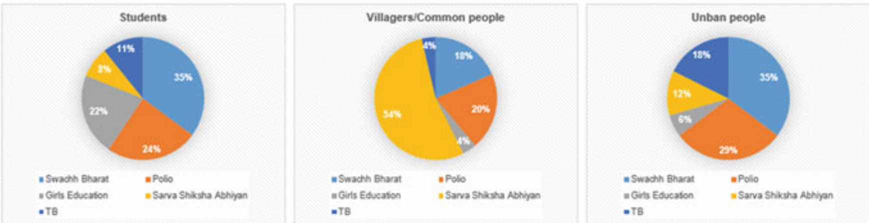

Fig. 64.5 Survey-2 result details

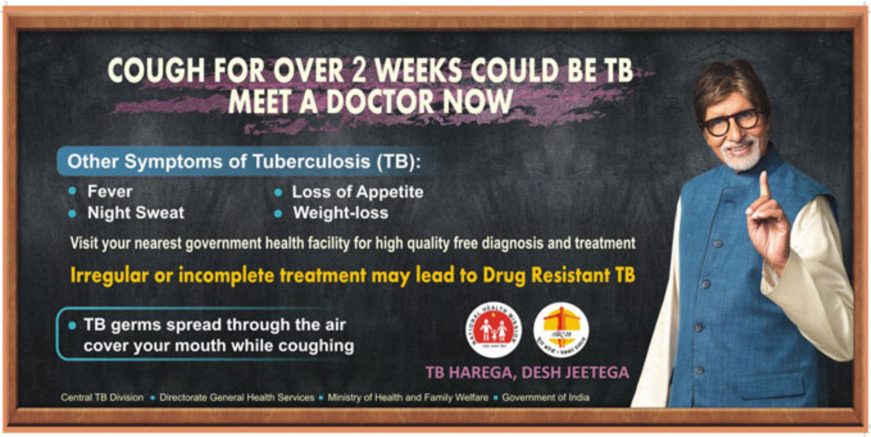

Fig. 64.6 Survey-2 poster original

Table 64.3 Outcome "Survey-2" poster image

Comments on	Number participants
Swachch Bharat	29
Polio	25
Girls Education	11
Sarva Shiksha Abhiyan	34
TB	9

Problem," 17 are on "Girls education." 16 people think this poster image accompanies by "Female Related Issue," and 18 participants said, "Do not Know." Out of 108 participants, 17 are from the urban area. 53% of urban participants said they "Do not Know" about this poster image. 27% of students' participants think this poster image is related to "Girls Education," 35% of village participants go with "Reservation for Girl," 19% of students consider this image poster is for "Save Girl." 16% of student participants could not answer anymore. 22% of the village people think of female related problems. More or less in all groups of people are very much cluttered (Figs. 64.7, 64.8 and 64.9; Table 64.4).

Fig. 64.7 Survey-3 poster image (*Image source* Ministry of Health and Family Welfare)

Fig. 64.8 Survey-3 result details

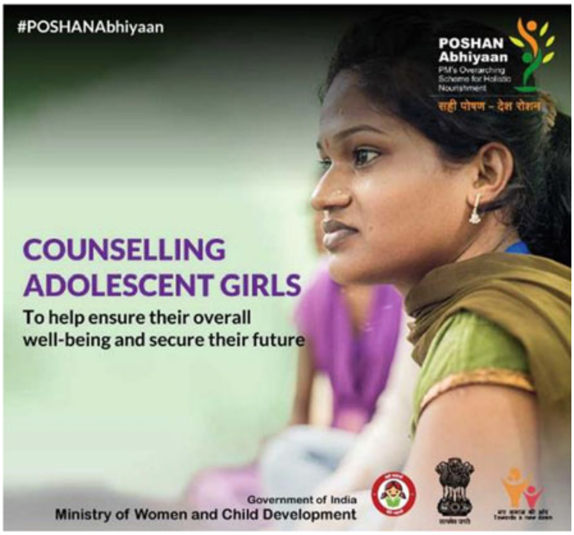

Fig. 64.9 Survey-3 poster original

Table 64.4 Outcome "Survey-3" poster image

Comments on	Number participants
Save Girl	11
Physical Problem	19
Girls Education	17
Reservation for Girl	27
Female Related Issue	16
Don't Know	18

64.4 Discussion

The language of photograph always communicates emotions with imagination where we can see several perspectives. In this paper, we have presented a present scenario of using the photograph for social awareness poster design. In the first image, one girl looks like with school uniform, with child education India Government logo and Ministry of Women and Child Development (MWCD) logo. Second poster is with a celebrity image with the blackboard. That conveys this poster related to education, in the third poster with a young lady, it feels like women empowerment. The selection of photographs needs to be relevant to design awareness posters. Each photograph should be selected according to the poster context. Visual communication through photography involves two-step process: vision and perception [4]. The eye receives a figure in the photograph, but the brain interprets as a celebrity or girl child or young lady. A photograph provides a considerable impact on message comprehension.

64.5 Conclusion

The experimental results verify the impact of the social awareness campaign poster on the target audience. Photograph of each poster tries to communicate with the target audience. Every poster image has been used as per the context. However, it is difficult to understand that are photographs carried relevant messages? Most of the participants were confused with a photograph. The audience is not able to connect with the context of using such kind of human photograph. It is evident from the visual social awareness campaigns running through various media that it cannot create awareness among the target audience. Future research will help to establish contextual photographs using for the social awareness campaign. This research will add the right dimension when such awareness posters are made again later.

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Chapter 65
CREATED METHOD: Pedagogical Approach for Diversity in Creative Design Process

Iko Avital and Charu Monga

Abstract The principal objective of this paper is to demonstrate the capability with creativity and innovation to develop ideas for technology driven students (Simonton in creativity in science, Harvard University Press (2008) [12]). The new teaching Created Collab Model: (CCM), examine with undergraduate also graduate design and engineering students at various aspects with step-by-step progressive process. "College education must help students to develop those competences in collaborative environments and better address these needs. Developing students' knowledge and skills in contextualized engineering environments [14], practicing teamwork, leadership, decision making, experimental work, and critical thinking are some of the important aspects addressed in this track." (Viegas et al. in 21st century challenges in engineering and technological learning (2017) [13]). The paper describes 21st Design Education as a creative method focused on innovation for society and industry. One that combines mass wisdom and talents in multidisciplinary fields through advanced digital technology [11]. A virtual studio was proposed that contains number of teams exploring a topic, studying, and designing innovative products. Each team is comprised of different areas of knowledge: product design, mechanics, graphic design, architecture, art, animation, etc. A joint online project "Innovation in Project Design," using an On/Off synergistic studio was practiced during one semester (Avital and Mazor in circling the square, creativity in engineering design, STANFORD, US (2014) [5]). Multidisciplinary teams (Israel, India, Australia, and Japan) were challenged in projects of social importance. The teaching method relates to a synchronous virtual environment, where the teams interact and learn at the same time, and also asynchronous, where they plan and respond at different times. The purpose of the joint course is to learn and work in global teams, as well as to create and design innovative projects within the limitations and barriers of geography, time

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A. Chakrabarti et al. (eds.), *Design for Tomorrow–Volume 3*,
Smart Innovation, Systems and Technologies 223,
https://doi.org/10.1007/978-981-16-0084-5_65

zones, cultural and demographic backgrounds, in team of diverse learning disciplines. This qualitative field research, along recent years, present lot of team design processes and final projects.

65.1 Introduction

The world is growing in terms of ideas and technology so fast in this twenty-first century globally, in businesses and social life. Upcoming industry is growing with multidisciplinary approach by using cross-cultural and cross-functional solutions in R&D teams globally [6, 11]. In a scenario where demand of the raw materials, design, and manufacturing is growing, companies are playing strategically to solve the problems of cost cutting, quality with profit and logistics simultaneously. When the global distribution strategy is planned and designed in a company, the profit projections in terms of price, sales and profit margins are very important factors to consider. Here, design plays a huge role to fill the gap [8].

The main aim of the educational institutions in varied areas like various divisions of engineering, design, art and science is to teach and train young talented minds on how applied science, technology and hands-on skills work together creatively with each other in critical conditions during the projects [10]. Also, how to be prepared when you work in teams, who are working in cross-cultural projects so, that it can function effectively to produce innovative and unexpected results. Online education represents a significant paradigm shift in the history of higher education [7], but not in integrative engineering, science and design together [12].

65.2 Created Collab Model

A new method is been designed called “Created Collab Model” (CCM) to bridge the gap between cross-campus collaborations in a Laboratory and studio-based scenario. The method is based on the on/offline approach in which we focus upon fostering interaction and learning via online platform between engineering and design with hands-on training in various projects [5]. When we talk about engineering and design in various countries, the nature and process of work differs drastically in terms of inventions, techniques and technology. The conditions in different countries differ from culture to work ethics point of view. So, this method has been designed to help the students to have an interaction with cross-cultural and cross-functional approach via interdisciplinary signification. CCM moves a new educational shift, which will help the student to have an instructor-centric approach to student’s team-centric approach. Also, we have involved industry to create a knowledge hub between different countries students, where instructors and students take up a new interactive approach to understand each other’s research constraints in their own respective countries. With this new roles have emerged, which students have to handle in their respective teams, like dealing with the project coordinator of both the country teams, dealing with the company problem statement, etc.

CCM generates emphasis on innovative and creative concepts from mixed interaction among various students' talent, their skillsets and knowledge. This method is an extension of E-studio approach [1]. It follows peer-to-peer approach with mix of design thinking in two phases: The teams include six students, each from varied backgrounds and mix from campus. We have set up a virtual team studio with internal and external design processes and cross-campus approach as well. Pedagogically, based on asynchronous and synchronous learning, a team catered teaching leading to a project oriented method, which involves online learning and de-coding of the project brief instead of constraints like language, place, distance, etc.,

Such as one team location was in SCE Israel and another located in other corner of the word at IIT Guwahati in India. The sessions were the part of semester in which time was the biggest constraint. Participation of students from varied sections from Bachelors and Masters as well as research scholars from mechanical and design backgrounds was involved in this mix media Created Collab approach. Teaching with basic principles, scientific innovations, discoveries, and methods has been shaped the upcoming generations and incorporating them into the course structure and bringing out insights got the main emphasis [2–4]. CCM model follows pedagogical approach to advance innovation in design that enhances thinking approach, creative thinking within individuals among group members enhancing their diverse skillsets, talents and personal/cultural background. This course challenges students on several levels: How to create team framework? How to use the diverse talents of team members? How to design together? Different professional fields, geographical distance, wide time zone, syllabus gap and academic scheduling, gap of knowledge, skills and talents. This qualitative field research, along recent five years, presents a lot of team design processes and final projects.

65.3 Methodology

Our research objective is to find out a way to make classroom teaching much more collaborative, interactive, and knowledge driven where concepts, principles, processes, and hands-on activities with fact finding can be encouraged to come up with creative and implementable solutions for the society. We have conducted nine such sessions over the period of five years starting from the August month of 2015 till the beginning of 2020 with multidisciplinary teams from different universities.

(a) Course content-related collaborative lectures were organized and also invited online sessions that were conducted by National and International faculties.
(b) Further students were divided into groups according to their expertise. For the same, detailed document with individual details was shared with everyone.
(c) Individual presenters were invited from various industries like animation, product design, design thinking, gaming, etc., to share their knowledge.

(d) Initial activity demonstration was given by the individual instructors to the students including sharing of the material, digital notes and supporting material and references.
(e) Student teams were made to interact with each other and problem statement were shared. Further, individual teams did redesigning of the brief.

For the same in each course, around eight multidisciplinary groups were made 5–8 students from different disciplines with visual communication designer, mechanical engineer, animator, field researcher, etc., were divided and progress were shared by individual team members via software's like slack and Trello. For the internal communication between the student groups, applications like WhatsApp, Gmail, Teams, Skype, etc., were used.

65.4 Model Structure

CCM is based on team-centric approach, which breaks the barrier of traditional classroom practice to an open studio creative space, where students who are the next-generation thinkers can crunch on their ideas and concepts. In Fig. 65.2, The model brings the interaction with a larger group and users in their respective countries and allows them to organize their interaction with online discursions, their team views or post a reply in a face-to-face forum of messages with the help of online chats, mails, etc. Also, during the discursions they can upload the videos, animations, and ideas in form of sticky notes on the discursion desk. This approach was followed supported with different forms of communication like texting, chat, voice messages, video conferencing, blogs, wikis, etc., for sharing their ideas and discursions (Fig. 65.1).

In Fig. 65.3, one can see that Team A from Israel campus and Team B from Indian campus has started working on the common problem statement and through interaction started by the facilitator from both the campuses, who were mentoring and guiding the students on how to come up with ideas and concepts based on innovation in design and engineering instead of barriers and time differences. Innovation in design thinking is based on the collective knowledge and thinking skills, with combination of ideas and flexibility of thoughts encouraging student teams to work in a collective way. In Fig. 65.3a, one can see the classification of various students collecting major data from their teams and in Fig. 65.3b one can see the individual country mentors are guiding multiple project leaders with their teams.

One of the important aspects of team design is the ability to self-criticize and evaluate as also mentioned in Fig. 65.3, the quality of the design process, the passion for quality, and the innovation phase of the final output. In light of this, we asked each team leader to score for each member of his team and himself for a ranging from 50 to 100. This request gave the team leader an attempt to a new outlook perspective at team design as a personal process of each member, of the facilitator vis-à-vis the team leaders; to a large extent, we can state that the personal and immediate familiarity of the team leader improve deep quality of the project guidance.

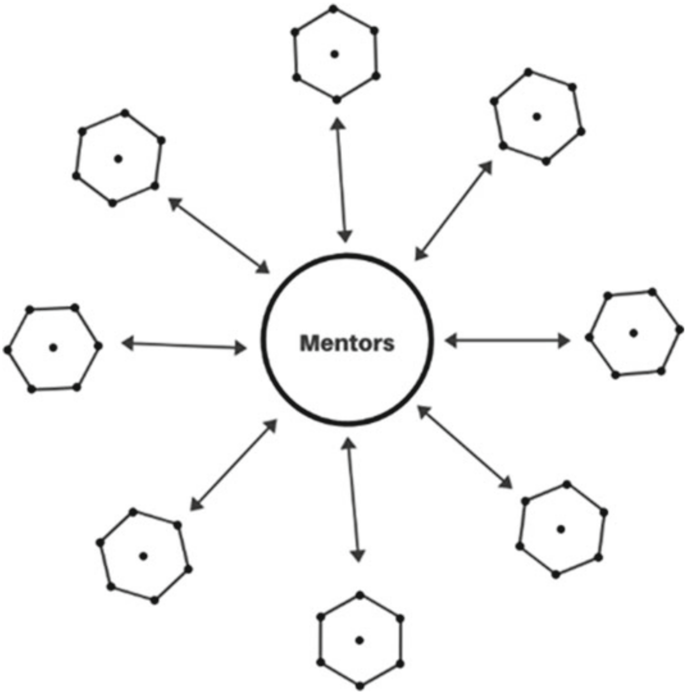

Fig. 65.1 CCM case study I: Tangible team (Figure by author)

65.4.1 Structure of Each Team

Each team has two facilitators, who maintain continuous interaction throughout the CCM project. The place of the facilitators in this project is very special. They bring two voices, two opinions, and two areas of expertise to the team. The team members are interacted by the guidance of two facilitators, but also really challenged by their differences in design approach to the project and their say and opinion. But, this is the CCM tipping point: in this interaction, the teams learns to develop independent and flexible thinking, and to deal with two completely different facilitators; their professional background is different, their expectations from the project outcomes are not necessarily uniform, they teach different fields in different languages and in a different academic environment, including the duration of a the course. One teaches a continuous semester course every week, and the other teaches the entire course for two full weeks. The schedule is so different besides Skype troubleshooting but this is a great challenge that joins a host of other gaps that include different levels of English, accent, professional terminology, and even methods for planning a project and setting a presentation. This chaos of obstacles is an important part of CCM project because it is a unique design training teaching students to work in different global frameworks stress of time and locations and also look for ways to overcome

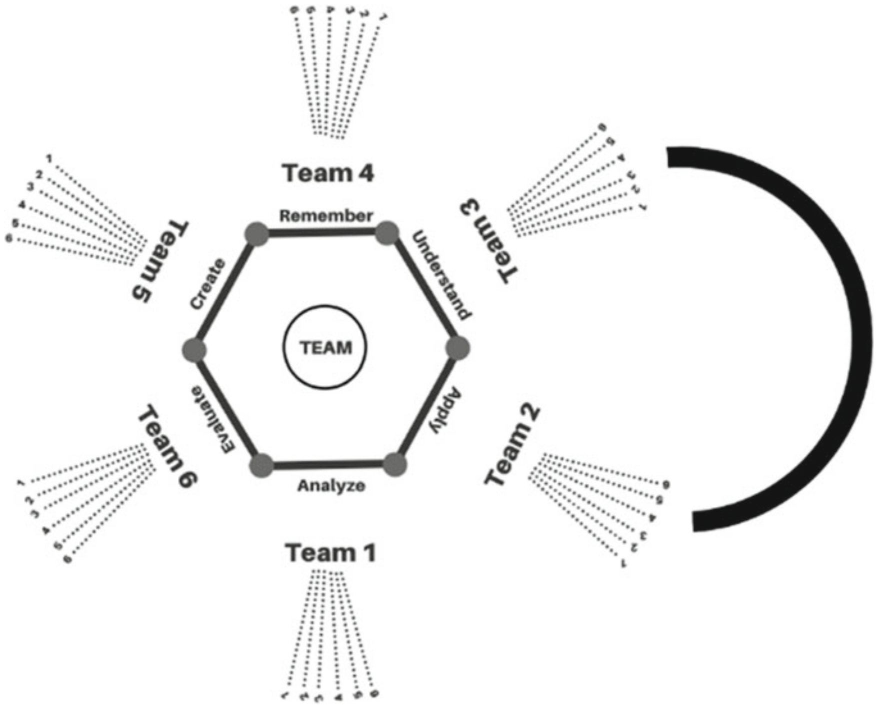

Fig. 65.2 CCM case study II: COVID-19 teamwork (Figure by author)

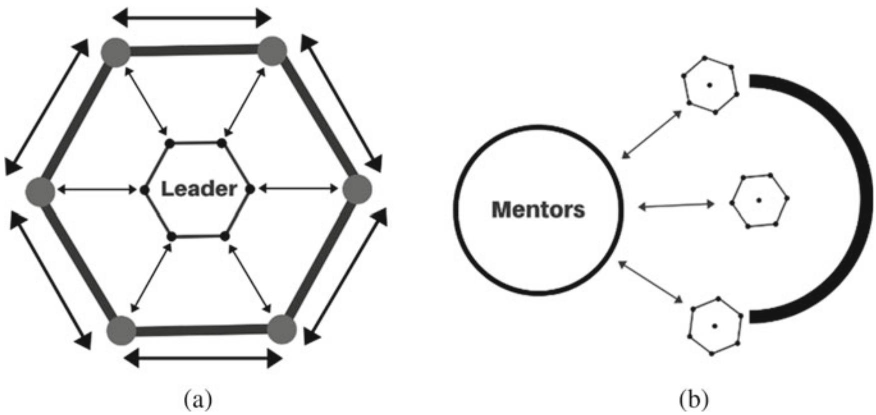

Fig. 65.3 CCM case study II: **a** self-criticize and **b** evaluate (Figure by author)

the obstacles and meet a set schedule. The facilitators ensure that there will be time-sensitive work and strict requirements to train each team leader in the division of research tasks, ideation and conception, product rendering and prototypes, in strict observance of the schedule, and engineering and design quality.

Teamwork in the product design has several advantages that affect the quality of the final outcome. The synergetic experience teaches each student to interact with others' knowledge and talents, to get and to give in an integration process. An initial acquaintance is created and personal friendship develops between the members of the team from one country to another, then professional acquaintance, personal abilities and talents. At this crucial point, they begin to plan and design together the project. The team leader divides tasks, and they split to their own challenge. This initial stage in CCM is critical and is the main productive process during the project. The disadvantage of large work teams is the different output of students. There are those who are lazy and work little or slowly, and there are those who are challenged to the subject and goals of the project, are excited and work day and night. There are interesting insights from the facilitators; they recognize the diverse talents of the students, as well as those who can lead a design team. Also, because they are involving in all group chats of different team discussions, they learn better how students try to bridge distance problems.

65.5 Case Study I: Scoodent Project and Game Design Project

There were two projects proposed in the year 2016–2017 covering two semesters. First project is to design a campus scooter for students and second project is to create a game for visually impaired kids between the age group of 8–12 years. The project was facilitated by course instructor in two different countries in cross-campus classrooms by encouraging team discursions in two stages: firstly in order to introduce the session and motivating the student's introduction session is been organized also to introduce the new teams with each other. Secondly session on idea generation and design thinking in relation to the project development was introduced. Encouragement is the integral motivation factor kept which leads to innovation. Sessions were introduced on how to define a problem, use contextual enquiry etc. discursions on how to ideate, prototype, and present the ideas is been discussed. In the end, the instructor describes the main challenge of combining scientific thinking of engineering and creative thinking of designers to come out with creative ideas for the following projects. Other parameters were also kept in mind like climatic conditions, time constraints, space for both the projects also target audience (Image 65.1).

Gamification has been introduced, with the help of which students have applied and learnt game mechanics and techniques to bring engagement factor for the users. Later aim and objectives of the project were detailed out to both the teams like to build

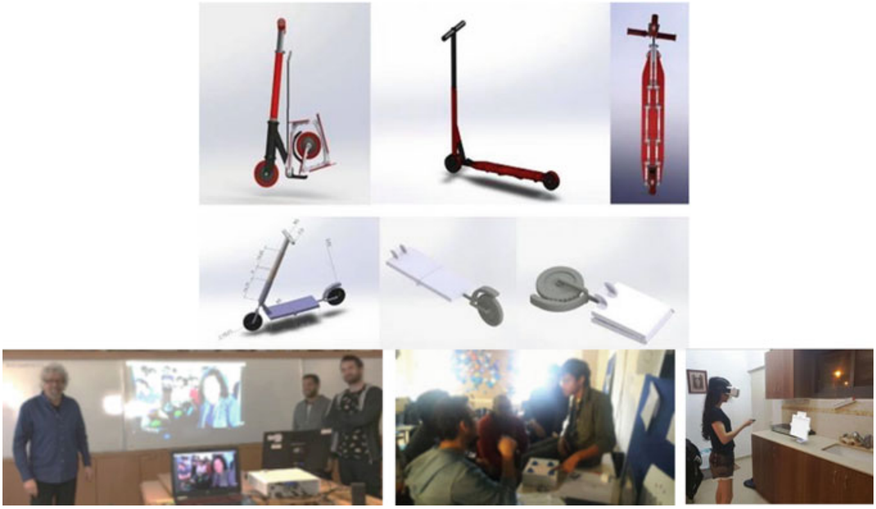

Image 65.1 Intercountry teams interaction (Images by author)

a game that can be enjoyed by blind or visually impaired as well as sighted players. You can use any material, sound, touch, and other senses to enhance your ideas to create something educational [2]. Use the concepts of science, engineering, design, and technology. There are countless angles one can use for possible exploration, like what happens when you see dark everywhere and you start-experiencing things around you with your other senses? Uses of empathy as a tool for creating the experience for visually challenged were incorporated (Image 65.2).

It was also mentioned that the game design project should have the young, creative look and feel. Using design thinking as a tool to create interesting and innovative idea generation tool in the systematic search sources for interesting way to tell about concepts/stories was encouraged. We encouraged **internal sources**, which refer to the team's talents and skills. **External sources** refer to sources outside such as customers, competitors, and suppliers, and **design sources** refer to product biography of all kinds of games. The importance was given to use of various materials, local techniques, local crafts and use of skills sets, which the team is good at. The teams have continuously been in touch with their teams in both the countries, setting timetable and setting the project process, sharing knowledge and skills, preparing a flow process of project steps, and presenting in a form of presentation. For the communication, WhatsApp, Skype, Gmail, etc., were used. Leader for every team was taking care about the timetable of the project and plan of how to overcome the barrier of culture, actions, situations, decisions, etc., within a team.

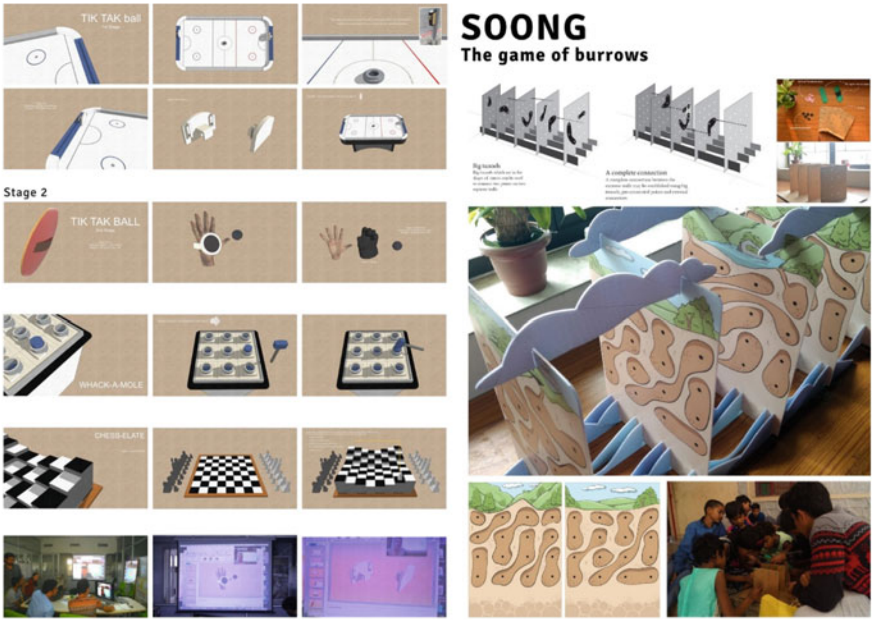

Image 65.2 Developing games (Images by author)

65.5.1 Case Study II: (Design Thinking and Creativity)

In 2015, collaborative sessions on design thinking and creativity have been done with teams from India, Israel, and Australia, in which common session activities were designed and conducted (Image 65.3).

Group of students has started with the sketching and doodling exercises by taking inspiration from nature. Further an invited session on "importance of line of action" in sketching was conducted. On the basis of it, various visualizations were done. Similarly teams were asked to discuss about their output and develop a narrative on the same. Further in the second part creation of 2D to 3D exercises was developed like the creation of character in 3D form [9]. The purpose of this creativity exchange exercise was to develop understanding about various aspects of 2D to 3D transformation and understanding aspects of color, line, motion, etc [4].

65.5.2 Case Study IV: (Redesigning Social Robots and Water Purifier)

In an E-studio project on nurturing creativity and innovation in students, design and development of a socially active robot with its instructional manual was done with

Image 65.3 Hands-on activity sessions with teams (Images by author)

the cross-country teams. They have to design a robot, which can help students in developing creative tasks. Total 35 students participated in semester long session. Teams have used the process of been divided and many sessions were conducted to come up with the final output (Images 65.4 and 65.5).

In terms of design thinking that strives for innovation, there were two distinct problems that challenged the facilitators. The first, some students limit their imagination to create innovative output of their professional field. For example, mechanical engineering students bought on mechanical ideas, without using other engineering fields such as chemistry, programming, and the like. An important step within the guideline was to encourage them to think outside of their disciplinary box and to create advanced and innovative ideas even if they themselves did not know their design stage. The goal is to release cables of the acquired knowledge field for the sake of developing curiosity and breaking student conventions, at the idea stage, in order to achieve innovation. The second problem, independent decision-making by student staff in the field of ideas, slows down the pace of the project. The team is hesitant to choose between the different alternatives. The diverse background of the team members creates a problem that needs to be solved. The facilitators, at this stage, try very hard not to interfere or help, because the dynamics within team will lead to authenticity and thought independence. As a general rule, the facilitators in these two stages are navigable in general and avoid introducing solutions. In contrast,

Image 65.4 Social robots developed by student teams

internal discursion is encouraged in each team, allowing all team members to get involved and bring innovative ideas out of their world and professional background.

65.6 Evaluations and Feedback by Individuals

A survey was conducted to analyze the effectiveness of the "Created Collab Model" among 30 students out of which 26 responses were received. When asked about the most interesting phase of the whole project (as example in game design project) some of them mentioned that they have found the whole process deeply engaging and learned about varied methods used in different countries. Collaborative lectures helped them in redesigning of the brief. Creating ideas together by understanding the universal feasibility is quite a learning experience for students. When asked about the least interesting part, some of them mentioned about rescheduling meeting was quite

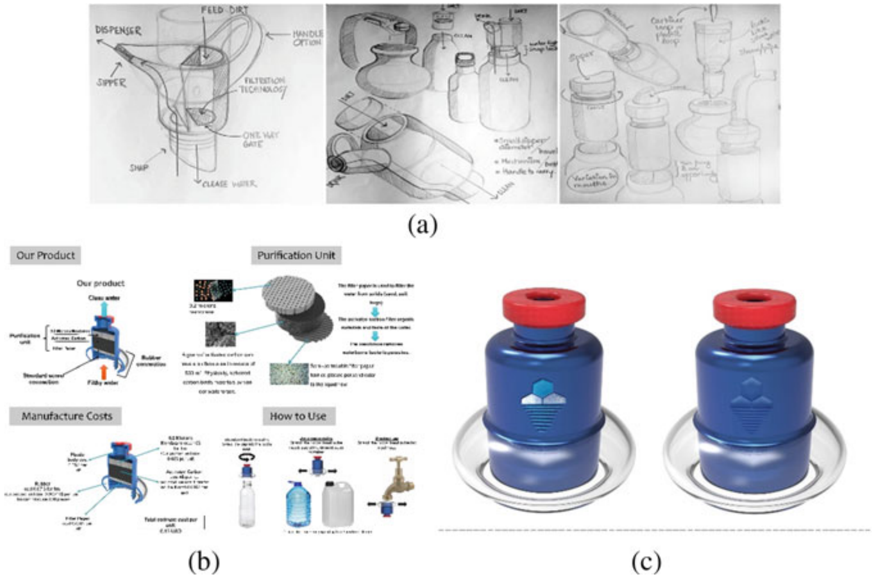

Image 65.5 Project on water purifier

tiresome for them. When asked about most satisfying part of the whole process, some of them mentioned that they have found similarities in their ideas and that helped them in building the compatibility with other team members internationally and that helped them in better team building and interaction. 60% of students have found that they have communicated well by the use of technology and found engagement in the discursions. Respondents also mentioned that processes like design thinking and other experience have helped them empathizing well with the user and the approach helped them in the understanding of the user group. When asked about whether the process of research has helped them understand in developing the idea, some of them mentioned that it has helped them in understanding of user behavior, lifestyle, and their needs in step-by-step manner. When asked about how well closer interaction between the collaborating institutions assist students to develop design skills, on that 80% of the respondents were highly satisfied and 20% of them said that because of time constraints, it was difficult for them to manage the schedule. Overall "Created Collab Method" was found suitable to make classroom teaching more collaborative, interactive, and knowledge driven with incorporation of many hands-on activities, which encouraged student teams to come up with more convincing solutions.

65.7 Conclusion

(a) We have come to know that an important part of design education is to challenge the students in social projects, for the sake of the individual and the general, which is if interest to them.
(b) A meeting of students from a multidisciplinary background with rapid technological innovations presents a rare opportunity for students to experiment deeply with creativity.
(c) Teamwork, practical and virtual, develops the student's ability to utilize one another's talents and, at the same time, contributes to the team's abilities.
(d) We have come to the conclusion that facilitators are not lecturers, but mentors whole role is to generate positive energy in each team to produce design innovation.
(e) We found that a team leader has the ability to be highly motivated to excel in competition with other teams.
(f) We found that the many challenges facing students (geography, culture, communication, schedule, etc.) set a high threshold that required a different approach in the project's process.
(g) The facilitators were involved in each team chatting (through various tools like WhatsApp, Trello, etc.), monitoring the internal dynamics of the team. They focus on each team leader on the small details level.
(h) Collaboration between varied disciplines (engineering, design, graphics, animation, architecture, and art) yields lateral thinking that comes from working on a collaborative project, and generates many innovative opportunities out of the box. We have found that team list is important and can predict the team's success in meeting the many challenges this CCM poses to students.

Acknowledgements We would like to express our gratitude to all the facilitators from SCE Israel, IIT Guwahati, IIT Bombay and participants for this study also users for their time and knowledge.

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Chapter 66
A Study on Design of an Illustrated Book for Communicating Maternal and Child Health to Semiliterate Rural Women of Kanpur, India

Rohit Kumar and Shatarupa Thakurta Roy

Abstract In this study, a maternal healthcare illustration book to convey the message and create awareness on key maternal and child health problems to semiliterate rural pregnant women was developed and evaluated. Appropriate maternal and child healthcare information was collected, segregated, and conceptualized for the book design. The book design process included initial pencil sketches followed by refinement and digital rendering of visuals with color on photoshop software. Finally, adding text messages to support visuals. The evaluation experiment consisted of a literacy test (S-TOFHLA) and comprehension test on one hundred and six rural pregnant women, performed with ASHA's assistance (Accredited social health activist). The study was conducted at two rural health centers in Kanpur, India, followed by pretest and post-test on two groups, one control and one experimental. Participants were chosen randomly under control and experimental group, 53 pregnant women to each group. Pregnant women in the intervention group received maternal and child health illustration books as a visual information aid. A comparison result showed that pregnant women in the experimental group received a significantly higher score than the control group in terms of comprehension of messages and compliance.

66.1 Introduction

Health issues related to pregnancy and childbirth are quite common around the world. If we see the numbers, about 292,000 maternal deaths occur every day due to pregnancy complications. India is also among the countries suffering from this situation and accounts for approx. 20% of maternal death happens worldwide [1], which is

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A. Chakrabarti et al. (eds.), *Design for Tomorrow–Volume 3*,
Smart Innovation, Systems and Technologies 223,
https://doi.org/10.1007/978-981-16-0084-5_66

around 44,000 maternal death every day. As evident from UNICEF data, maternal deaths are high among women with low education and economic background.

Many studies highlight that when women are well aware of maternal and child health and know proper health care, they have better maternal health outcomes than those who do not have proper knowledge [2].

In developing countries like India with a dynamic culture, education level, economic status, language barrier, etc., communication between patients and doctors is more difficult than in developed countries. Considering the rural community's low education level, it is often difficult for the patient to understand health messages and translate health concepts to match their understanding; the probability of making an informed decision and taking the right measures is very low [3].

Many reports suggest that for making the right health decisions, it is essential that one should understand and remember information given by the healthcare provider [4–7]. But very less research talks about the cognitive issues in the context of rural populations with low literacy. Understanding drug regimens is easy, but it does not guarantee complete follow up of drug, lack of awareness about diseases, signs, symptoms, and severity can prevent the most willing patient from the following regimen. Kunim et al. [6] highlights some of the key points for the healthcare provider to ensure complete adherence and reduce misconception among patient by

- Explaining the importance of drugs along with their purpose and related health issues.
- Avoid jargon and simplify dosage instruction.
- Provide verbal counseling along with written text (use of graphics and images in case of semiliterate or illiterate).
- Evaluate the message comprehension with the help of non-judgemental inquiries.
- Monitoring patient compliance and drug use over a given time.

As the optimal approach to create awareness and effective drug usage, these researchers and other highlight the use of design intervention that focuses on the simplicity of message design, recalling these messages over time, and enhancing patient awareness of the severity of diseases, signs, symptoms, and self-care [8, 9].

Schwartzberg et al. [10] surveyed a sample group of 356 doctors, nurses, and pharmacists in their research. They identified the three most common health communication techniques: use of simple language, the use of graphics and illustration materials, and speaking more slowly while conveying the message.

In the context of rural population with low literacy, the visual graphic intervention has been found to be effective in communicating disease symptoms, drugs and assisting rural people in their understanding [11, 12].

66.2 Objectives

- A study on design of an illustrated book on maternal and child health for rural women.

- Assessment of comprehension and preferences of newly designed educational material.

66.3 Theoretical Framework

The guidelines and measures for visual aid intervention in behavior change can be traced to the "social Learning Theory of Identificatory Process" by Albert Bandura [13]. According to it, four processes lie in the representation of the model and the desired change of modeled behavior. First, the targeted group must pay attention; second, the target group should store information, and perhaps practice it; third, if the target group has required capability, he or she practices and improvise the observed behavior; and fourth, when provided good motivation, the target group able to perform the learned behavior.

66.4 Methodology

66.4.1 Participants and Study Location

A total of 106 pregnant women, along with 20 accredited social health activists (ASHAs) were included in the study. ASHAs assisted the experiments at the two health centers. Shyam maternal-child healthcare and Panki maternity center of rural Kanpur region were chosen for intervention; both the locations are 18 km apart. The study was conducted over a period of five months, from November 2019 to March 2020. Initially, a total of 120 women participants was recruited from the selected maternal health centers, out of 120, 106 women participants completed the full experiment, 12 women participants did not wish to perform and undergo the further study after completing initial literacy test and thus were not included in the study. Women participants were included if they had sufficient visual acuity to understand and read the designed book and assessment test material in either regional (Hindi) or English language.

66.4.2 Assessment Tests

Literacy test: a short test of functional health literacy (S-TOFHLA) was used to assess the health literacy of pregnant women; it is use for evaluating written data and numerical interpretation [14, 15] and is considered the most comprehensive literacy reference standard. With respect to test scores, a score of 28–36 represented adequate, 24–27 represented barely adequate, 16–23 as marginal, and 0–16 as inadequate. A score of 24–27 representing a barely adequate participant group was considered and included for this study, as it was felt that 24–27 scores are not high enough to be included in the adequate group.

Comprehension test: to access comprehension of designed maternal and child health graphic book, a cloze test was constructed, in which the fifth word of the text message in each page of the book was deleted. For example, “lack of …… in body causes ……; iron and folic acid tablets are used for ……… deficiency.” Participants were asked to fill the words in the blanks. Comprehension is directly related to cloze scores, where a low cloze score indicates poor comprehension.

Feedback questionnaire: A feedback questionnaire considering the designed health book was created in both the regional (Hindi) and the English language. The questionnaire included literacy demand, content amount and appropriateness, section layout, content suitable illustrations, typography, etc., these were assessed through the 5-point Likert scale. The level of learning satisfaction and motivation was assessed using a 10-point Likert scale. There was a total of 30 questions, along with space for comments and suggestions.

66.4.3 Procedure

The study was conducted at both health centers following the same methodology, information book (designed and existing material), and assessment test. The participant went through a literacy test followed by an information dissemination session and comprehension test session. Figure 66.7 represents the study design process.

Information dissemination session: Designed maternal and child health graphic book was distributed among the pregnant women (experimental group) and accredited social health activist (ASHAs) and were asked to go through the book; this was done a week before the start of the experiment. ASHAs were instructed about the study objectives, ways of information dissemination from the designed health book, and making the session interactive. ASHAs were asked to encourage pregnant women to ask their doubts during this session. Figures 66.1 and 66.2 shows a sample illustration from the designed booklet. Figures 66.4, 66.5 and 66.6 shows initial sketches, digital outline and digital render of health information.

Comprehension test session: ASHAs were present and assisted in conducting the test session. Participants in both control and experimental groups were given comprehension test sheets, which included cloze test statements from the health material (designed and existing health book). Another feedback questionnaire sheet with Likert scales to assess participants’ level of satisfaction, ease of reading materials, engagement, information retention, content coverage, etc., was also distributed.

The overview of the study design is represented in Fig. 66.7. The participants were randomized after completing the literacy test (S-TOFHLA) and divided into either control and intervention groups. Pregnancy health information was communicated

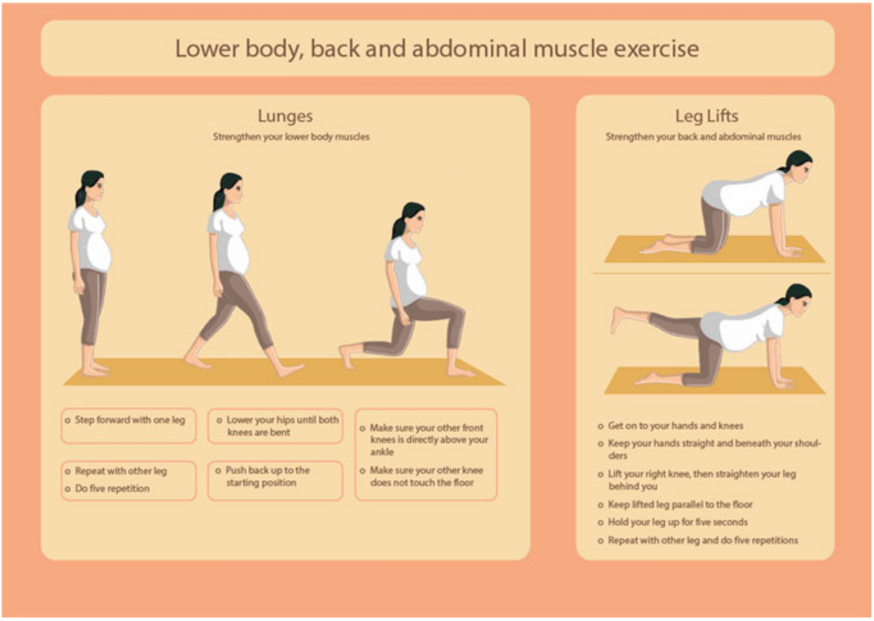

Fig. 66.1 Sample from the illustration booklet showing foot and ankle exercise

Fig. 66.2 Sample from the illustration booklet showing strengthening exercises for leg and shoulders

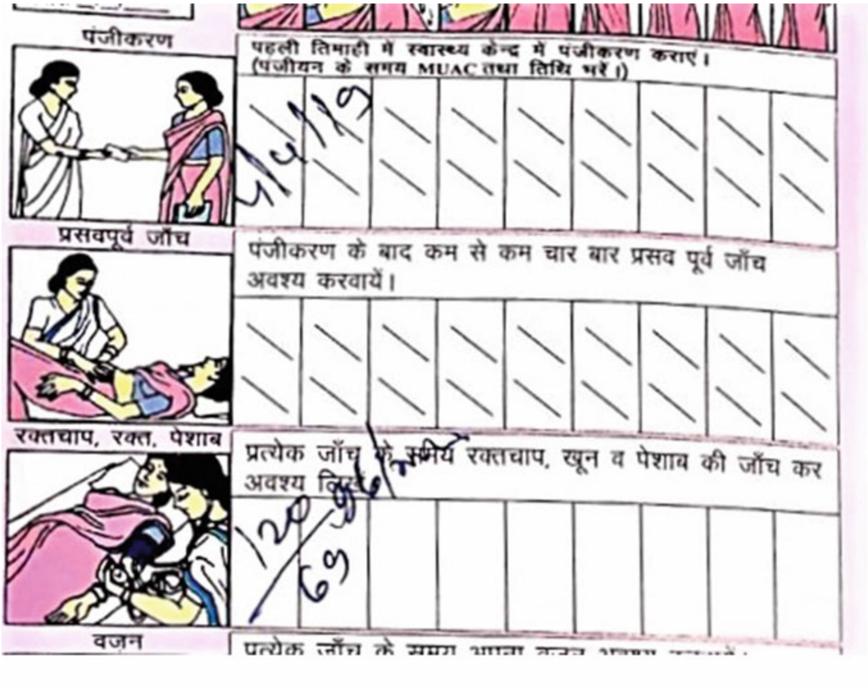

Fig. 66.3 Existing sample from pregnancy health booklet, sample booklet is very brief and does not include antenatal exercises: Reference—Marti & Sishu Suraksha card, National Health Mission, India

with the help of a newly designed booklet among the experimental group, whereas the control group went through the usual pregnancy talk with ASHAs. After completing the information dissemination session (which lasted for over four weeks), a comprehension test was performed on both groups. During the comprehension test, ASHAs assisted in the study and distributed test sheets to both the control and intervention groups. Time taken for completion of tests was noted individually. There was no time restriction for filling the feedback questionnaire sheet.

Participant information, S-TOFHLA scores, time taken to perform cloze test, feedback questionnaire, along with comments and suggestions, were collected for each participant.

Scores and times were analyzed using Excel spreadsheets (Microsoft corp.). For continuous variables, a simple *t*-test was used, and for categorical variables, the chi-square test was used. For significance, a value of $P < 0.05$ was considered.

Fig. 66.4 Initial sketches

Fig. 66.5 Cleaned outlines of illustrations

Fig. 66.6 Sample from digital render

66.5 Results

66.5.1 Participant Characteristics

The majority of women participants (67 women) were in the age group of 21 to 30 years (Table 66.1) and had education level till 10 grade (68%), followed by 5 grade (15%) and graduation (11.3%). More than 70% of women participants were housewives.

66.5.2 Literacy Test (S-TOFHLA Scores)

Test of functional health literacy for adults found that 53 percent of at Shyam maternal and child health care and 51% at Panki maternity center had "marginal" or "inadequate" literacy skill (Fig. 66.8). *P* value of 0.75 shows no significant difference between sites (Fig. 66.8; Table 66.2).

66.5.3 Comprehension Tests

Cloze test: Cloze test was performed after the completion of the information dissemination session. Cloze test included statements from each chapter. There were 40

Table 66.1 Demographic data of participants

	Age			Education				Occupation			
Category	18–20 year	21–30 year	31–40 year	No education.	Up to 5th grade	Up to 10th grade	Graduation	Housewives	Private job	Government job	Other
Data	12	67	27	6	16	72	12	74	9	1	22
Percentage	11.3	63.2	25.4	5.6	15	67.9	11.3	69.8	8.4	.94	20.75

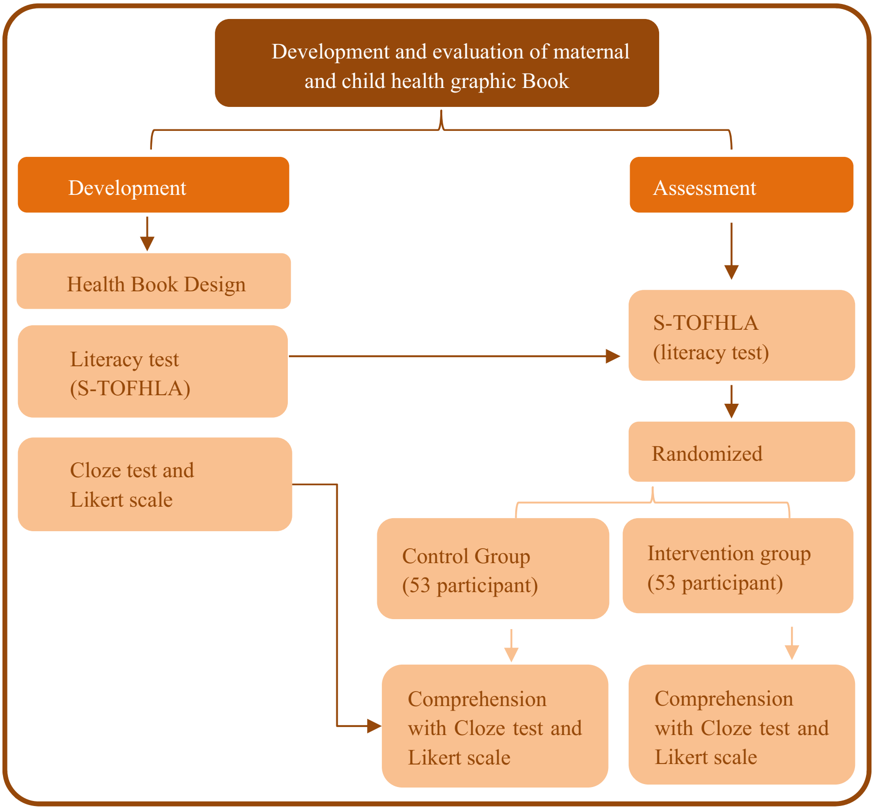

Fig. 66.7 Overview of the study

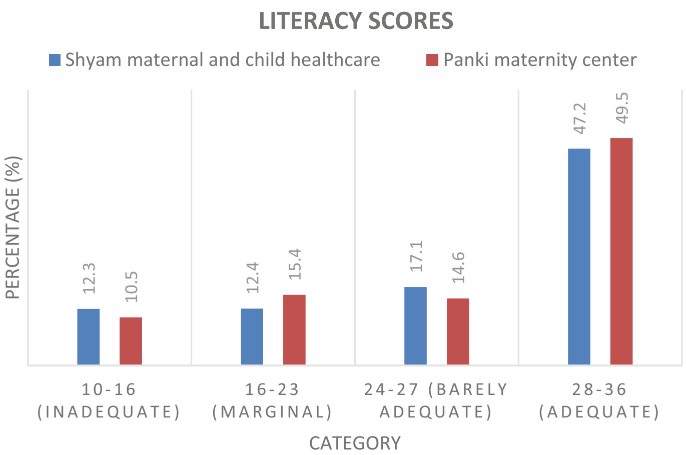

Fig. 66.8 Literacy scores of participants from both health centers

Table 66.2 Participants education, language preference, and literacy scores

Variables	Study location 1	Study location 2	P value
Participant with 10 grade education level (%)	47	52	
Participant with Hindi as their native language (%)	97	98	
Average age (y)	27	29	
TOFHLA score (%)	79	82	0.75

Test of Functional Health Literacy for Adults (TOFHLA)

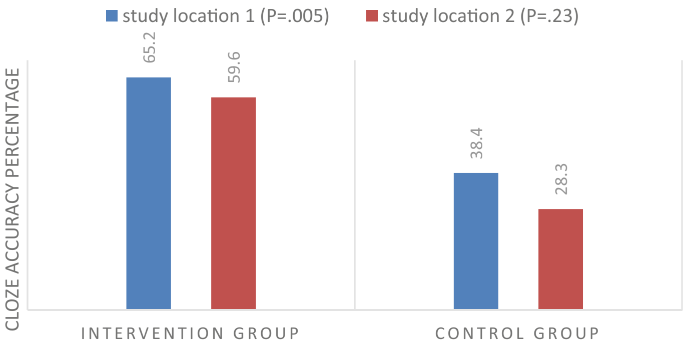

Fig. 66.9 Cloze accuracy percentage for the control and intervention group at both study locations

statements, 2 statement each from 20 chapters of designed and existing book. Statements were written in both the regional (Hindi) and the English language. A score of 1 was given for the correct response.

The intervention group had significantly higher comprehension (Cloze scores) of maternal health information compared to the control group (65.2 vs. 38.4; $P = 0.005$) (Figs. 66.9 and 66.10).

Similarly, both health centers' combined data showed that the intervention group scored significantly higher than the control group (57.3 vs. 46.6; $P = 0.0059$) (Fig. 66.10).

The health material (designed and existing) consisted of the same number of pages with similar content except for the health information presentation. It was observed that time spent reading the designed health information book was considerably low compared to the existing one (8.42 min vs. 15.61 min; $P < 0.0001$) (Fig. 66.11).

66.6 Discussions

The higher comprehension of health information among the intervention group compared to the control group suggests that illustrated graphic health material with less text increases understanding. The results and interpretation from this study were

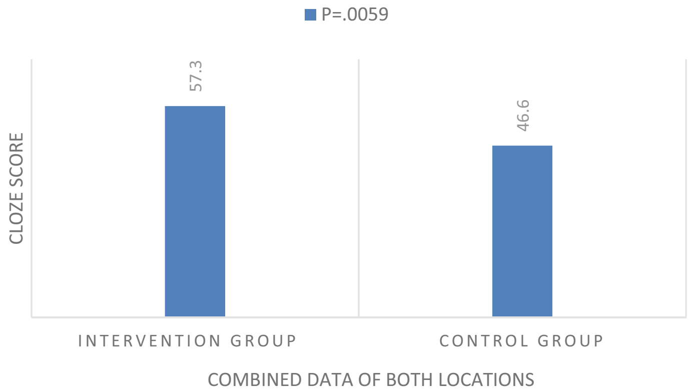

Fig. 66.10 Cloze score for intervention and control group at both locations combined

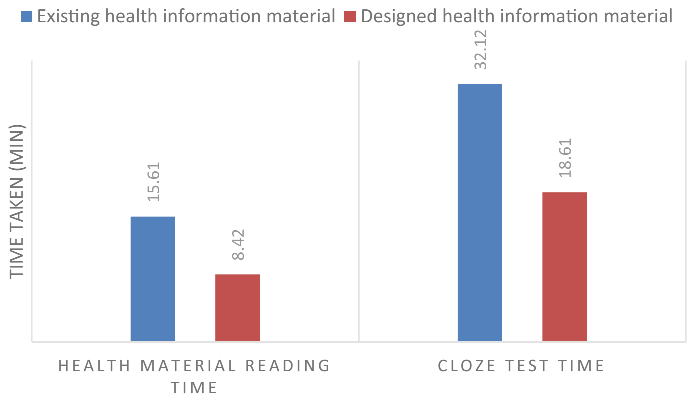

Fig. 66.11 Time spent reading the health material and performing Cloze test for intervention and control group

similar to those by Muir et al. [16], who did a survey on glaucoma patients and found that watching health education videos designed with pictures and less text had higher comprehension and compliance among patients with low literacy. Although we measured comprehension of illustrated graphic health material instead of medication compliance, it is not unreasonable to connect the link between increased health understanding and medication compliance. Many studies have highlighted that in chronic and asymptomatic health issues (such as diabetes, anemia, and hypertension), low literacy has a significant association with lower measures against disease and leads to severe outcomes [17, 18].

During the design and development of visual aids, collecting health information, sorting it according to priority, supporting text to graphics, creating the layout, digitizing sketches, and feedback with health experts and community health workers were major tasks. Apart from that, comprehension and identification of illustrated graphics were significant issues encountered. Some of the illustrations which looked good to ASHAs (community health workers in the village) were not clear to the study group (pregnant women). The study group understood the illustrations as isolated information but could not find a logical sequence to a whole. This particular problem (comprehension) was sorted out by including sketches illustrating a woman taking a specific diet in each picture box, along with the trimester mentioning below. There was no misinterpretation as to what diet to follow during a particular trimester.

The second problem, which was identification, was sorted by collecting a set of photographs showing activities of scenes. The intended message was explained, and the participants were asked to select from it, which they felt represent the message appropriately. The selected photographs were then used as a reference for creating illustrations. Later, during the pre-assessment tests, participants identified the message depicted by illustrations.

Research on written health and drug instructions has already been shown to have positive impact on patient compliance with instructions [19, 20]. Well-designed visual aids with proper content and context may results in similar outcomes among rural population with low literacy. However, intervention through visual aids for effective communication requires additional demand on community health workers (information dissemination) and researchers (development). To make visual aids effective, they must be designed specific to the context of targeted population. Graphics and visuals which are suitable in one population might not be suitable in another, as the interpretation of graphics and visuals is culturally based [9]. Therefore, the graphic content representing information has to be adapted to the culture of the population and region [8, 21–23].

66.7 Limitations

The smaller sample size taken for the study at both health locations may not significant representation of low literate rural population. Future studies considering a large sample size and effect of illustrated health material (with less text) on low literate population may be beneficial.

Although it is evident from the study that designed health material increased comprehension, we did not measure how information comprehension and awareness affects behavior outcomes. Future studies that explore the impact of low literacy health material on specific maternal health issues progression or visual acuity would be more valuable.

66.8 Conclusions

At both the study health locations, about 45–49% of participating women have marginal or inadequate literacy. However, despite this low literacy level, the majority of women comprehended designed heath material compared to existing text-written health material.

Our study highlights that participants with better literacy scores also preferred health material designed for low literacy group. This suggests health material should be designed at such a level so that it can cater to a wide range of populations without making multiple versions and thus reduces the time and cost required for production.

Declaration Informed consent was obtained from participants included in the study.

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Chapter 67
SEED: Storytelling, Engagement in English Language Decoding. Identifying Features in Learning Tools that Aid in English Decoding for Learners

Aishwary Khobragade

Abstract English language learners are introduced to multiple features of learning and storytelling tools that strengthen different areas of language such as vocabulary and pronunciation. Development of such individual characteristics influences in attaining comprehension of the content in the language. This study probes for the engagement of a learner with features provided by existing learning tools to supplement word decoding ability for English as a foreign language (EFL) learners of India. A week long experiment was conducted with three learning tools, namely LETS storybooks, LETS application and Microsoft's Immersive reader. The focus of the experiment was to check for reading engagement with the learning tools and assess their features affecting the decoding skills for EFL learners. The paper discusses strategies used by the learners to decode a piece of text and the ability of a learning tool to supplement this need. It provides insights with design implications and suggestions for the features that could build a learning tool to support EFL learners achieve word decoding abilities.

67.1 Introduction

A number of schools and students enrolled in the schools have been ever increasing. However, the quality of teaching in primary schools of rural areas has not improved. Many schools in rural India are multigrade schools for the reasons of scarcity of resources and infrastructure, very few teachers and attendees. Given the limitation to the teaching aids as unmatched to the curriculum designed for monograde schools and higher load on teachers, the schools become inefficient to produce results [1]. According to ASER report 2016, only 24.5% class V students across India were able to read Class I level English sentences despite learning English as part of their

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A. Chakrabarti et al. (eds.), *Design for Tomorrow–Volume 3*,
Smart Innovation, Systems and Technologies 223,
https://doi.org/10.1007/978-981-16-0084-5_67

curriculum [2]. A recent ASER report 2018 reveals that only 50.3% of class V students across India are able to read Class II level text in their first language. Out of which 65.1% students pursue education in private schools [3]. In the multilingual Indian social context, English is seen as a language to attain functional opportunities and inclusion, also termed as English as a foreign language (EFL) [4]. Here, educational set-ups like schools become the sole mode of instruction and practise for a student to learn the language [4]. Students exposure to the language outside the classroom, through conversation, movies, videos, books and other text is fairly limited. Studies suggest that listening to and reading stories have been effective in acquiring a language [5]. Narratives engage learners, stories provide comprehensible input and promote social interactions [6, 7].

The study exploits LETS presence in underserved parts of India. Learning English Through Stories (LETS) is a supplementary English learning programme that facilitates learners (12–14 years of age) who have little or no knowledge of English. The stories originate from the learners' own contexts, made available to the learners as English storybooks in hardcopies [8]. A new LETS mobile app offers learners with a professional voice-over to these storybooks. It is currently deployed in 5 evening centres in rural Andhra Pradesh under the Operation Vasantha (OV) Programme by Agastya International Foundation. These OV centres run 1.5–2 h daily evening sessions at a government school in the village. These sessions are carried out by a volunteer, usually an educated person from the village, a student or a school teacher. Listening to English stories through LETS app become one of the several teaching activities mandated by the Agastya timetable.

Students from class 6–8 participated in the activity. Most of the participants had Telugu as first language but varied across their religious backgrounds and locations of the village. Most students have attended primary schooling in multigrade government schools and some of them have shifted to private school for secondary education. Multigrade schools have students of two or more classes study together under a common teacher in common classroom. A strong disparity between the reading skills of the students from private and government schools were observed. Most students could not decipher the meaning of unknown words and self-reported to face difficulties in comprehending the story. Most participants repeated the words along with the read aloud, while mapping it with their fingers on the storybooks. Since the speed of voice over could not be controlled and no control for pause and play, the reattempt for read-aloud would slip unless reinforced by the volunteer.

67.2 Background Work

Perfetti proposes an interconnected relationship of decoding, vocabulary and comprehension in a heuristic triangle that combine to produce reading skills of an individual. Learner's limitation in one constituent limits the overall reading skill. He notes that comprehension skills are fundamental to language fluency. The ability to read words encodes their meanings, forming semantic content by using sentence structure and integrating these meanings across sentences and prior knowledge as critical components to comprehension skills [9]. The two essential aspects of reading fluency are word identification and effortless decoding. A learner's decoding ability depends on the conditioning of their phonological skills, orthographic skills, ability to map proper sound onto the letter or combination of letters and to synthesise the sounds to form corresponding phonological representation of the written word [9–11]. The DVC triangle indicates that effects of decoding on comprehension and vice versa are mediated by depth in vocabulary. Studies show that existing depth in vocabulary becomes a mediator to learning of new words, thus expanding their vocabulary [9–11]. On the contrary, in a society with multilingual cultures, the effect of competency in native language to second language acquisition is evident. Findings from several studies note the cross-transfer of leaner's decoding ability in native language facilitates second language decoding ability [10, 12]. The vocabulary–comprehension relation is such that as a learner reads a text, they access the meaning of the word that is appropriate to the context of the particular text. At the same time, comprehending a segment of text containing an unknown word causes the learner to grasp something about the meaning of the word. This exposure to refined word representations increases precision and enables a learner to gain fluency by reading a piece of text rapidly and relatively automatically. Listening ability contributes to both explicit and implicit improvement of language. It brings out the relationship between letter and phonemic knowledge [9].

Explicit phonics instruction increased word recognition, spelling and reading comprehension among students across various socio-economic levels. Nardagani reading programme is one such system which developed 12 different symbols in addition to the English alphabet, which goes as accent marks, to resolve this issue. This specific symbol system looks at the multiple sounds made by different letters in a given word.

In addition, linguists point out the five factors that impact language learning: social context, learner characteristics, learning conditions, learning process and learning outcomes [13]. The study particularly discusses the impact of learners characteristics that range from personal, social and attitudinal characteristics of the learners. Family's involvement and exposure to environment affects the process of reading during non-school hours while friends and teachers affect them in an educational set-up. A child acquires native language ability from their guardian(s) and their environment [14]. Given the students already engage in multigrade teaching set-ups, the constraint could be used as an opportunity for a learner to learn from others with higher abilities within the "zone of personal development" as established by Vygotsky [1].

Recent efforts have been made through development and deployment of learning tools addressing several constituents in the language acquisition process. Some open-access applications like Google Bolo, Fundoodaa, StoryWeaver, BookBox AniBooks, among many others provide multiple features on mobile such as story narration, speech-based reading, correction of misspelt words, word meanings, etc. This gives the learner control over medium to progress in the application.

The study expands on the knowledge of what role ICT plays in decoding competence in the English language and focus on the following research question: *What interaction features of the learning tools engage learners around story texts?*

67.3 Methodology

Due to operational issues, conducting the experiment in the context of primary study was not feasible. Hence, the experiment was conducted at a high school in Mumbai, for a deployment of 7 days for 1 h everyday after school hours, to test for the engagement of three selected learning tools, i.e., LETS storybooks, LETS application and Microsoft's Immersive Reader.

67.3.1 Participants

The study included 12 students of class IV aged 09–10 years of age for the experiment. The high school follows Maharashtra State Board syllabus teaching students both English and Marathi languages from class I. Out of the 12 participants, 08 participants were native Marathi speakers, whereas the other 04 participants were native Hindi speakers and used Marathi extensively for academic purposes and communicating in academic set-up.

67.3.2 Sampling

To gauge the participants basic reading skills in both L1(Marathi) and L2 (English), the students were screened through ASER test. Given the difficulty of text under the experiment, 06 students each were shortlisted from highest reading skill of story level (Level A) and sentence level (Level B).

67.3.3 Applications

LETS storybooks are written and illustrated by learners (12–14 years of age) with little or no exposure to English. The children were residents of remote, underserved and resource-strained parts of India.

Features
To facilitate decoding to aid pronunciation and vocabulary, a pull-out glossary of difficult words were provided. The glossary included a syllabic split of the word,

the transliteration in Marathi and the word's meaning relevant to the context of story both in L1 and L2. The transliteration was obtained from Google Indic Keyboard, English word meaning from Google Dictionary and Marathi translation from Google Translate. The pull-out tabs were placed on each page of the book such that it did not cause much obstruction to the illustrations or to the printed text.

LETS application offer learners a professional voice-over to storybooks that delivers the prosody of the text that may helps the learner be engaged with the story and aid comprehension.

Features
Each page of the book is mapped with its corresponding curated read aloud of the content in prosody, which is triggered by a page turn. Each participant is provided with a headphone to cancel out surrounding noise. The phone is placed on a stand specially designed for the purpose such that interaction with the mobile screen is negligible. Each participant may choose to follow the audio on the book with their fingers.

Microsoft's Immersive Reader was developed to enable children with learning disabilities such as dyslexia and dysgraphia improve reading comprehension, though its use cases address a broader audience.

Features
The interactive desktop application provides with read-aloud, word translate, picture library, focus mode among other features which facilitates decoding skills. The application provides other graphical controls such as line spacing, part of speech identifiers, etc. The learning tool was accessed with laptop and a mouse along with headphones. For the experiment Immersive Reader was used with read aloud in female voice at 0.75× speed, words with syllabic split, 1-line focus and picture dictionary. A participant may at any time during the interaction could pause and play the interface, click on any word for its meaning in English, picture dictionary and its pronunciation (Figs. 67.1 and 67.2).

67.3.4 Activity

The three tools were assigned a book each from the LETS storybooks collection. "Clever Kalyani" was physically read with assisted glossary. "The Crazy Monkey" was accessed by the LETS mobile app. The content from book "The Circus" was used for Microsoft Immersive Reader. The participants were divided in 2 groups of 06 students each. Each group had 03 participants from Level A and 03 participants of Level B. One group was assigned LETS storybook, and the other group was

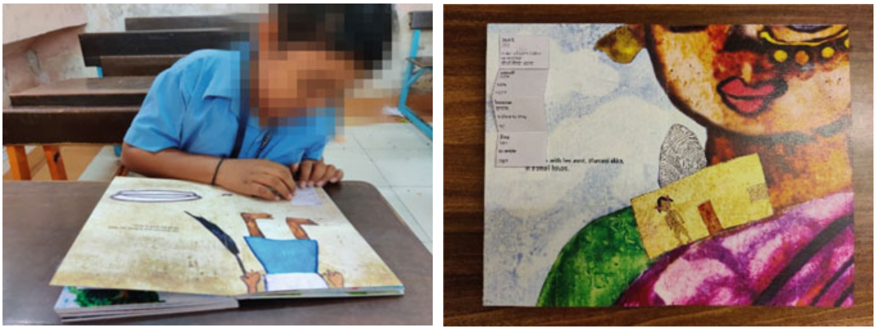

Fig. 67.1 **a** Participant using LETS storybook. **b** Pull-out tabs on LETS storybooks

Fig. 67.2 Participant using **a** LETS app. **b** Microsoft immersive reader

assigned to Immersive reader, while each participant of both the groups was to use LETS mobile app. The scheduling was formulated such that each participant must get at least three sessions with each of the assigned learning tools during the entire period of deployment. Each participant was introduced to the respective learning tool in their first session.

In a session, the participant may place the apparatus according to their convenience. There was no time limit for a participant to use any particular learning tool. The first session for each learning tool was followed by an interview to establish rapport with the participants. The interview questions were specific to their reading habits, interests and some strategic knowledge they employed to decode the content. Each participant was interviewed mid-week, i.e. after going through each learning tool at least twice. Here, the responses from previous interviews were included as follow up questions that meant to probe for more information and clarify ideas based on observations. This ensured the participants would reinforce my observations by voicing their thinking [15].

67.4 Analysis

Kirkpatrick provides a tool to evaluate a learning tool on four levels: reaction, learning, behaviour and results. Provided the short period of deployment, we seek to evaluate the different tools in the experiment up to level 2, i.e. learning. It will be a giant leap for us to claim to have any visible impact on behaviour or to claim a demonstration of any return on investment when under deployment. The study checks for a participant's engagement and their reaction towards the tool through verbal feedback after completion of the experiment. A smileometer survey based on user experience questionnaire was used as a prompt for feedback. There was no time limit for a participant to use any particular learning tool. The observations of the study could be discussed within the following themes.

67.4.1 Features of Learning Tools

All the participants, irrespective of their reading skills, used the in-page glossary, word pronunciation provided in LETS storybook and Immersive Reader thoroughly during the sessions. The usage of these assistive features reduced over subsequent readings but continued to be fairly used by the Level B participants. All participants referenced back to previous pages of the stories across the different tools to map continuation. Participants reported that the line focus feature available in Immersive Reader was helpful to keep track of their reading. The word highlight feature during read-aloud helped them make the connection between sound and its spelling. Immersive Reader's picture dictionary feature was lauded by the participants stating that they could understand the meaning without the need of reading. However, it was observed that this feature does not conform to the context of the text and currently displays one fixed meaning of a homonym. Inability to read the diacritic marks and conjuncts posed a challenge for Level B participants as they could not use transliteration or L1 word meanings. Instead, they relied on L2 word meanings to decipher the word meanings. However, the participants could easily speak and understand as well as converse in their native language. They could quickly decipher the meanings of the same when readout to them, indicating low competency only in terms of reading. Level A participants could effectively use syllabic split of a word to pronounce any word, still making some intelligent mistakes. Level B participants faced difficulties to read the individual syllables. Only Level A participants reported to have aided with the syllabic partition of the words. However, mimicking the read-aloud was more favoured as participants would need minimal effort to know the sound of the word.

67.4.2 Attraction Towards Media

Introduction of new learning tools is in a formal classroom set-up where such tools were sparse, closely gained attraction of the students. The LETS app and Immersive Reader attracted all the participants' attention throughout the deployment period. Most of the Level A participants focused on the content delivered through the three mediums. They demanded for new stories and reflected inertia towards repetition of the same story. Participants of Level B had strong inertia towards reading the physical storybooks. Some participants pointed out that they could not read the words or understand the meanings from the glossary. Hence, they preferred the other alternatives of LETS app and Immersive Reader, as the content was being read out to them. Among the two read-aloud, most participants liked the prosody in the read-aloud by LETS application.

67.4.3 Controlling the Features

Participants enjoyed to have control over features of the learning tools. Be it re-initiation in LETS app, pop out meanings from the storybooks, or pause, play and show meaning in Immersive Reader. Their ability to control the learning tools also meant that participants were actively participating in the reading activity. This was noted as a positive connotation towards a feature, where limited yet specific controls should be made available for the learners in order to participate actively. Across the three different tools, Immersive Reader provides most number of features which could be controlled by the participants. The pause and play function in Immersive Reader enabled participants to pause and play the read aloud at a specific word and listen to its pronunciation. In LETS app, to listen to a repetition of a certain word, the participant had to reinitiate the page. If the word is missed during the repetition, the function becomes an exhausting loop, resulting in participants dropping out of the attempts. Immersive reader includes speed modifications for read aloud, which could be used to enable slow narration of the text allowing participants to try mimic pronunciation of a word or a piece of text.

67.4.4 Strategies for Decoding

67.4.4.1 Marathi

All participants read the consonant first, then they say "adding a diacritic", spell the consonant with the diacritic, and then proceed to the following consonant. Thus, when a participant contemplates to pronounce the consonant and corresponding diacritic mark, they tend to forget the previous consonant (or string of consonants).

This triggers their previous knowledge and they spell out the word as taught in the school for the first encountered consonant and use of this consonant in a word. Say, the word is मीनाक्षी(Meenakshi; a hindu name), they read through each consonant and the diacritic, unable to stitch the consonants and diacritic marks would say मांजर(Maanjhar; meaning cat). This is despite the fact that the word exists their mental vocabulary, as when spelt out to the participants, they could understand the meaning. Most of the participants were not able to recognise conjuncts and diacritic marks of uncommon vowels. The above-mentioned issues contradicted with the hypothesis of L1 supplementing L2 through reading due to underdeveloped reading skills of L1.

67.4.4.2 English

All the participants, in coherence with literature, could identify a word by spelling letter by letter, then break it into phonemes and try to pronounce the word [14]. It was observed among Level A participants, that they could easily identify uncommon words. Level B participants particularly found it difficult to do such break downs. To support this ability, Smith, in his book, mentions about the readers demonstrating the ability predict the probability of letter sequences in English, as combinations with consonant–vowel pair like th, st, gh occur more than combinations like dw, ae, ao, etc. [11].

67.5 Discussion

67.5.1 Motivation

A learner's orientation towards language learning affects their competency in second language. This factor drives the explanation for the success or failure in the completion of any task. The need for participants to learn L2, English, arises out of the functional aims like passing exams, provided the sociocultural environment for the students does not demand for communication in L2. In the study, the fallout rate for learners in the activity was negligible, given the study was conducted in an academic set-up and notifying the extrinsic motivation of not being left out amongst other batchmates. The study tries to record the intrinsic motivation of participants by mapping enjoyment to engagement in an activity with a learning tool. The motivation factor leads to a critical feature requirement for learning tools. For adoption and retention by a learner on a platform, it is important to strengthen their ability by providing meaningful rewards and allowing them to make mistakes and re-attempt without a baggage of being humiliated for their incompetence [16].

67.5.2 Disconnection: Establishing Phoneme and Grapheme Connection

Word identification problem was evident among Level B participants. Despite being able to recognise letters, they faced tremendous difficulties in chunking the spellings (graphemes) to their sounds (phonemes). This confirms the limited exposure to conditioning towards decoding in second language. Adler in their studies notes that phonics instruction is beneficial for early age learners [17]. Explicit phonics instruction increased word recognition, spelling and reading comprehension among students across various socio-economic level. Addition of features like syllabic split assisted with voice over could help overcome this gap.

67.5.3 Language Conditioning

The participants were consistent with prior conditioning of reading L1 Marathi texts and reproduced a similar strategy to read English texts. As the participant pauses to decode unfamiliar words, letter by letter, thoughts about the portion of text gets disrupted. Particularly, in the case of less skilled learners, the uniform teaching method used in schooling and tuitions does not seem adequate. These students, to be able to improve reading skills needs to be empowered with other learning techniques, which could be customised, adapted and disseminate with the use of ICT supplementing the existing teaching practices.

67.6 Limitations

The study was conducted in a localised sample group that may not be representative of the contexts which LETS programme addresses. However, repetition of studies in different locations with a more diverse sample might yield different results. The study conducted after school hours in the school set-up impacts the motivation of eligible participants to exercise the activities. Also, since all three learning tools were available in the same room at the same time during the activity period, I assume some effect on participants motivation to use a specific learning tool on the other. The study does not take into account factors such as the impact of gender, education of family members, cultural backgrounds or motivation on performance.

67.7 Future Work

The engagement with features of the given learning tools grounds the exploitation of these features for upcoming learning tools. This study could be replicated after adapting some changes to the features noted above in LETS application. The work could form a background for optimisation and customisation of features in a learning tool. Another comparative study of with and without features for LETS app could be carried out.

This study conducted over a short duration was limited to check for engagement. However, a long-term longitudinal study of the interfaces could help understand the impact on learning and for noting any change in behaviour. Nardagani reading programme could be introduced to carry out an experiment to check for the effectiveness of the syllabic division of words to the Nardagani system, with respect to pronunciation improvement of EFL learner [18].

67.8 Conclusion

The study corroborated the need for assistance via learning tools towards decoding strategies for EFL learners. We expect that the future design improvements on learning tools for EFL learners may use the following characteristics specific to decoding:

1. Establishing the grapheme–phoneme connection is crucial for effective pronunciation. In the study, this was achieved via read-aloud, assisted with line focus and highlighting of words in Immersive Reader. However, prosody in read-aloud allowed maintaining the interest of the participants while keeping the content exciting.
2. Features must supplement the learners' depth in vocabulary. Providing in-line word meanings helps a learner decode effortlessly. Word meanings could also be provided through picture dictionary, and translated in L1 could be useful, provided the context of the story (or text) is preserved. However, if a learner's L1 reading skills are not developed then L1 may not supplement the L2 reading skills, as discussed above.
3. The participants felt empowered with tools where they could control the tools and could predict the actions and feedback they may receive upon an action. Hence, it is safe to mention that learning tools could provide specific controls for features and the number of these learner-dependent controls must be limited.
4. A learning tool must adapt to the ability of the learner's exposure to the language and customise their interaction with the tool. A learner must have a shorter set up time for the tool.
5. For fluent learners, add-on features could be made available, where leveling up their language skills could be incentivised by unlocking new benefits of features. This would improve motivation towards the activity and give other

learners situated in the same educational set-up to aspire for achieving higher skills.

Acknowledgements I would like to thank High School administration for extending their support for conducting the experiment during a busy exam schedule. My sincere gratitude to Agastya International Foundation and LETS programme. A special thanks to Dr. Alka Hingorani (Principal Investigator, LETS), Manjiri Joshi, Malay Dhamelia, Dhriti Dhaundiyal and Abhijith Krishna for their contributions towards the project. And thanks to many others who have directly or indirectly contributed towards the project.

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Chapter 68
System Mapping: Understanding the Value Chain of Organic Farming in Sikkim, India

Neeraja Kulkarni and Mohammad Shahid

Abstract Sikkim is the first official organic farming state in India. However, organic farming has brought challenges to both farmers and distributors. Secondary research shows issues in the value chain of the organic produce. Design research was carried out to understand organic farming in Sikkim at a broad systemic level. After understanding the issues faced by various stakeholders through primary research, system maps were created. This paper puts forward a qualitative study about the gaps observed in the organic farming scenario in Sikkim, thus putting forth the role of service design as solutions, and its role in making the whole system environmentally sustainable.

68.1 Introduction

The most practiced occupations in the state of Sikkim are farming and tourism. In 2003, the Sikkim Government made the decision to transition Sikkim to organic farming, as it was believed that it would not only be economically profitable but also enhance the environmental status of the state, thereby encouraging eco-tourism and promoting biodiversity. Organic farming is a method of farming that does not use chemical fertilisers and genetically modified (GM) seeds. It is a more environmentally sustainable practice compared to conventional chemical fertiliser based farming. Secondary research, however, showed that every stakeholder in the value chain of organic vegetables faces significant difficulties, particularly the farmers. Additionally, the environmental impact as well as the value of the end product remains ambiguous. To understand the current scenario of the 'Organic State of India', design research on fresh vegetable produce was conducted. It must be noted

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A. Chakrabarti et al. (eds.), *Design for Tomorrow–Volume 3*,
Smart Innovation, Systems and Technologies 223,
https://doi.org/10.1007/978-981-16-0084-5_68

that Sikkim received 14.5 Lakh tourists in 2017 while the projected local population after the 2011 Census was 6.43 Lakh [1]. The imbalanced flow of distribution in the state has led to the formation of an intricate web of concerns in the supply chain. Solving these concerns synchronically or efficiently has proven to be extremely difficult. This study looks at the relation of Sikkim organic produce with its distribution and consumption, and thus attempts to understand the scope of services keeping the environment in mind.

68.2 Methodology

The tools and methods used in this research include contextual inquiry, in-depth interviews, observational notes, brainstorming sessions, ecosystem maps, and data synthesis. The study was conducted on the field with an ethnographic approach. The initial phase was dedicated to interacting with local people and vendors as well as tourists to understand the social and cultural context. A total of 20 participants including farmers, entrepreneurs, organic vegetable vendors, Sikkim State Government officials, conventional produce vendors, locals, and tourists were interviewed. Design research was conducted, which aims to extract in-depth information through a lesser number of participants through qualitative rather than quantitative data. It was followed by the analysis of the collected data and its synthesis. An ethnographic approach provided a deeper understanding of the lifestyle and obstacles faced by the indigenous people of Sikkim, especially the farmers.

68.3 Observations

The following section summarises the observations derived from desk research.

68.3.1 Stakeholder Mapping

Understanding stakeholder mapping involved dividing stakeholders according to their primary, secondary and tertiary importance to organic farming in Sikkim. Primary stakeholders include organic farmers of Sikkim, the National Programme for Organic Production (NPOP) [2], infrastructure (storage and transportation), private farmers, locals, and banks. Processing units (collection/supply/flaking/packaging), traders, produce, brokers, export market, government officials, marketing people, post-harvest management, seed banks, and laboratories are the secondary stakeholders. Tertiary stakeholders are restaurants, fast-food packaging units, NGOs,

Table 68.1 Stakeholder mapping for the study

Stakeholder	Type	Number of stakeholders
Farmers	Primary	4 (3 Marginal + 1 FPO head)
Sikkim Locals	Primary	4
Vendors	Primary	5
Entrepreneurs	Secondary	2
Restaurant owners	Secondary	2
Tourists	Tertiary	2
Government Employees	Tertiary	1

countries of export, states of export, and farmers of other states of India. Table 68.1 shows the number of stakeholders considered for this study. Different government officials have different tasks; this makes them stakeholders at various levels accordingly [3].

68.3.2 Infrastructural Importance

Owing to Sikkim's high altitude and inaccessibility, the reach of chemical fertilisers during the Green Revolution was limited. This made the transition to organic farming easier. However, the state faces several infrastructural difficulties in its practice. Most farmers are not financially capable of buying cold storage units to support their production. Further, the returns after using cold storage are questionable due to unpredictable market rates. Organic edible oil is not produced in Sikkim. Therefore, the organic tag cannot be used by restaurants (i.e. the end product is not tagged organic), which leads to a downfall in the value chain. Sikkim, being a comparatively smaller sized area in the mountains, has fewer units producing supporting raw materials such as cardboard boxes and paper. As of now, these kinds of raw materials are procured from adjacent states; thus, increasing the end cost of the products. There is also a lack of entrepreneurs in the organic sector of Sikkim.

Figure 68.1 shows that an increase in supporting industries can lead to an increase in entrepreneurship and vice-versa. That can also lead to an increase in employment opportunities. The role of the Sikkim State Government here is to enable the local populace by either creating new policies for entrepreneurship related to organic farming or by communicating the existing policies with similar functions.

68.3.3 Role of the Government

The Sikkim Government has made organic farming a mandate and provided a provision for free certification (SSOCA) for all farmers in the state. It claims to have

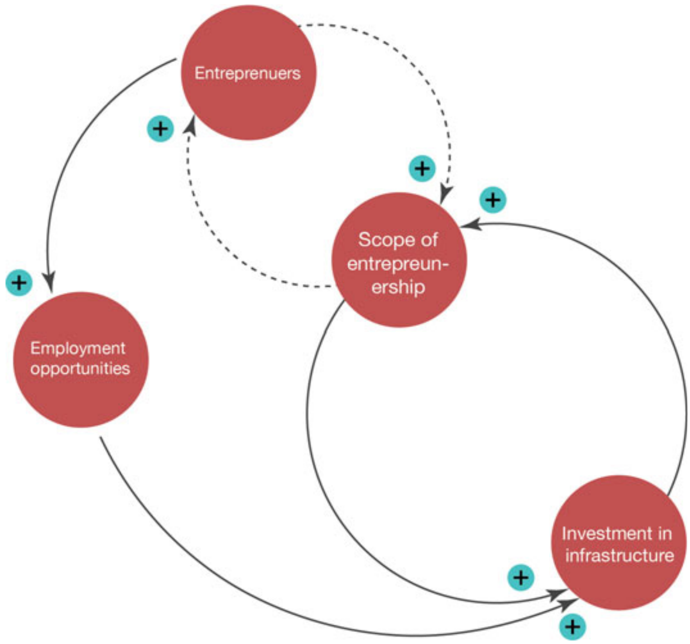

Fig. 68.1 Importance of investment in infrastructure for organic farming

certified more than 66,000 farmers. However, some small scale farmers are not included [4]. Presently, only two of the twenty-nine proposed FPOs (Farmer Producer Organisations) are functional.

In this case, Fig. 68.2 describes the need for resource allocation during the transition period for farmers. This will act as a strong financial support for vulnerable, fragmented landowners and will discourage them from using chemical fertilisers again. If farmers do not transition to organic, it will lead to the deterioration of soil health in the long run, recovery from which will be difficult. This will further decrease the quality of produce and reduce yield quantity in the coming future. However, farmers often face losses in terms of quantity and quality during the transition period from conventional to organic farming. It is a delayed process, which requires financial support. If the quantity of yield is reduced, the income for that particular season will decrease. In this case, vulnerable farmers around India (not specifically in Sikkim) opt for (often Government subsidised) chemical fertilisers. Increase in the usage of chemical fertilisers leads to an increase in the quantity of the yield for a short term and fills the expected loss gap of the organic transition.

Thus, it can be concluded from the findings of this section that service level changes are important from the private sector to influence traders and reduce malpractices. Collaboration of the private sector and the State Government to encourage self-sustaining agri-industries in Sikkim can increase entrepreneurship, which can be good for the state economy as well as the mental health of citizens therein. The

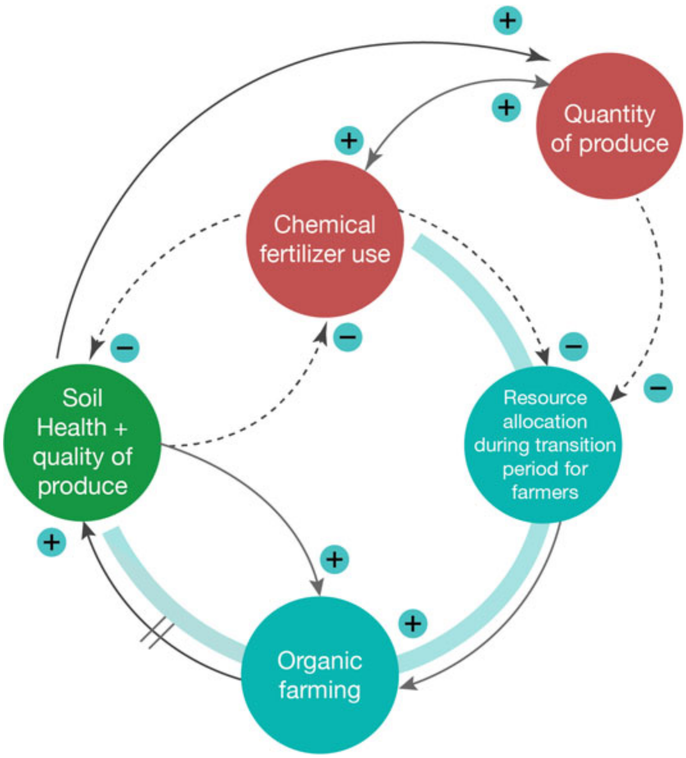

Fig. 68.2 Importance of resource allocation for organic farming

role of the government is considered an enabler, but policy level changes in terms of subsidising the three-year process can result in a win–win situation.

68.4 Synthesis and Analysis

To understand the gaps in the value chain better, the findings have been divided as production (farming), distribution (supply chain) and consumption.

68.4.1 Production

It is observed that, often the overall quantity of production through organic farming methods is lesser than the conventional produce. As a result, the cost of organic produce increases. In addition, chemical fertilisers are effective in getting rid of pests instantly while organic fertilisers require dedicated, timely applications. Using chemical fertilisers then becomes more economically viable for the farmers, until over time, the quality of soil deteriorates and the output reduces. The other side of the debate is that organic vegetables are healthier for the body. Health risks like cancer have increased due to the over-usage of chemical fertilisers. Chemical fertilisers can also enter the body by consuming meat and dairy products. This is called bio-accumulation [5]. Harmful water containing chemical fertilizers used on farms is let out in rivers affecting the aquatic life therein. Government bodies have constructed numerous ill-planned dams for water-security on farmlands, which has led to river depletion [6]. Farmers practice mono-cropping (not multi-cropping), which does not lead to a formation of rich soil [7]. Companies such as Monsanto have been allegedly misusing the problems faced by farmers for their own profit. This is referred to as disaster capitalism [6]. As shown in Fig. 68.2, transitioning to organic farming is a solution for increasing productivity, soil health and returns. If this is not done, farmers will be in a financially troublesome position, which will be a huge economic crisis for India, as a nation with 60% of its population practicing farming as a key occupation. One of the Sikkimese farmers interviewed mentioned that the reason he wouldn't ever use chemical fertilisers was because he believed that the soil is his God, and asked why anyone would pollute their God. This was an example of the deep-rooted cultural values that probably gave impetus to the organic movement in Sikkim.

68.4.2 Distribution

Distribution of any goods involves displacing them from the place of production to another place: another business, treatment, or directly to the end-consumers. Different products and services require different types of approaches, depending on factors like consumer trends, area, and financial feasibility. In the case of Sikkim, the distribution or the supply chain of vegetable produce is one of the major issues observed.

Organic farming is a seasonal process and at present, any one crop cannot be produced throughout the year. Consumers, however, demand variety. Potatoes and tomatoes being the staple food are required year-round. These factors and the lower capacity of organic produce in the tourist season enables conventional produce from adjacent states to dominate the market.

A contextual inquiry showed that the produce from Sikkim is supplied to Siliguri (West Bengal) but is mixed with conventional produce, knowingly or unknowingly. These vegetables have been supplied back to Sikkim in the form of conventionally farmed vegetables via a chain of traders. This leads to an excessive value decrease of the organic produce. As a mountainous state, Sikkim is less accessible making it difficult to supply vegetables to the adjacent states. Hence, a well-managed decentralised distribution of organic vegetable produce can lead to substantial value growth and can save the cost of transportation and cold chain, thereby reducing the waste as well.

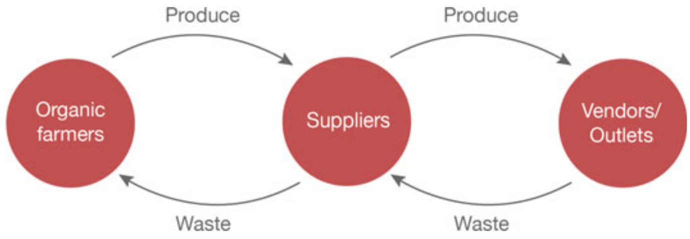

Fig. 68.3 Circular Distribution Model

Figure 68.3 shows how farming can take up an ideal Circular Distribution Model to increase productivity in small areas.

Exotic crop production, such as that of shiitake mushrooms, can theoretically lead to economic growth, though the high investment in cold chain infrastructure for distribution results in low returns. At such times, perishables are packaged with ice cubes in polystyrene sheet containers. This opens up the possibilities of sustainable packaging, which may play an important role for ecological preservation, as polystyrene sheets are not environmentally friendly.

68.4.3 Consumption

A product/service/policy is made for the consumers. Consumption patterns depend on several factors. Usually, the factors that affect consumers are the method of purchase, place of purchase, frequency, item and purchase potential. Motives, learning, attitudes, lifestyles, experiences, mirroring, peers, health outlook, priorities, society approval, and patriotism are deeper factors that affect consumerism.

Figure 68.4 shows how a decrease in the reliability of authentic organic produce (due to imbalanced supply chain) among Sikkimese locals can lead to the reduction of demand and hence a reduction of value. Therefore, even if the cost is high due to less availability, consumers or customers won't be willing to pay the price. One surprising observation among the consumers was that locals were aware of organic farming and its benefits; they could distinguish between conventionally grown produce and organically grown produce just by judging unreliable visual cues of the farmers or the vegetables.

Consumerism steered by advertising has led to an overuse and over-extraction of materials. It has also inculcated a 'disposable culture', which has led to environmental degradation [8]. In terms of environmental sustainability, consumers need to be aware of where their products come from; otherwise, they tend to get manipulated by monopolies responsible for massive environmental degradation through their inefficient production processes. Consumers should also be aware about their responsibility towards the environment and act accordingly.

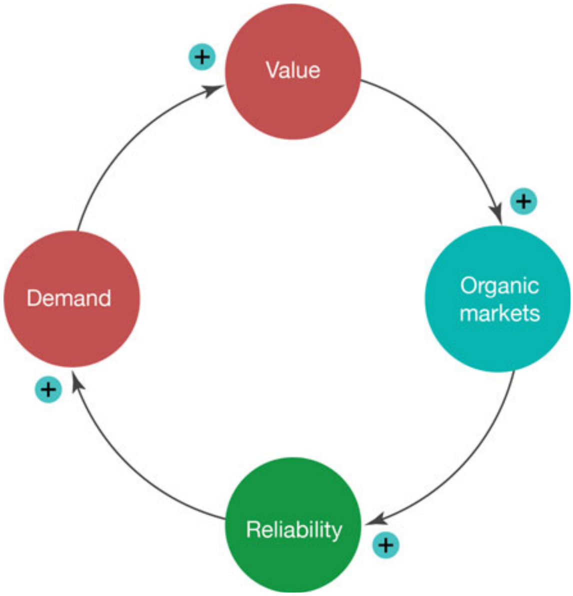

Fig. 68.4 Importance of organic markets to increase reliability

Sikkim has, thus, essentially managed to transition farmers to farm organically, but to properly promote organic farming, several levels of issues need to be solved. Though in recent years the shift towards services or products that are more environmentally sustainable (similar to Sikkim transitioning to organic farming) has become visible. This can either be aimed towards making an actual difference in carbon emissions or simply be a deceptive marketing tool.

68.5 Results and Discussion

Service design is a process that enables designers to innovate solutions, usually in the form of services or products after thoroughly understanding and defining the problems in the chosen context. This section summarises the scope of service design in the value chain concerning organic farming in Sikkim. Table 68.2 shows scenarios covered during a user-centered brainstorming session which helped in defining the three potential areas i.e. production, distribution and consumption, which might be considered for service design intervention sites.

Table 68.2 Scenarios covered during user-centered How Might We (HMW) brainstorming session

Stakeholder	Scoping intervention areas
Consumers	• How might we create a new value equation of organic produce among the consumers? • How might we communicate the authenticity of fresh produce to the consumers?
Vendors	• How might we create adaptable guidelines for vendors to store organic food? • How might we create a supportive environment for the vendors to separate the produce?
Processing Units	• How might we create supportive environments for the redistribution of the produce?
Traders	• How might we provide guidelines for the traders to enable them to form a relationship with the government for a more streamlined supply chain process?
Farmers	• How might we eliminate the barriers to participation for the new generation farmers? • How might we create an accessible user experience for the SSOCA certification system to certify all Sikkimese farmers? • How might we make technological interventions to provide efficient cold storage to decrease waste and increase the shelf-life of the produce? • How might we enable fulfilling relations and cultivate an ecosystem of knowledge sharing among all stakeholders for effective outputs and data collection? • How might we create a sub-system for redistribution of waste for processing at the market level?

68.5.1 Scope of Service Design Interventions

Once mapped, the gaps in potential intervention can be identified and further dealt with using design thinking to introduce innovative alternatives that do not economically degrade the product profits.

In terms of Production. If other states in India, no matter how small or big, discover the political and civil will to transition to organic farming, policy intervention for subsidising income in the transition period can be beneficial. Making farmers aware of their long-term losses if they use chemical pesticides and fertilisers is an important start.

In terms of Distribution. The supply chain of organic farming currently devalues the product due to an absence of organic focused markets (regulated or unregulated). Sikkim, as an organic state, is self-sufficient in terms of the produce, but could decentralise the supply as supplying fresh vegetables outside the state is not deemed profitable. This will in turn reduce the carbon footprint of long distance transportation and avoid the need for cold chains. An increase in entrepreneurship can lead to a rise in agri-industries making farming organic and economically viable as well.

In terms of Consumption. Sikkimese locals' preference for organic shows the cultural importance of organic food. Reliability in terms of organic authenticity can trump the sale of conventional produce. The cultural wave of producing organic fresh vegetables needs to be adapted. A farmer/user-centred design thinking process can be used to innovate more alternatives or specifically service design solutions to reduce waste and increase value.

68.5.2 Using a PDC Lens During the Ideation Stage

Using the PDC lens (Production, Distribution, and Consumption) to understand the environmental impact of products and services during the ideation stage of design thinking is theoretical and needs to be validated with substantial primary research. Figure 68.5 illustrates the PDC lens where overlapping areas of P, C and D may be considered as an 'Ideal Product' situation. Furthermore, valid participation of private multi-nationals is questionable due to their repetitive lack of ethical and ecological responsibilities through the decades. Therefore, government policies for carbon emission mitigation, such as an introduction of carbon tax, are necessary.

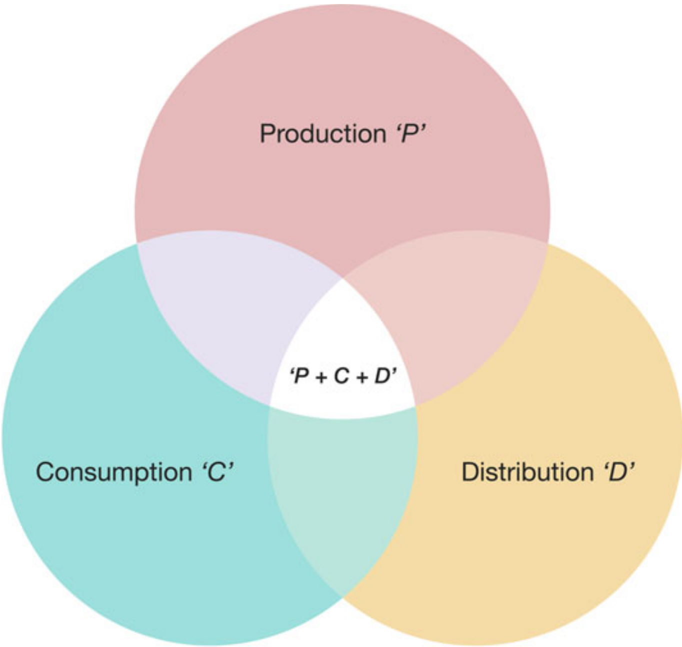

Fig. 68.5 PDC (Production, Distribution & Consumption) lens

68.6 Conclusion

History has taught us that no matter how great the idea is, it may lead to unprecedented destruction of the environment or the well-being of people. Having a preliminary and holistic perspective when it comes to the journey of a particular invention before it is introduced to the market is essential. Innovators could map the impact of their inventions through the PDC lens during the ideation stage. It can also be researched and developed further to calculate the decrease of carbon emissions in existing products and services in different sectors at a micro level.

Acknowledgements We would like to thank Dr. Savita Kulkarni, Tenzing Ninzey, Sonam Gyaltsen, Prajakta Kulkarni, Gajanan Kulkarni, Deergha Joshi, Harshi Rambhia, Chitrupi Eeshwaran, Tanvi Joshi, Mandar Mhaskar, Sushant Ahire, Sushant Arya, Sanket Inamdar, Mathew Samuel, Raghvi Kabra, Anshul Agarwal, MIT Institute of Design, and Echostream Pvt. Ltd.

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Chapter 69
An Empirical Study on Styling Trends and Concept Approach of Augmented Reality

Sandipan Bhattacharjee and Bhaskar Saha

Abstract Development and progress in a particular domain are based on user interests. In this context, beauty and styling were given importance to a standard which might be difficult to ignore. The visual perception of being presentable and appropriate for a particular event is a necessity in the modern world. So, an application design model would be appreciated and encouraged, that could deliver appropriate styling trends for occasions and events. The perspective of the users was explored through a twofold survey. The dependability of the market infrastructure belonging to the service providers depends largely on the market strategies and the quality of work provided by them. The use of augmented reality elements to reach essential milestone for a suggesting application was sought. It was a design-concept approach to overcome the obstacles raised and to enhance the present market scenario. In this paper, the impact and scope of augmented reality elements on commercial basis for beauty and styling apart from just entertainment purposes have been discussed with users and design based students on how enhancements could be made in this crucial domain.

69.1 Introduction

The use of cosmetics and medical cosmetic products has gathered less attention into dermatological researches and so, a need is felt to introduce this aspect of styling into an organized and well-structured system. Habitually, people associated beauty and grooming with color and makeup but actually have five extensive categories like skin care, hair care, make-up, fragrance, and personal hygiene [1]. According to Nair, as people are changing their habits and are more into using cosmetic products to

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A. Chakrabarti et al. (eds.), *Design for Tomorrow–Volume 3*,
Smart Innovation, Systems and Technologies 223,
https://doi.org/10.1007/978-981-16-0084-5_69

look good as well as presentable at different occasions, the necessity of an organized system in this area was encouraged. People relate good looks and smartness with beautiful skin and idyllic body [2]. Beauty products especially for women were in a demanding position for a long time and presently, their counterparts have also started giving importance to how they look, resulting in flourishing of the male grooming industry. Men are now more aware of how they present themselves in this modern world and prefer to dress accordingly [3]. Usage of products in a varying range might lead to troubles, where there was difference in skincare quality of the user than actually required quality, which might lead to skin problems. External features like environmental stress factors could also affect the quality of skin of a person. It is of utmost importance that a person knows the type of skin one has and what cosmetics would be appropriate for them [4].

The sales statistics from top companies of the beauty industry revealed that more than 40% of the sales were from the European companies and were just followed by the American companies, while the Asian companies held around 13% only [5, 6]. A shift was noticed throughout the cosmetic industry, where emphasis was on styling which was based on region irrespective of gender [7, 8]. As recent researches depicted, the concept of using cosmetics and styling was not limited to only women and has extended to other genders and yet the cosmetic choice has a gender separation [9]. For being appropriately presentable for an occasion, it is essential to know the current trends along with the desired choices of the user [10]. Often there were cases where a person was considered inappropriately dresses for an occasion. People possess a desire to be seen as presentable and to look good however, styling is a personal aspect. According to Grubb and Cash in their respective studies, they state that there exists a psychological impression on a user and the onlookers on the basis of styling and hygiene [11, 12]. Well dressed and perfectly presentable people attending an occasion would leave an impression of confidence, boldness, and radiance. Visual appearance is one of the first impressions that one casts on other people and it is very important to make the most of this impression [3, 13].

In a very recent approach toward upgradation and modification in the field of styling and beauty, technology and devices based on the principles of augmented reality were widely used. The actual surrounding or the environment could be altered and modified with computer-generated imagery to give out a sense of actual reality. The concept of using this technology is present in the fields of aviation to gaming and has a vast number of day-to-day users where AR has far-reaching areas of potential use. It is a technology which is being evolved through the tiresome hardwork of tech-engineers and researchers [14–16].

A very interesting feature of AR is that it expands the physical world around us by adding several layers of digital information. Differing from the concept of virtual reality, where entire artificial environments are generated, it appears in direct view of the existing environment and then adds layers of sounds, videos, and graphics. In other words, a view of the real physical world is along with superimposed computer-generated imagery, thus changing the perception of reality [17–19].

Since its origin in 1990, it has been a technology accepted by the society for commercial use in televisions and in military too. As modern-day commodities like

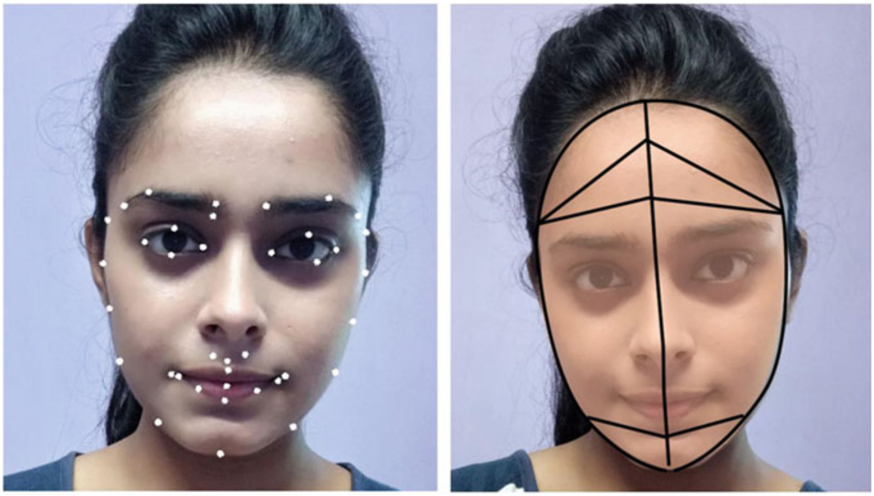


Fig. 69.1 **a** Tracking and **b** measurement of the facial periphery

the Internet and smartphones, AR has rolled out to these fields and is mostly related to interactive concepts. Computer-generated 3D models are either directly projected onto real things or superimposed together in real time to give out a sense of reality for the users. In the present situation, there are a number of applications and sites that use facial periphery and trackers to capture face structure as shown in Fig. 69.1a, b and offer services related to AR for entertainment or interactive purposes. Researchers believed that these various AR applications held a good amount of impact on the users' habits, social life, and the entertainment industry worldwide [20–22].

In this paper, it was intended to explore the areas of augmented reality into application of styling and beauty, to come up with an interactive system to measure and suggest appropriate benchmarks, while specially taking consideration of the user's needs through a twofold survey conducted in Kokrajhar, Assam, India. It was to put the functionality of the technology into an application that ran on AR-supported devices, to look for better styling and beauty solutions with informative implementation. The aim of this paper was to propose a hypothetical application embedded with AR technology, for beauty and styling tips and services. The objectives that were desired to be achieved through this paper were to establish a proposal of AR technology into mobile beauty applications for commercial purpose, which would establish a well-connected network among service providers and service seekers, which would ensure systematic structure toward the services of beauty and styling.

69.2 Design Process and Method

69.2.1 Methodology

In correspondence to initial discussions, there existed multiple scenarios, where a user of a particular service in context to personal styling might find it difficult or even unsatisfactory. Because of this fact, the people have become aware and self-conscious regarding styling and dressing, which prompts them to look for dedicated tools to aid them in the described area of interest. In this context, a dedicated mobile application could provide a certain mode of control to the people, so that the inconveniences of going through the existing styling process could be eliminated accordingly. The whole point of creation of this mobile application was to address the issue of usage of high-end technology for entertainment purposes rather than its usage on a commercial base for beauty products and styling tips, service providing and suggestive information regarding personal hygiene and styling. Considering that different users would belong from various places, their choices of styling would also differ from one another and so, the application had to have a filter regarding region. Beauty and styling are a day-to-day practice and as the current trend indicates toward being presentable at every occasion is a delicate task. Therefore, it was necessary for the application that would have a filter for different occasions and events. The application would also showcase styling and beauty services that the local service providers had to offer and so it was essential for the application to showcase services according to the status of availability of products and man power. It was also very essential to keep in mind the extent of expertise the local service providers had and the quality of work the users expected from them. Lastly, the application was dedicated to one user at a time so it learns the way one likes to dress or groom based on initial questions asked by the application and previous choices that the user has made and while doing so the application proves to be a useful suggestive tool for the users. The application would eventually need funding to keep up the network chain between the seekers and the providers and it was of utmost importance that both the seekers and the providers were comfortable and consented about a percentage that they would have to pay to the application.

The quality of user engagement is one of the key points to a successful application design as it keeps the user base engaged into the application and makes them come back to the application repeatedly. The bigger picture of user engagement is that there is optimal use of the application by visiting all the options it has to offer. The key to achieve this was aesthetical composition of the application along with easy navigation. In the proposed application, it was considered that the tone and set of the application was unbiased toward any particular gender. The user interface was designed in such a way that the users could navigate between the various pages with ease. The alignments of graphical elements in the application gave out the sense of simple aesthetical structure for the users. The implementation of augmented reality was a crucial task as it was the essential factor for the application to learn about its users and in time become a suggestive tool to them. The implementation of this high-end technology would see the application taking real-time images of the users, through sixty-eight non-identifying parameters to produce real-time videos and photographs for makeup, beauty and styling, hair and skin simulation. Due to the presence of these parameters to derive the simulation, there exists a variety of options that the user can choose as per their need.

The application calculatingly provided the user with validated skin assessment to ensure the user's exact skin tone, texture and fine lines and simultaneously advised the user accordingly. With the help of dynamic lighting adaptation present within the proposed application, it derived photo-realistic styling simulations of the user. The implementation of augmented reality in the application enabled the user to look for trends of choice while going through the services provided by local establishments at the same time. The entire user interface along with augmented reality technology together constitute to the wholesome user experience. The users would usually find the experience of using such an application and the services along with it seamless. The entire design process for the study has been put up in Fig. 69.2.

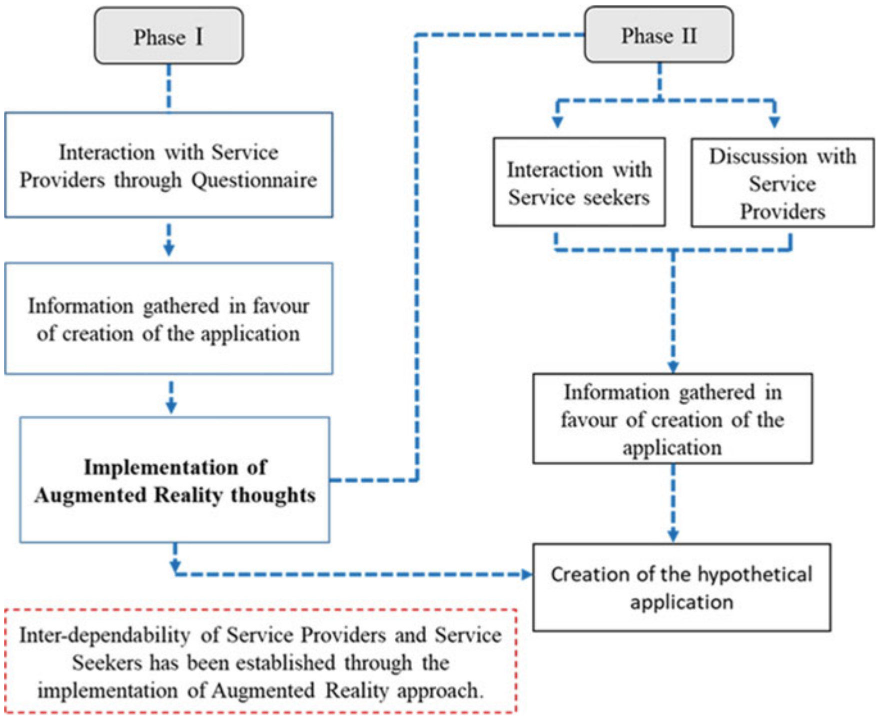


Fig. 69.2 Follow diagram of design process and methods

69.2.1.1 Phase I: Interaction with Service Providers Through Survey

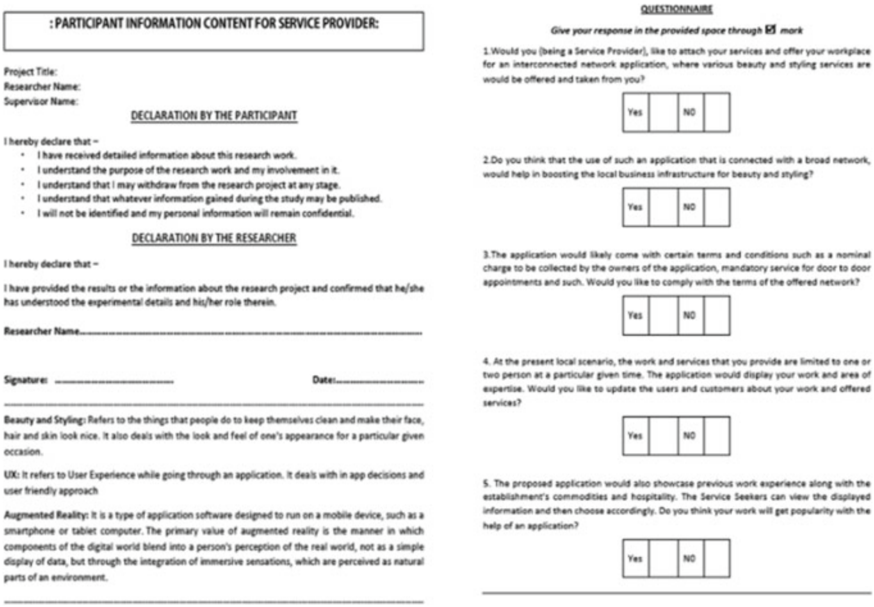
To support the above assumptions and hypothesis, the consent of the users about the application played a vital role for the build-up of the application, though the application would mainly focus on service seekers and yet the service providers remained the first step to the approach. To investigate, whether or not they would prefer to associate their local establishments with such a dedicated mobile application, a questionnaire was prepared regarding various criteria and aspects of the application. The questionnaire was distributed among thirty service providers with local establishments. The questions were presented keeping in mind that both the genders would be involved in the survey and eventually would be using the application. The criteria for age were also kept under consideration as people belonging to young generations are more likely to follow trends.

The first question to the service providers was about their willingness to collaborate their local establishments with the application. It was understood that some service providers might want to work independently, while some prefer to join hands and grow their business. The second question was about the perception of the service providers for the application as a helping tool to strengthen their business infrastructure and status. The third question raised the issue of expenditure as the application is not non-profitable and so, if the service providers were readied. The fourth question informed about the various services that the customers or users were mostly unaware of, which the local establishments offered. The fifth question was directed toward the opinion of the service providers about the popularity and appreciation for their work gathered from the customers. It was understood that there might be areas that were left uncovered in spite of all the discussed questions regarding work dynamics for the proposed application, so a sixth question was presented, where they had to share any information, ideas, issues, and queries. Figure 69.3 is a screenshot of the questionnaire presented.

69.2.1.2 Phase II: Interaction with Service Seekers Through Survey and Implementation of AR

Once the collection of data from the first phase was completed, it was turn for the second phase of the survey, which was to be done along with the service seekers also termed as customers. While integrating the augmented reality technology is certainly a buff to the overall application and yet what the users felt was of immense priority along with the consent of service providers. To exactly determine the user choice regarding the use of such an application, a questionnaire was prepared and distributed among seventy people from different age groups and livelihoods and yet gave importance to styling and beauty.

The first question to the service seekers was to validate toward having an application that allowed them to customize all their necessary beauty services offered by the local establishments at their fingertips using augmented reality. The second question discussed about the issue of having to wait for their turn in a local store for



: PARTICIPANT INFORMATION CONTENT FOR SERVICE PROVIDER:

Project Title:
Researcher Name:
Supervisor Name:

DECLARATION BY THE PARTICIPANT

I hereby declare that –

- I have received detailed information about this research work.
- I understand the purpose of the research work and my involvement in it.
- I understand that I may withdraw from the research project at any stage.
- I understand that whatever information gained during the study may be published.
- I will not be identified and my personal information will remain confidential.

DECLARATION BY THE RESEARCHER

I hereby declare that –

I have provided the results or the information about the research project and confirmed that he/she has understood the experimental details and his/her role therein.

Researcher Name……………………………………………

Signature: ……………………… Date:………………

Beauty and Styling: Refers to the things that people do to keep themselves clean and make their face, hair and skin look nice. It also deals with the look and feel of one's appearance for a particular given occasion.

UX: It refers to User Experience while going through an application. It deals with in app decisions and user friendly approach

Augmented Reality: It is a type of application software designed to run on a mobile device, such as a smartphone or tablet computer. The primary value of augmented reality is the manner in which components of the digital world blend into a person's perception of the real world, not as a simple display of data, but through the integration of immersive sensations, which are perceived as natural parts of an environment.

QUESTIONNAIRE

Give your response in the provided space through ☑ mark

1.Would you (being a Service Provider), like to attach your services and offer your workplace for an interconnected network application, where various beauty and styling services are would be offered and taken from you?

Yes		NO	

2.Do you think that the use of such an application that is connected with a broad network, would help in boosting the local business infrastructure for beauty and styling?

Yes		NO	

3.The application would likely come with certain terms and conditions such as a nominal charge to be collected by the owners of the application, mandatory service for door to door appointments and such. Would you like to comply with the terms of the offered network?

Yes		NO	

4. At the present local scenario, the work and services that you provide are limited to one or two person at a particular given time. The application would display your work and area of expertise. Would you like to update the users and customers about your work and offered services?

Yes		NO	

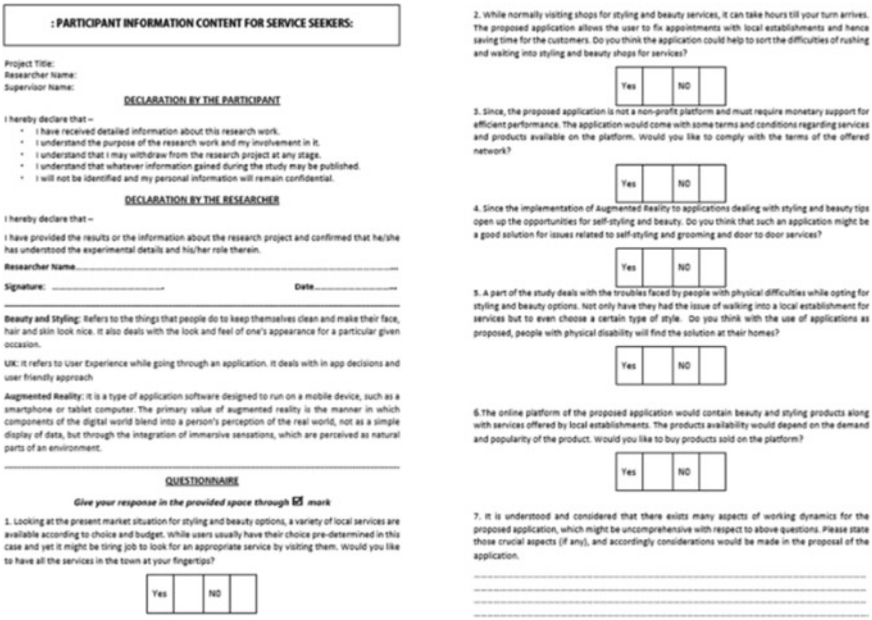
5. The proposed application would also showcase previous work experience along with the establishment's commodities and hospitality. The Service Seekers can view the displayed information and then choose accordingly. Do you think your work will get popularity with the help of an application?

Yes		NO	

Fig. 69.3 Questionnaire presented to service providers

a long time, whereas the application provided home services. In the third question, the focus was on the consent of the service seekers as the application would need an amount of expenditure. The fourth question investigated about the perception of such an application could be a solution for dedicated door-to-door services with proper appointments keeping in mind the security and authenticity of the people involved. The fifth question dealt with a more complicated issue often faced by individuals who are physically impaired and find it troublesome to walk into establishments for styling and beauty services. The sixth question to the service seekers was regarding beauty and styling products that would be sold on the application's platform. The users were asked to give their views on if they would like to buy products from the application. But covering all the aspects of work dynamics for the proposed application might be missing from the above questions so a seventh question was presented to the service seekers regarding additional inputs from their side. Figure 69.4 is a screenshot of the questionnaire presented.

From the above two surveys, a culmination of data was received and changes were made accordingly for the development of better user experience.


: PARTICIPANT INFORMATION CONTENT FOR SERVICE SEEKERS:

Project Title:
Researcher Name:
Supervisor Name:

DECLARATION BY THE PARTICIPANT

I hereby declare that –

- I have received detailed information about this research work.
- I understand the purpose of the research work and my involvement in it.
- I understand that I may withdraw from the research project at any stage.
- I understand that whatever information gained during the study may be published.
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DECLARATION BY THE RESEARCHER

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Signature: ……………………… **Date**………………………

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QUESTIONNAIRE

Give your response in the provided space through ☑ mark

1. Looking at the present market situation for styling and beauty options, a variety of local services are available according to choice and budget. While users usually have their choice pre-determined in this case and yet it might be tiring job to look for an appropriate service by visiting them. Would you like to have all the services in the town at your fingertips?

Yes		NO	

2. While normally visiting shops for styling and beauty services, it can take hours till your turn arrives. The proposed application allows the user to fix appointments with local establishments and hence saving time for the customers. Do you think the application could help to sort the difficulties of rushing and waiting into styling and beauty shops for services?

Yes		NO	

3. Since, the proposed application is not a non-profit platform and must require monetary support for efficient performance. The application would come with some terms and conditions regarding services and products available on the platform. Would you like to comply with the terms of the offered network?

Yes		NO	

4. Since the implementation of Augmented Reality to applications dealing with styling and beauty tips open up the opportunities for self-styling and beauty. Do you think that such an application might be a good solution for issues related to self-styling and grooming and door to door services?

Yes		NO	

5. A part of the study deals with the troubles faced by people with physical difficulties while opting for styling and beauty options. Not only have they had the issue of walking into a local establishment for services but to even choose a certain type of style. Do you think with the use of applications as proposed, people with physical disability will find the solution at their homes?

Yes		NO	

6.The online platform of the proposed application would contain beauty and styling products along with services offered by local establishments. The products availability would depend on the demand and popularity of the product. Would you like to buy products sold on the platform?

Yes		NO	

7. It is understood and considered that there exists many aspects of working dynamics for the proposed application, which might be uncomprehensive with respect to above questions. Please state those crucial aspects (if any), and accordingly considerations would be made in the proposal of the application.

Fig. 69.4 Questionnaire presented to service seekers

69.3 Result

The results obtained from the first fold of the survey were satisfactory as it was done along with all the possible local service providers and experts and collected a number of responses out of which 48.1% were male and 51.9% were female. Selective service providers were chosen for their quality of service, infrastructure, and availability with establishments.

Based on the data obtained during the first phase of the survey Fig. 69.5, Question 1 has 88.9% favoring while 11.1% were in denial. In Question 2, 85.2% agreed while

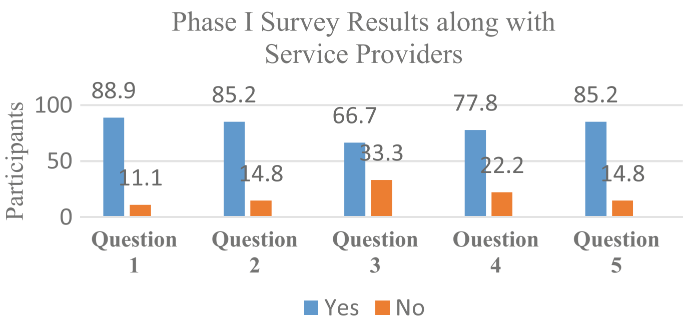

Fig. 69.5 Phase I: Survey result with service providers

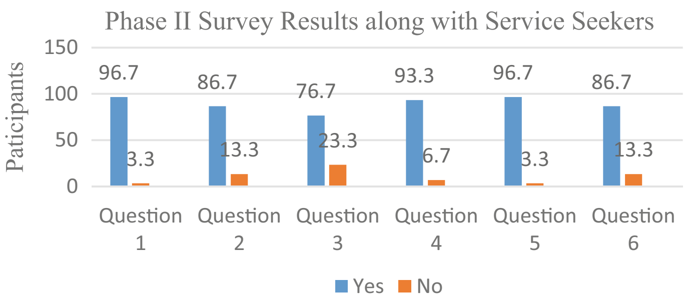

Fig. 69.6 Phase II: Survey result with service seekers

14.8% were against the statement. 66.7% favored and 33.7% disagreed in Question 3. Question 4 had a result of 77.8% supporting while 22.2% disagreed. In Question 5, 85.2% were in favor and 14.8% denied.

In Question 6, the service providers talked about the issue of availability of time slot to maintain door-to-door appointments for their services. The room for more service opportunity would be appreciated by the service providers.

According to the data obtained during the second phase of the survey with service seekers as participants, as shown in Fig. 69.6, Question 1 has 96.7% in favor and 3.3% disagreed. In Question 2, 86.7% were positive, whereas 13.3% were negative. Question 3 had 76.7% of participants who agreed which left 23.3%. Question 4 had 93.3% in favor while 6.7% in denial. In Question 5, 96.7% of the participants agreed whereas 3.3% disagreed. 86.7% were in favor and 13.3% disagreed in Question 6.

Based on the inputs of Question 7, it was found that the potential of such an application to solve the feasibility of self-styling with the help of augmented reality was required. The responses further explored the idea of having affordable styling services from the local establishments.

From the collective data gathered, it was evident that the majority of the service providers were enthusiastic about the hypothetical application during the first phase of the survey. They were interested in using the application through collaboration.

During the second phase of the survey, it has been found that majority of the service seekers were keen to use the proposed hypothetical application as the domain of augmented reality was interesting to them.

The study primarily focused and encouraged on the idea of using augmented reality in beauty applications for a particular region and offered styling and beauty services from the local establishments. Figure 69.7 represents the possible workflow of AR and its use in the application.

The user's facial periphery is captured by the device in form of digital data and then processed along with information and data stored in a cloud storage about the beautification and styling imagery that would overlap and superimpose with the user's actual facial periphery.

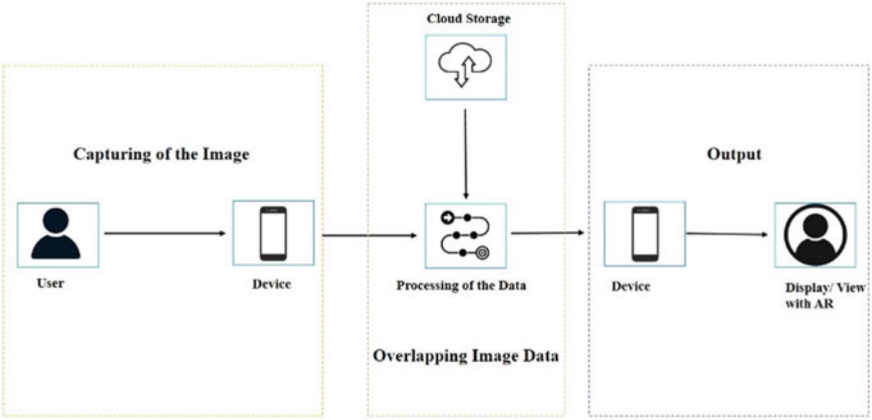

Fig. 69.7 Workflow of the proposed application

The processed data is then transferred to the device screen that would display the images of the user with the implementation of the technology. Figure 69.8a, b shows the visualization of the proposed application and its usability.

The integration of features for user navigation with its acceptability was evident to be of utmost importance. The aesthetic aspect of the application was discussed and decided along with students of design background as their course curriculum dealt with aesthetic features and accessibility. The elements of the interface were also made final after discussion with design-based students and key features were noted. The aspect of augmented reality was well appreciated as it was implemented on a commercial basis rather than just entertainment purposes in the proposed hypothetical

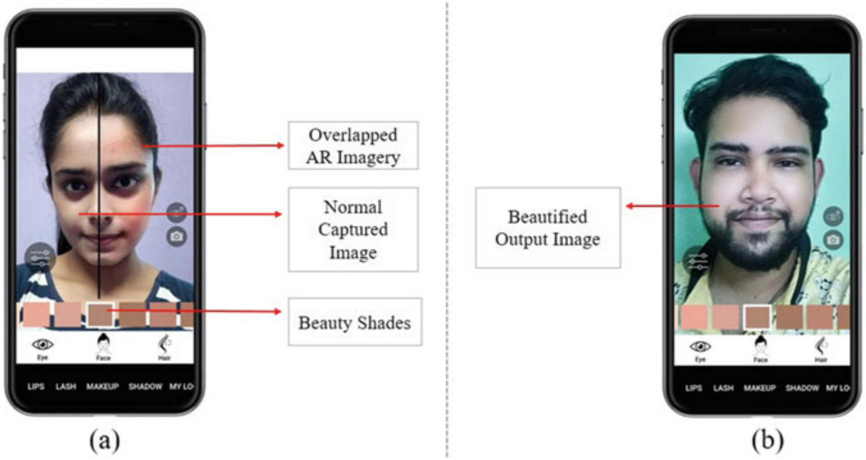

Fig. 69.8 Visualization of the application

application. On an overall basis, the user experience is the accumulation of all the elements and inputs given to user interface along with augmented reality. In this modern era, a number of Web sites and digital platforms provide tools to support augmented reality which might be useful for small-scale projects and customized AR applications. With a revolutionary service of augmented reality offered by a Web site, Modiface [23] deals with creation of customized augmented reality applications. One existing such Web site is Lenskart, which implements the AR technology and aids its customers to convenience [24]. Consistently creating innovating augmented reality applications for multidimensional media could be an essential help and tool to opt for custom AR implementations.

With the revelation of results of the study, it was evident that there was intensive need of an application with implementations of modern high-end technology such as augmented reality and put into use in the cosmetic industry for commercial purposes, starting with small-scale areas such as developing towns and cities so that the need and obligations of common people could be understood and addressed accordingly. An application with dedicated goal to make the aspect of styling easy, which could serve all people regardless of their variant tastes and standard of living, essentially for all age groups, was needed. More importantly, the physically impaired individuals could actually stand still to their own choices as such an application would provide them with door-to-door services according to their affordability and the opportunity to choose from a number of styles and beauty trends, without being worried about rushing into a specific styling salon or parlour. This aspect of the application would remain generic because all the users could really save their valuable time and not wait for long hours for their turn. Both new and existing brands and products that would register themselves and offer to sell their products would find a platform to get recognition and expand their popularity among a variety of people with different cosmetic obligations and choices. Such an application could not only be an essential tool to customers or users but could also act as an essential knot in uplifting small-scale business establishments in local areas and hence contributing in a higher social economy. More interestingly, the fascination among people about a technology like AR could possible prove to be a huge boost into the cosmetic industry when handed to common users and customers for daily use. People who are enthusiastic about styling and beauty could keep track of their own trends as well as the trend around them using an elaborated version of the application.

69.4 Conclusion

Based on the study, it can be concluded that a number of critical obstacles and inconveniences to attain desired beauty and styling could possibly be solved through the commercialization of augmented reality-based application. Such application could also prove to be helpful for the customers who desired such dedicated application.

There exists possibility of coming up with more innovative service designs by implementation of augmented reality in commonly used applications. For such, the collaboration of design students and experts from various technical and aesthetical fields would be necessary to reach a stable and successful design approach. The possible scope of future work elaborated in discussion could prove to be a helpful tool to the masses. Extensive and intensive work on potential and elaboration of such an application establishes a future possibility that it could be used to identify regional styling trends.

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Chapter 70
Changing the Traditional Lingerie Shopping Experience Through Interaction Design

S. Navyashree, Aasta Mawlikar, and Wricha Mishra

Abstract Despite the digital age, and Internet of Things, bringing shopping to the comfort of one's living rooms, at the click of the mouse, lingerie shopping, in India, however, has not been able to change the prevalent mind-set of women. Women in India, we find, have stuck to the time tested traditional mode of physical visits to their favourite shops. The reasons primarily being to physically try them on and avoid the cumbersome process of online returns. Through this study, we, the authors, seek to help women overcome their inherent inhibitions, elevating their offline shopping experience. This has been arrived at through a set of user-centric design methods, addressing the issues confronted by women during shopping. In the course of the study, we found that women predominantly spent much of their time (a) picking brassier styles, (b) checking brassiere sizes and (c) closeted in trial rooms, before making their final purchases, if any. The study has evolved a concept, which optimises the search for lingerie in stores, saves frequent visitation to trial rooms and facilitates brands understand better customers' trial choices and purchasing patterns. The inherent benefits of the proposed solution and future scopes for possible adoption have also been detailed in the study.

70.1 Introduction

The Indian lingerie market, which stood at around $3 billion in 2017, and projected to log in a robust 14% CAGR to touch $6.5 billion by 2023 [1], has been witnessing a definitive churning as also consumers alongside.

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A. Chakrabarti et al. (eds.), *Design for Tomorrow–Volume 3*,
Smart Innovation, Systems and Technologies 223,
https://doi.org/10.1007/978-981-16-0084-5_70

The segment, today, boasts of around 25 styles of brassieres and seven styles of panties [2, 3], with niche stores pushing their latest collections through advertisements, but failing to pitch upon their functionality. As a result, customers get the feel of their functionalities only after their first purchase.

Furthermore, it is found that Indian women's purchase patterns have seen a paradigm shift in keeping with the fashion trends moving away from traditional outfits to western, health and physical awareness, as also, in tune with the demands of professional work environments [4, 5].

As a result, lingerie shopping turns out to be more of a planned purchase when there is limited stock, or occasion based for weddings, travel, medical requirements, etc. However, these determinants are given the go by during a "off season" sale wherein price becomes the main motivator queering the pitch for the customers to indulge and splurge.

It is to be noted here that studies have pointed out how Indian consumers lack basic knowledge of the right fit, style or fabric suitable to their body type and pairing of various inner wears styled to be worn under different attires [4, 5].

But hardly has there been any serious research to explain: **(RQ1)** why women lack these knowledge? And **(RQ2)** why lingerie brands have failed to raise awareness?

The primary purpose of this study, therefore, has been to understand the aforementioned issues and help women enhance their shopping experience into a pleasurable and purposeful one.

The objectives are:

(a) To study the lingerie shopping process of women,

(b) To gain insight and analyse their pain points during their shopping experience, and

(c) To provide a suitable solution to enhance their retail shopping experience.

70.2 Methodology

As researchers, we undertook a mix method approach to identify, study the process, cull out pain points prevailing in lingerie shopping and design methods that were applied to address these specific issues.

70.2.1 Contextual Inquiry

Contextual inquiry [6] was taken up in five stores at Phoenix Mall, Pune. These were leading branded retailers—Marks and Spencer, Amante, Wacoal, Hunkemoller and Westside. The first four are exclusive lingerie stores, while Westside has an inclusive lingerie section in a larger shopping store. All five sales representatives of the respective stores were interviewed.

70.2.2 Pilot Study

Since privacy issues did not allow for active observation of customers during their purchases at the stores, a pilot study was undertaken by interviewing seven teenagers between the age group of 21–26 years drawn from different segments of society.

The questions posed were based on demographics, brand preferences, their individual experience in stores, shopping process and problems they generally confronted. All conversations were anonymously recorded on the phone.

70.2.3 User Survey

To validate the findings from contextual inquiry and interviews, a user survey was conducted. The survey saw 58 respondents between the age group of 20–41 years being covered for the purpose. The user survey ensured confidentiality by not collecting any personal identification details addressing privacy concerns and the questionnaire was divided into **two** segments:

The **first** contained demographic and purchase questions. The **second** saw respondents take a quiz to check their awareness of bra styles. See Appendix Table 1 for a complete structured questionnaire. The questionnaire was formulated using Google Forms & Data collated by circulating the form link on WhatsApp Messenger and some responses recorded in-person. Random sampling method was used.

70.2.4 Design Methods

The results from contextual inquiry and user survey were used to create personas and scenarios for our primary and secondary users. The breakdowns and pain points gathered during the study were used to iterate concepts, study competitors through competitive analysis and propose a possible solution (Fig. 70.1).

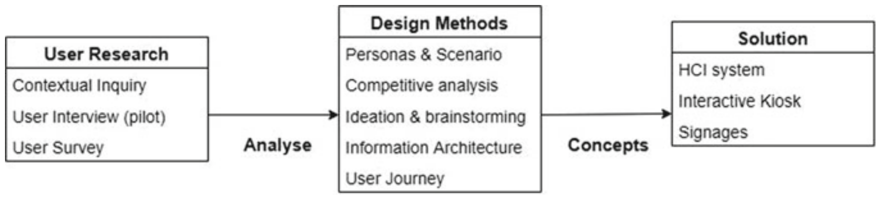


Fig. 70.1 Methodology

70.3 Results

70.3.1 Contextual Inquiry

Cultural model Fig. 70.4, sequence model Fig. 70.5, shopper flow model Fig. 70.3 and sales representative flow model Fig. 70.2 were created.

Breakdowns were represented in black ovals, charter communication hesitancy and annoyance between shopper and sales representative, product unavailability and trial waiting period.

The flow model depicts actors in circles, other objects in squares and each of those responsibilities are mentioned in points within the shape.

The cultural model describes the factors that influence lingerie shopping. The influencers are occasion, clothing styles, brands, heath, fitness, female figures, husband or boyfriend, sales representative and socio-cultural factors. Some have one way and others have two way influences. The sequence model depicts the steps involved in purchasing a product.

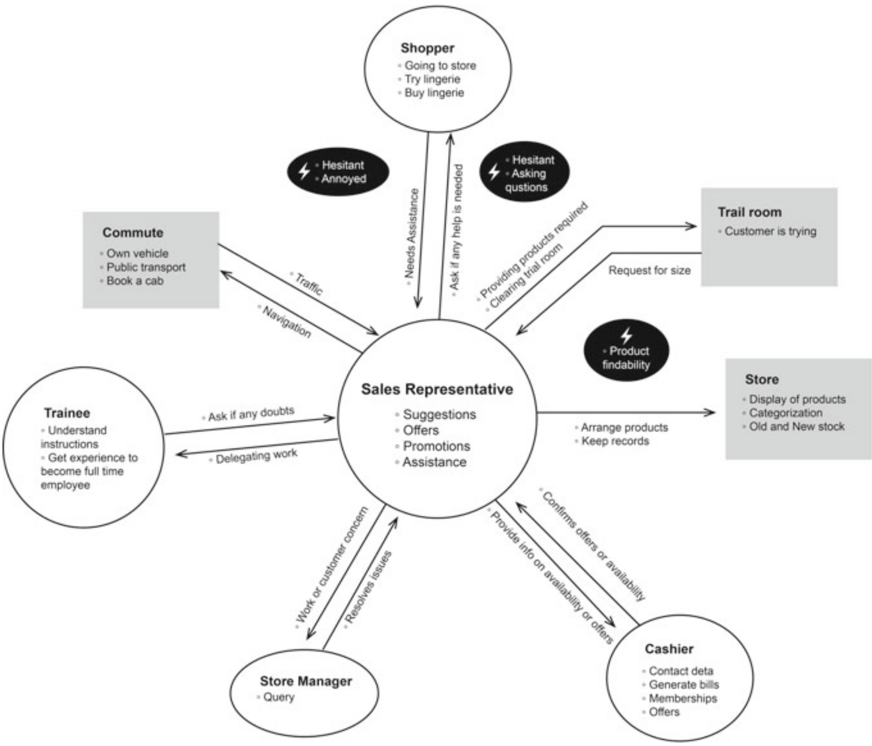


Fig. 70.2 Sales representative flow model

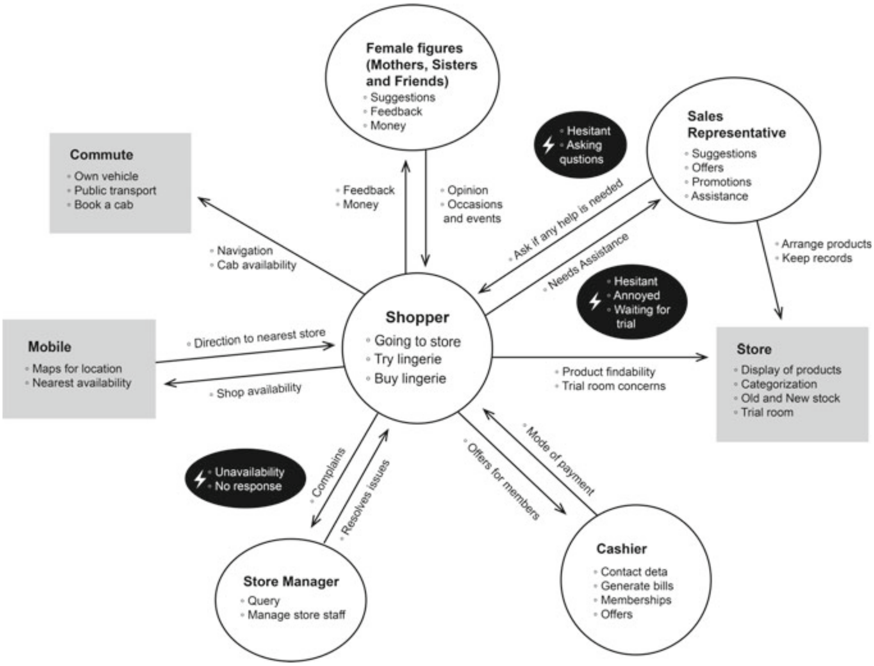


Fig. 70.3 Shopper flow model

It was found that most brands did not think it necessary to raise awareness about product functionality. Some brands, however, did have trained sales representatives to educate customers when questioned. Hunkenmoller has attempted to inform their consumers by targeting body types as a filter for brassieres.

Pain points identified during the user survey are classified into three sections: (a) Style, (b) Size and (c) Trial.

(a) **Style—**When the respondents were asked how they spend most of their time during lingerie shopping, 40% stated in choosing or selecting a style, 24% in checking size, 21% in trying a lingerie and 3% in finding the brand, as shown in Fig. 70.6.

The respondents concurred to purchasing lingerie in accordance with their lifestyle needs such as dancing, sports and parties, when quizzed on their choice of brassier styles for a corresponding top in the survey.

Figure 70.7 notes that 35% respondents knew about pairing of brassiere styles and clothes through researching themselves, 24% (14) through trial and error, 13% still did not know, 12% from advertisements, 8% from sales representatives, 3% through word of mouth and 2% did not care. Only, a few sales representatives were trained regarding all aspects of the products.

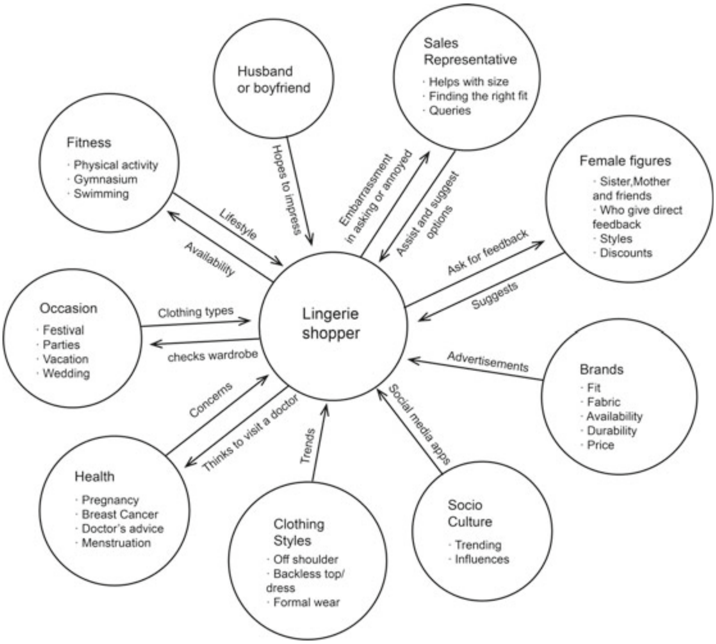


Fig. 70.4 Cultural model

Figure 70.8 depicts the number of respondents who picked the appropriate brasserie styles. A total of 53% picked the appropriate style for all seven tops, of which option 7 had the highest correct responses (Fig. 70.9).

(b) **Size—**In the course of the study, it was found that women's brassiere size changed due to fluctuations in oestrogen hormone caused by physical activity, pregnancy and medical conditions.
Likewise, during the study, it was also discovered that brassiere sizes are measured differently by different brands, while conducting contextual enquiry when the respective sales representatives were questioned.
Though the method is uniform, through use of measuring tape, the guidelines, however, differ between brands. Hence, it is to be noted that there is a very less chance of having a common size across all brands.
The pilot study interviews particularly found that this was specifically true for curvy and plus size women. Needing to know the availability of size or product is a common reason users seek help from sales assistants. When faced with an inventory issue, users place an order online.
Queried on the time spent during lingerie shopping, 40% stated in choosing or selecting a style, 24% in checking for size, 21% in trying on lingerie and 3% in finding the brand, as shown in Fig. 70.6.

(c) **Trial—**The interviews of sales representatives during the contextual inquiry provided an interesting insight. It was found that sales representatives stand

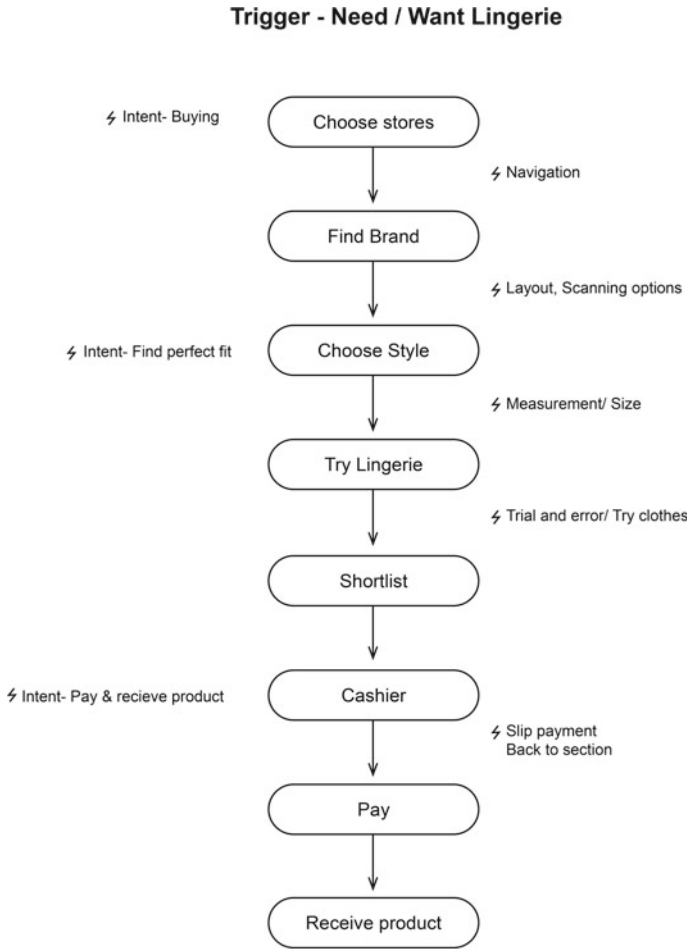


Fig. 70.5 Sequence model

outside the trial rooms to communicate with customers while they were trying the products. They then lobbed the products over the shut door following an exchange or suggestion. This was true of all stores we visited. 71% respondents took the help of sales representatives while 29% preferred not to. In such a situation, the customers had to wear their clothes back on to look for the right brand fit.

In regard to design methods, used personas were created after analysing the pain points. The primary personas were occasion based and high end shoppers since they had higher exploration tendencies in stores vs secondary personas who are usually sure of what they want and are less prone to explorations.

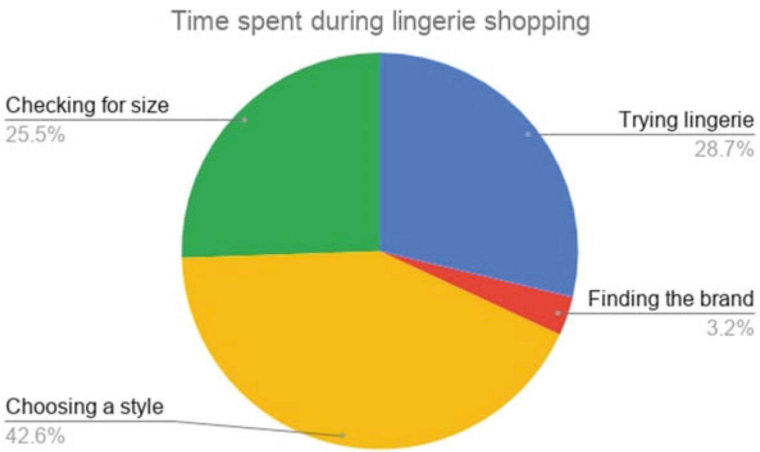


Fig. 70.6 Time spent during lingerie shopping

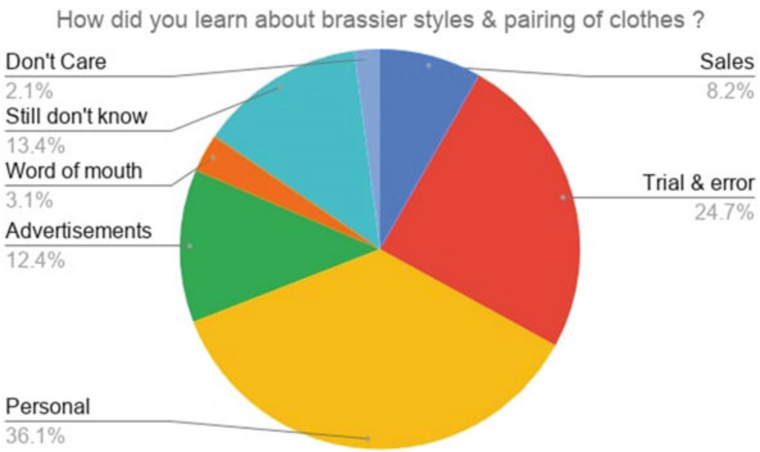


Fig. 70.7 Brassier styles and pairing of clothes

The sequence model Fig. 70.5 in the contextual inquiry was used to recognise direct and indirect competitors while constructing competitive mapping Fig. 70.10.

Each step was looked into individually for feature inspirations. The researchers were helped to come up with concepts to tackle the three sections we targeted by the competitors themselves.

Ralph Lauren's and Zara's [7] fitting rooms helped one understand the concept and feasibility of radio-frequency identification tags or RFID tags.

Sephora, Lenskart and Rigby and Peller helped one understand the concept of 3D mapping and smart mirrors.

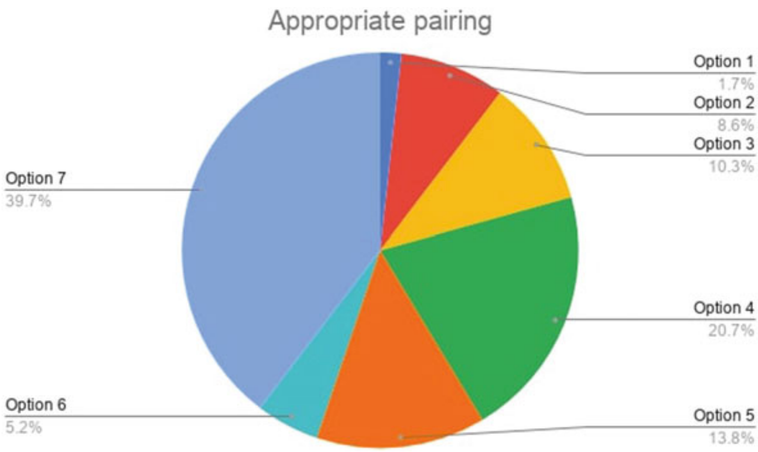


Fig. 70.8 Appropriate pairing

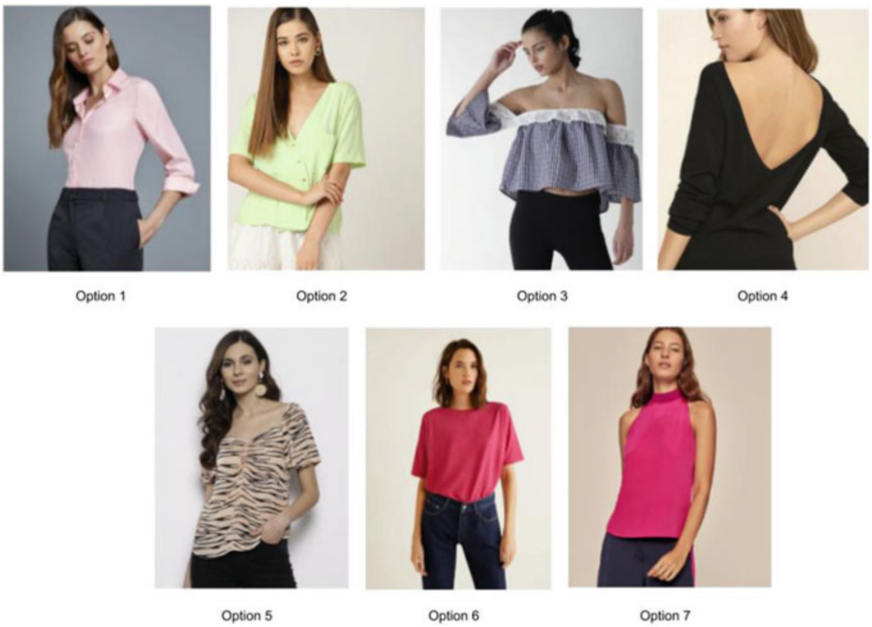


Fig. 70.9 Quiz options

70.4 Proposed Solution

Pain points identified through research results can be broadly classified into three categories: (a) Style, (b) Size and (c) Trial (Fig. 70.11).

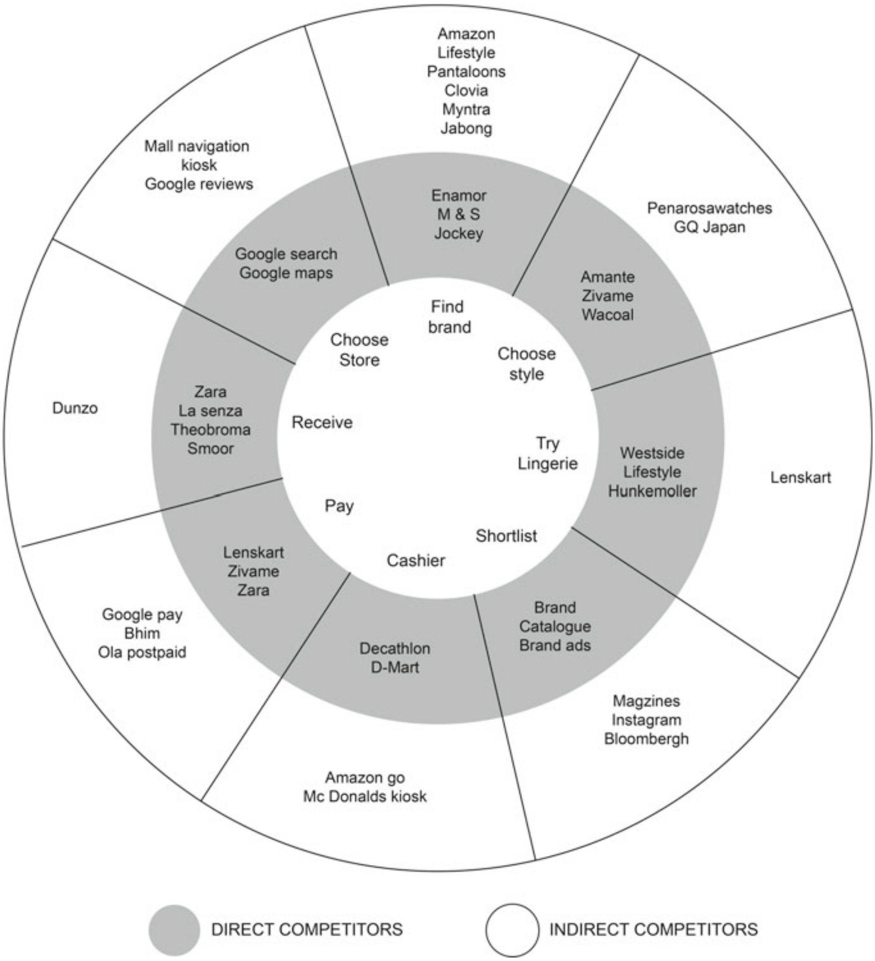


Fig. 70.10 Competitive mapping

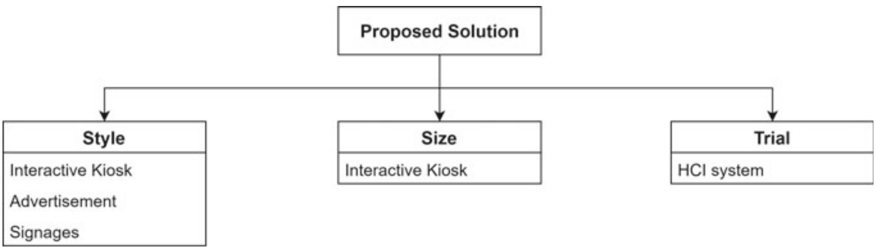


Fig. 70.11 Proposed solution

Based on our extensive research, the stores were recommended putting in place a human–computer interaction (HCI) system catering to the needs of customers, sales representatives and the brand.

The architecture of the system ensured it would follow the brand or store's visual guidelines. Tablets are attached behind every trial room and an admin tab handled by the sales representative. Information architecture was constructed for both the admin and customer trial view as shown in Fig. 70.12.

Each tab is logged in once the store opens, with trial room and admin view selected for respective tabs. Once a customer has selected the products to try on and enters the trial room, they are immediately recognised by the system through the RFID tag attached to each product.

The recognised product information is listed in "products you're trying" section, so that users can exchange the product by selecting the colour or size options, the "product you may like" tab suggests similar products for trial based on an AI powered analysis of customers trial and purchase patterns. And once the request is sent, a timer is displayed with the actions taken by the assistance to keep the user informed, as shown in Fig. 70.13.

The admin view has the complete list of trial rooms, once a request for add/exchange is received from an active trial room a notification pops up in the respected trial room number tab and the assistance actions are recorded and reported back to the user, as shown in Fig. 70.14.

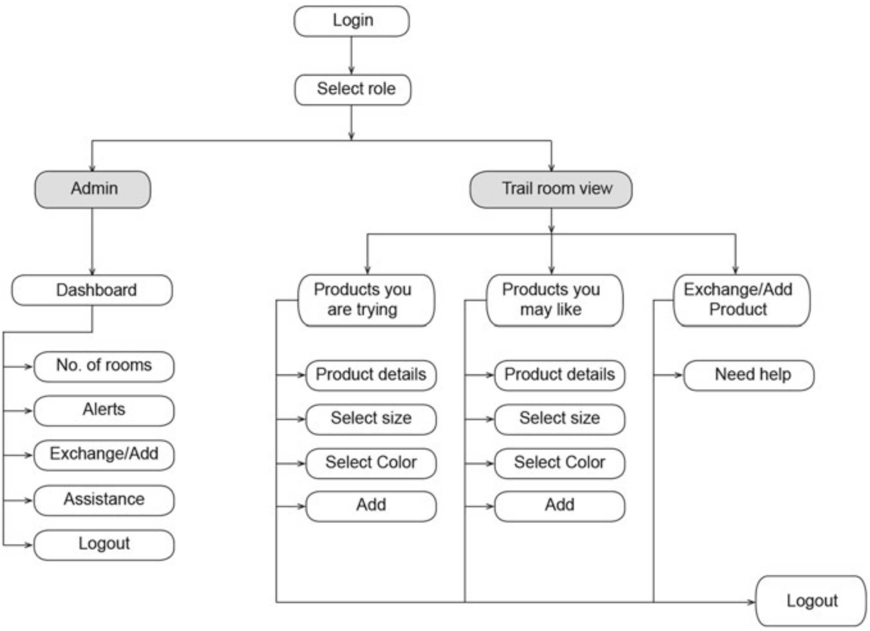


Fig. 70.12 Information architecture

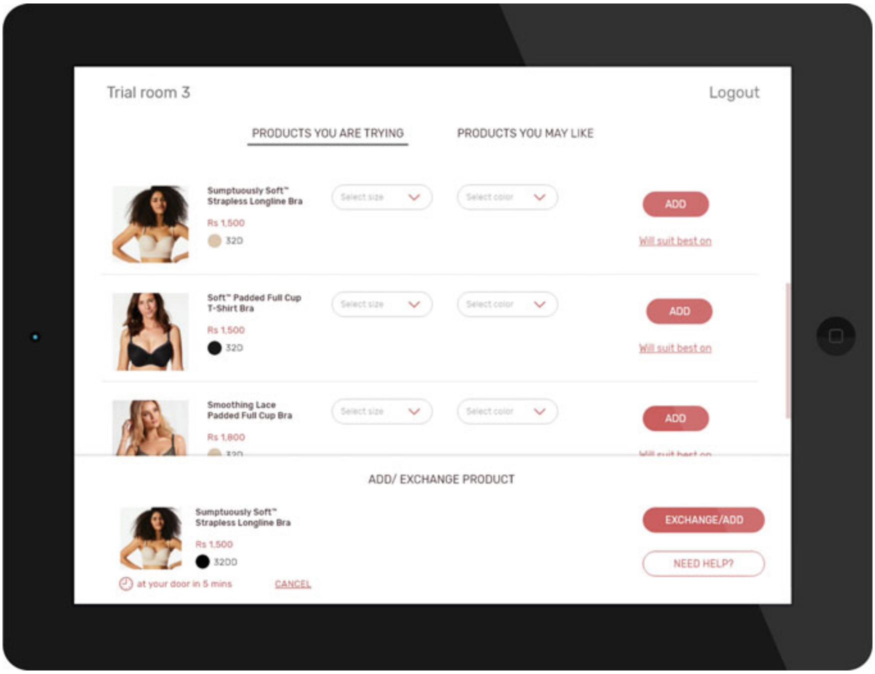


Fig. 70.13 Customer trial room view

In case of other special assistance, there is a separate button called “need help” in order to notify the representative to arrive at the trial room and the same request is notified in the admin view, as depicted in Figs. 70.14 and 70.15.

The system provides basic details of the products being tried through the help of RFID tags, the material of the product and the clothing options it may be best suited for based on the style, material and colour.

The above solution is for the trial aspects of shopping but it is suggested similar solutions for style and size could be implemented based on the budget of the brand.

For style issues, the types of brassiere like padded, wired or non-padded are the terms used in stores to define the style of the brassiere. However, brassier styles are full cup, demi, balconette, etc. and these styles can also all be padded, wired or non-padded. There needs to be differentiation between styles and types of brassier.

Thus, it is suggested that brands use style names as signages and forego types. Secondly, create an immediate link between the styles and appropriate tops to be paired with by displaying ads on kiosks, standees, posters.

As shown in Fig. 70.16, an example for a brasserie style. The best suited section can also change to body types or special conditions like maternity/cancer patients based on the brands guidelines.

For size issues, an interactive kiosk that recognises the radio-frequency identification (RFID) tags was designed to allow users to search for the required size,

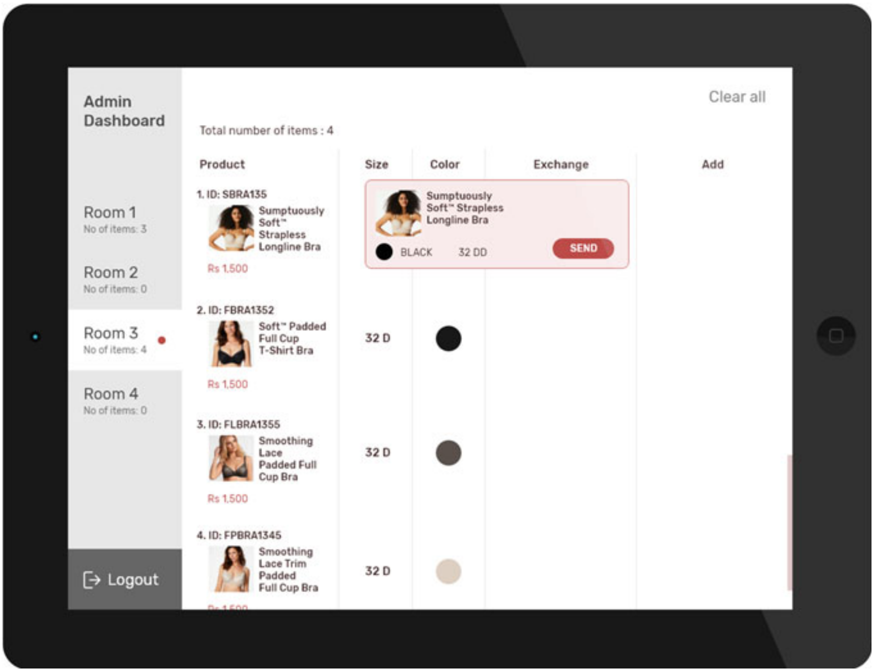


Fig. 70.14 Admin view exchange/add alert

colour with the system suggesting appropriate attire, information on fabric, body type, climate and other possible products. Results allow users to view if products are available, not available or in the trial room, as shown in Fig. 70.17.

70.5 Discussion

The study began with contextual inquiry, pilot user interviews and user survey. The results were in line with previous related findings, which predicted that women are not aware about pairing of their attire and lingerie [4, 5].

However, where previous studies left at that conclusion, pursuing further we found that women who are aware about pairing of clothes and lingerie get to know about it majorly through trial and error or personal research online, as shown in Fig. 70.3 in the results section.

As a result of which women spend most of their time in choosing style, as shown in Fig. 70.2 in the results section. Hence, the categorisation of the pain points into style, size and trial according to the hierarchy of time spent while shopping.

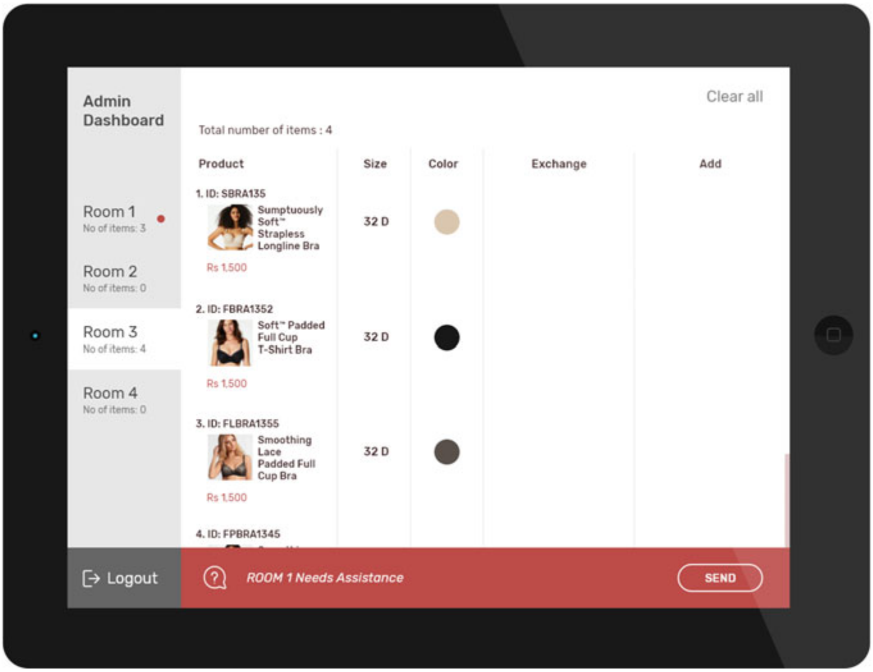


Fig. 70.15 Admin view assistance alert

With regards to size, previous studies depicted that some women assumed their size while purchasing lingerie especially in departmental stores but sought to be measured when in a standalone or exclusive store [4].

However, our findings found that the reason women spend time looking for size in a store is majorly due to the difference in size from brand to brand which requires them to be measured again and partly due to low stock of sizes in particular styles.

Most importantly, we found that women are displeased with their trial room experience due to the invasive sales representatives' mode of communication and separate sessions for exchange. It is important to note that the pain points are interlinked, when a woman is unaware of the styles either picks the next size assuming a coverage issue resulting in a cycle of trial room sessions or purchasing the product based on appeal and finds difficulty pairing it with their usual attire (Figs. 70.18 and Fig. 70.19).

In line with previous studies, women do prefer exclusive standalone stores over others. The personalised buying experience as mentioned by Singh N that involves dedicated trial rooms and personal interactions with sales representatives is a factor.

Our findings also point out that it is due to the ability to try and feel the quality of the products that users prefer shopping offline than online. Existing solutions in lingerie stores in regard to the pain points include training their sales representatives to communicate the functionality of the products when questioned and a recent luxury brand 3D tech that scans a women's profiles to predict the exact size [8].

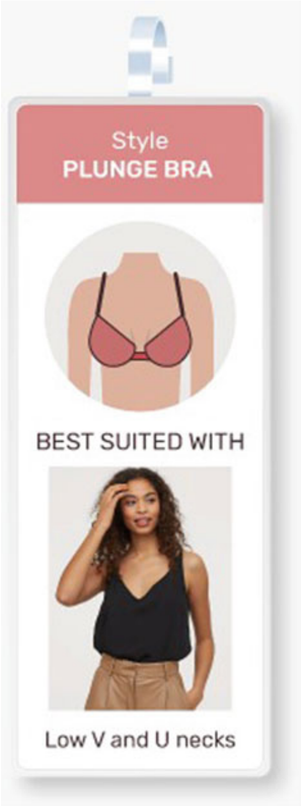


Fig. 70.16 Signage/advertisement

Fewer brands have tried to educate their customers on the functionality of their product through visual design like our findings propose. No major brand in India has tried to apply a HCI solution for allowing consumers to search for their sizes in store and most importantly apply the RFID digital fitting room concept to a lingerie setting.

Key takeaways from HCI concept.

The HCI trial room system will provide users with a sense of control and increase efficiency by minimising the above mentioned pain points. The RFID tags are very cost efficient and help in recognising products and their information faster than other scanning mediums.

The system is beneficial not only to customers but also to sales representatives as it allows them to manage time efficiently between customers, and more importantly, optimise their future inventory based on the size requests/findings and trial room statistics.

The brands will be able to improve productivity and save money as they will receive statistics plus data on their customers purchasing patterns based on the trial

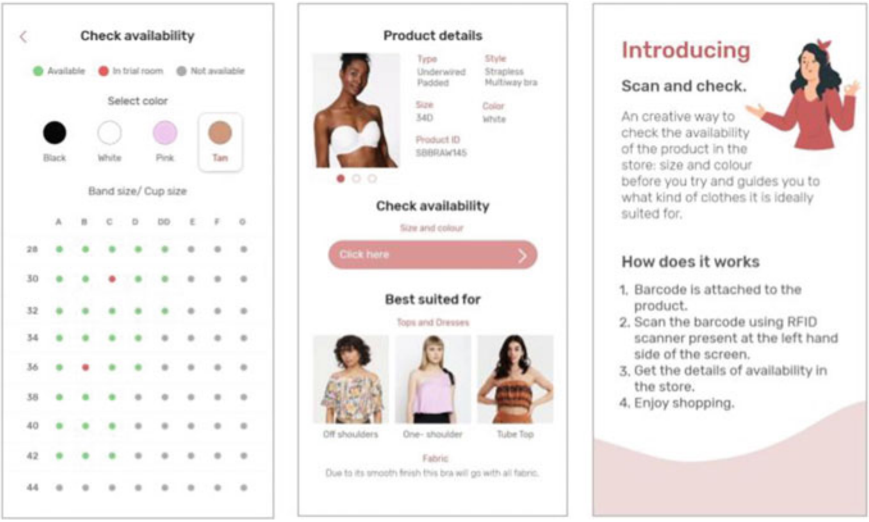


Fig. 70.17 Interactive kiosk

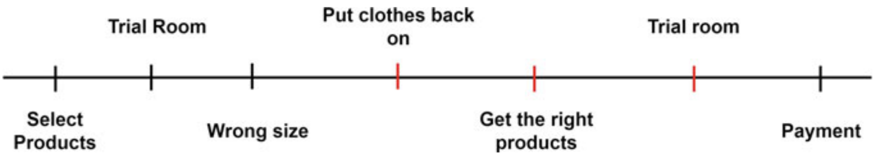


Fig. 70.18 Current user journey

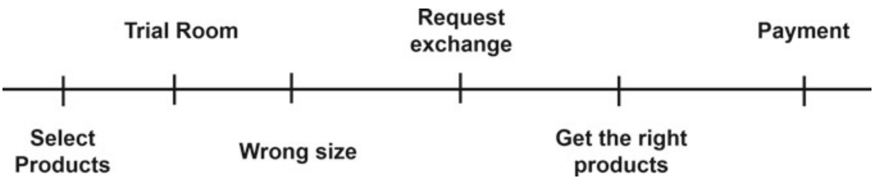


Fig. 70.19 User journey after the intervention

room data. The system provides trial data from most trailed sizes, styles and various other product details from converted and unconverted items that will help brands in understanding customers' trial patterns and purchasing behaviour to another level.

This allows them to improve their products based on design and need of their users which has not been applied to the lingerie industry. Though the proposed solution is for exclusive stores, the same can be applied to other stores as well.

70.6 Conclusion

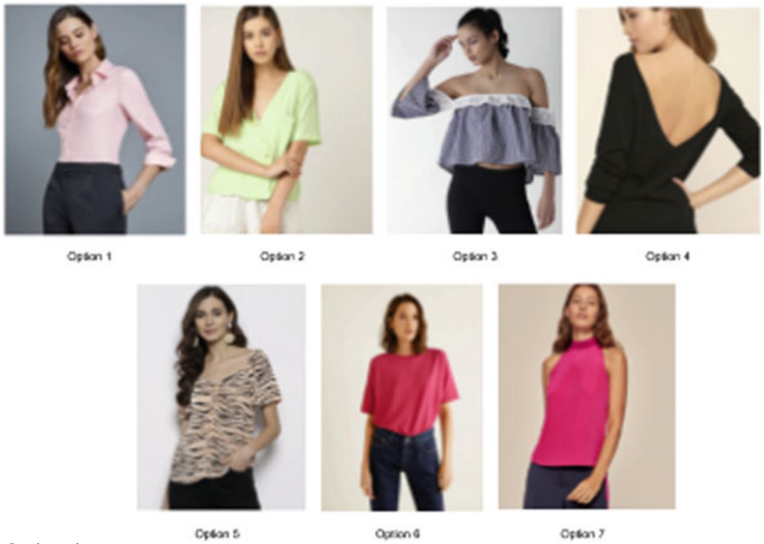
Based on our study, we posit that digitalisation of the retail sector in India requires more research especially in terms of design since there are still a large sector of customers who prefer shopping in stores despite the online surge. Through our study, we have been able to recognise the pain points during lingerie shopping in India and explored the possible solutions.

We recognise that this may not be the only way to resolve these problems. Universal measurement of size is a section that needs utmost attention and importance in the lingerie market. The future scope would include conducting usability testing and to link the store system with the brands online application. User testing will be required to enhance the product and get real time insights. We would like to encourage researchers to look into the lingerie domain and provide more insights.

Appendix

Questionnaire: Section 1.

Age, occupation and salary range (Below 1 LPA - Above 12 LPA).
Bra size and the price range of your lingerie? (Below 500 - Above 2500)
How often do you shop for lingerie?
Preferred choice of brand?
Where do you usually shop for lingerie?
Why do you prefer offline lingerie shopping?
What problems have you faced during offline shopping?
Where do you spend the most amount of time while lingerie shopping?
Do you take assistance from the sales representatives? If yes, Why?
Section 1.
Choose the appropriate bra for the following clothes:



Quiz pictures.

Out of seven, how many responses did you guess?

How did you get to know about the styles of bras and pairing of clothes? (Sales Representative, Trial & Error, Research, Advertisement, Word Of Mouth, Still Don’t Know, Don’t Care).

Is it important to know which bra to wear for what type of clothing?

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Chapter 71
Design Thinking Approach in Identification of Service Design Based on User Interface for Grocery Monitoring System in Indian Context

Leeladhar Ganvir and Pratul Chandra Kalita

Abstract The term design thinking (DT) has gained attention over the past decade in a wide range of contexts beyond the traditional preoccupations of designers. To design a smart gadget which could track and detect the usage of groceries and staples in the house and ease up their buying process, DT process was used. This study discusses the DT approach in identifying service design through stakeholder mapping, visualisation of service blueprint, data flow, and wireframe with a practical case of grocery monitoring system. Mainly, wireframes guide designers to establish an interface design for the product. This study would act as guidelines for service providers, designers, developers, and project managers for identifying and implementing service design. It would finally contribute to design for development.

71.1 Introduction

Grocery monitoring is a new trend due to people being conscious about what they buy and wastage of food. It has been observed that consumers find it difficult to store and take note of large quantities of food grains for a longer period of time but still end up doing the same. It is very difficult to track the usage of all ingredients in the kitchen and listing all the materials before going out for grocery shopping. Several product design strategies have been developed to help the consumer manage groceries and make the shopping experience effortless. However, there are no product service system (PSS) design solutions, on a system level that take advantage of these strategies. An integrated solution for grocery shopping and management will help the consumer track their purchases and food habits. In this era of online solutions, a service was developed for grocery management in Indian context. The target users of

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A. Chakrabarti et al. (eds.), *Design for Tomorrow–Volume 3*,
Smart Innovation, Systems and Technologies 223,
https://doi.org/10.1007/978-981-16-0084-5_72

this PSS are housewives, working women, and occasional cooks in Indian context. The design brief is to ideate a smart gadget for an urban household kitchen which can track and detect the usage of groceries and staples in the house, and ease up the buying process. This new PSS could help the users order groceries without them walking to a traditional grocery retail store [13].

71.2 Methodology

Design thinking is a well-tested approach that enables organisations to see the world through the eyes of their customers. IDEO has developed a field guide that includes a human-centred design toolkit [3]. Public sector organisations can adapt DT into a design toolkit, for their problem-solving activities. The DT model developed by IDEO includes the steps, inspiration, ideation, and implementation. The DT model developed by Stanford Design School includes: (a) Empathy; (b) Define; (c) Ideate; (d) Prototype and Test.

There are numerous techniques and methods laid out for understanding consumer behaviour and DT. This section will build upon and combine such already existing methods like ethnography research, user personas, user journey map, purchase cycle, and behavioural patterns of user groups to formulate strategic planning for understanding and analysing the consumer behaviour [16] related to: (a) urban household kitchen and (b) household grocery management. Using the grocery monitoring system as an example, we present stakeholder mapping, service blueprint, data flow diagram, and wireframe for the PSS design mobile application interface. The proposed paper is conducted based on secondary data.

71.3 Ethnographic Research

The research was done to understand activities in the kitchen and around it. The research mostly targeted towards understanding human behaviour, psychology, the need of an innovative product in the kitchen and modern-day technology. The users were interacted with, to understand their storage patterns, cooking patterns, grocery management patterns, shopping activities, and technological knowledge.

The user research helped in putting hypothetical target groups to test. It helped in learning human behavioural patterns, their lifestyle in and around the kitchen, spending patterns, technological knowledge, etc. that can affect the design and working of the strategy. Initially, different target groups were formed on the bases of professional designations: (a) housewives, (b) working women, (c) occasional cook.

We surveyed the kitchens of 24 families and interviewed them to understand users' behaviours and task flows [7]. We also prepared a questionnaire to understand the user preference for shopping (annually, monthly, and daily) and technological

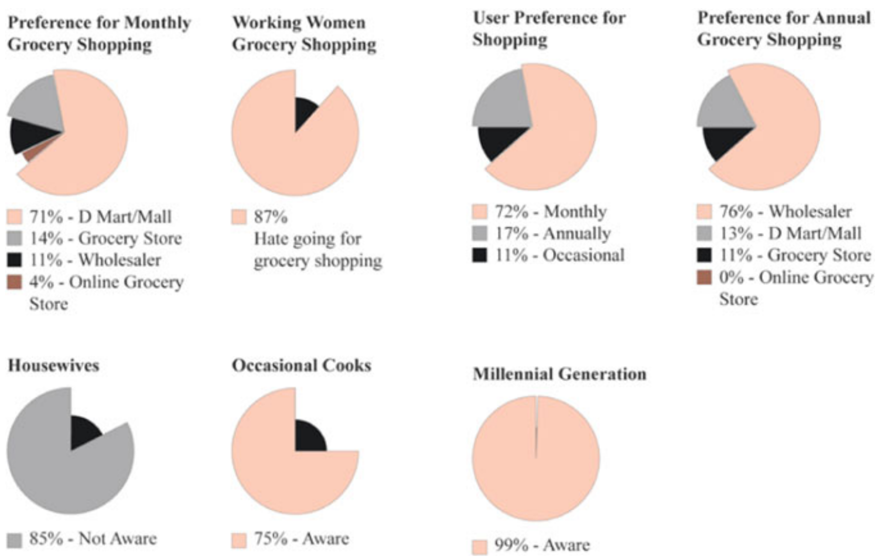


Fig. 71.1 Results of interview and survey

knowledge among our users. We received responses from six major urban cities and our sample size was $n = 179$, as shown in Fig. 71.1.

71.3.1 Empathy Mapping

Think/Feel: It has been observed that preparation of food starts a day before. Users think and decide on what can be cooked, according to available material in the house and what things need to be prepared with the help of the maid. Users like to work and keep themselves busy in life. Most feel they do not give adequate time to themselves and cannot pay adequate attention towards the family members. Most of the users hate to cook and shop for groceries. Users also feel the need to have a very smart and automated kitchen, where they can just tell it to carry out activities, without entering the kitchen.

See: Users see new technology and electronic appliances are developing faster and are a costlier compared to their utility. Most of the users have tried online grocery shopping but were not happy with the quality, rates of the commodities, etc. Users see there is a vast difference in the rates of commodities online. They also notice different ingredients have expired before they can use them. Also, some material they thought would last for a long time gets over quickly.

Say/Does: Users often say that they are not interested in cooking and hate going out for grocery shopping. Grocery shopping is a waste of time as they waste time in collecting things and then standing in huge queues for paying bills. Maintaining cleanliness in the house and the kitchen cabinets is also difficult. Users also say some things get wasted as they do not remember their presence in the house and these products expire before they can be used. Some users do all the shopping with their partner who helps them with the same as and when necessary. Users cook almost all days of the week but for less time. They do only the cooking part, with preparation of food left to the maid. Sometimes, users just dump things into the cabinets. Users also tell their kids to go and get the material if they run out of them when in need.

Hear: Users hear about a lot of new products and services entering the market. Online grocery shopping is one of them. They also hear about the issues related to online shopping, quality, rates, and time to deliver being a few of them. It is observed that family and friends want users to cook a variety of new food dishes, but they fall short of time due to their busy schedule.

71.3.2 Problem Identification

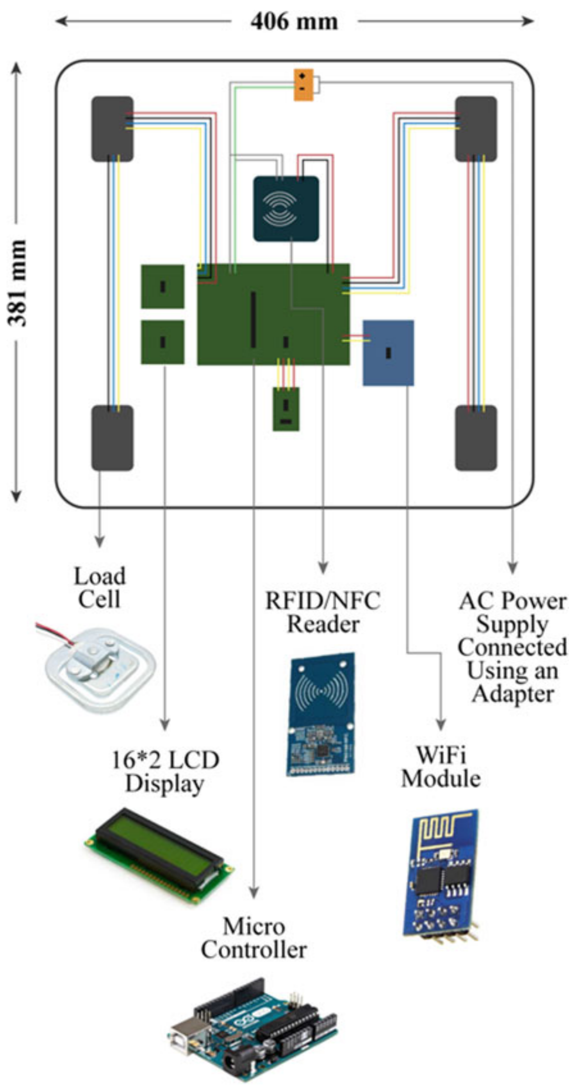
It has been observed that users find it difficult to take care and store large quantities of food grains for a longer period of time but still do the same. It is very difficult to track the usage of all ingredients in the kitchen and list all the material required before going out for grocery shopping. Users find stocks of material getting over or finding it inadequate at the last moment. It is also difficult to track the food ingredients which exist in the kitchen and to remember if any food item will run out before cooking is over. While out for shopping, users fail to remember the quantity of grocery items in the house. Also, at the same time, they fail to remember if they have the material they see while shopping. Most of the time, they end up buying extra stock as the quantity of material is not known and end up wasting food as they fail to remember to use the buffer stock before its expiry date. Most users are forced to plan what to cook beforehand and sometimes depending on some other person's requirements. Users hate going out for grocery shopping and wasting time and money in buying unnecessary ingredients and waiting in long billing queues. There is no assurance of time and quality of material delivered in online shopping and the user interfaces are unusable for many electronic appliances [12–17].

71.4 Results and Discussions

71.4.1 Product Description

The PSS concept is making a smart gadget which can track and detect the usage of groceries in the house, and ease up the buying process. The brief clearly states that the PSS contains of a product as an electronic appliance with some sensors which help it to track usage of groceries in a household kitchen. On a very traditional level, the working of such a smart product could be similar to the working of a weighing scale, which could sense the weight of contents in the containers placed on this weighing machine in the kitchen and would convey it to the user on their mobile phone with the help of a wireless device. The attachment placed would consist of load cell which can sense the weight of the contents inside the container. The attachment would consist of load cells, an analogue to digital converter and bunch of sensors which after reaching a certain limit would send a notification on your mobile phone. It would be important to figure out the different electronic components and sensors required so that it can convey the right data to the user through a wireless device (Figs. 71.2 and 71.3).

Fig. 71.2 Circuit diagram and components



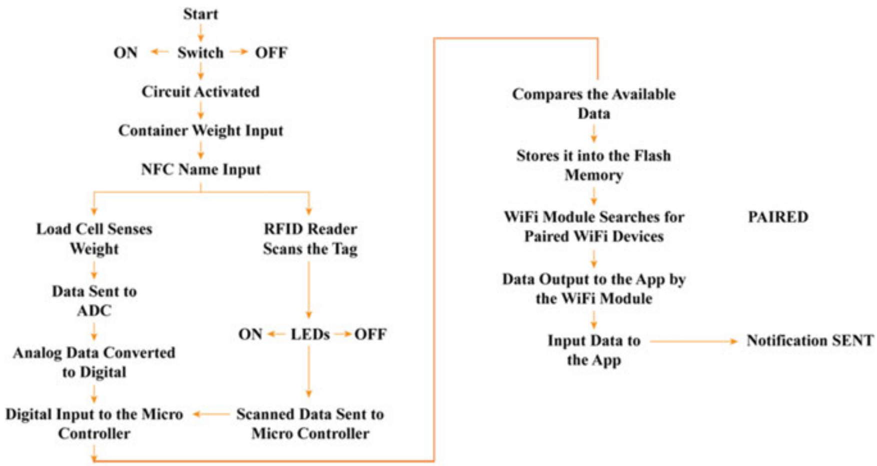


Fig. 71.3 How does it work

System level implementation can be performed by sensing the weight using load sensors, with the help of wireless data transmission using transceiver modules interfaced with micro-controller. Real-time data can be sent to the central node for processing and uploading data to the personalised IoT channel via Internet, which can help us in acquiring and analysing data for various applications. The load sensor (RAPG Low Capacity Single Point Aluminium Load Cell) is used as a transducer to measure the weight of the various grocery items. The resistive-type load cell, functioning on the principle of piezo-resistivity, outputs a raw electrical signal proportional to the “stress” (load) on the sensor [6]. By using an instrumentation amplifier, the raw electrical signal from the load cell is sampled. The acquired digital value is then processed by the micro-controller in order to transmit it via the wireless transceiver module. The data received by the central node (Raspberry Pi/controller circuit) via the transceiver is then uploaded to the personalised IoT channel. This acquired data can now be further analysed and utilised for various applications.

The main controller circuit has an analogue to digital converter mounted on the same PCB with the integrated chip. This circuit controls all the operations like processing, comparing, storing the data. The other two small integrated circuits are for the Wi-Fi module. These circuits act as supporting elements for the transfer of data to the Wi-Fi module. They ensure that there is no loss of data, during transfer. The RFID reader will be placed very close to the surface which will lie just below the smart gadget and above this whole circuit. It would be a sub-part of the upper mat and the lower enclosure. The RFID reader will read the information, i.e. the name of the content for which the weight is being taken and then transfer it to the main controller circuit [4].

The user interface for the product will be a mobile application, where all the data sent by the weighing machine will be stored. The data gets stored on the application on your mobile phone device. The mobile phone acts as an interactive device between the user and the weighing machine. The application is a very important part of the product as it is where all the data could be edited and stored. The application also allows you to order groceries online by yourself.

71.4.2 Stakeholder Mapping

Stakeholder analyses are important because of the increasingly interconnected nature of the world [12]. Stakeholder's analysis or mapping would aid in the design of specific knowledge of who has a stake and why. R. Edward. Freeman [9] defines a stakeholder as—any group or individual who can affect or is affected by the achievement of the organisation's objectives [5]. First stakeholders are identified with their power, influence, and interest. Next, essential stakeholders are prioritised in a system. Lastly, each stakeholder is mapped in a power vs. interest matrix to recognise what motivates them within the system.

Stakeholders were identified across different service domains to individuals working independently. Accordingly, the power vs. interest matrix was conducted concerning each identified stakeholder in mapping their stake in the grocery monitoring system. Figure 71.4 depicts the stakeholders mapping for the grocery monitoring system. The key stakeholders that are considered to be influential in this study are: online shopping services, as one of the stakeholders that influences the adoption

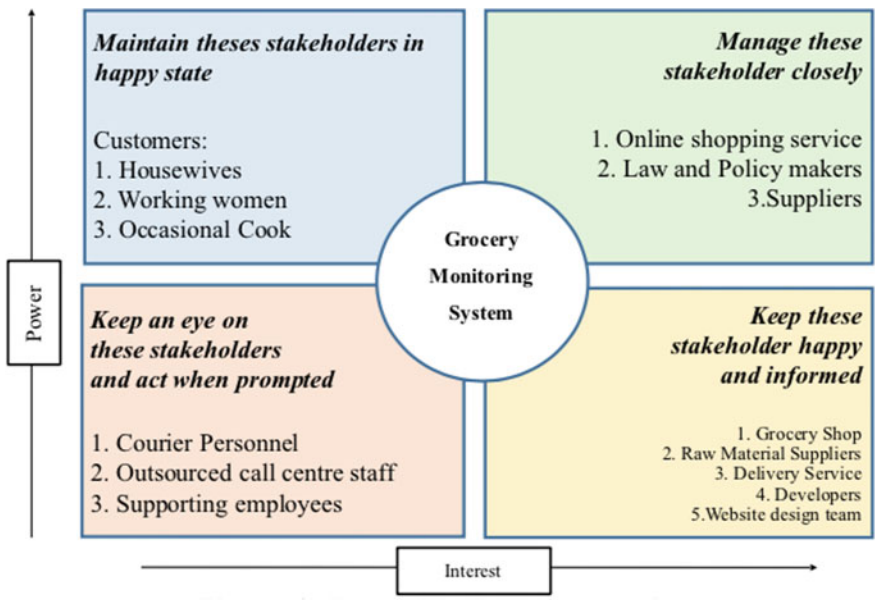


Fig. 71.4 Power versus interest matrix

process of online shopping by its role as a regulator; investors, an individual or a corporation who allocates capital to build and boost online shopping with the agenda of financial return; service provider, company or organisation handling the overall process between all the stakeholders; grocery shops, an independent outlet/shops and provides the groceries and food items, and it also maintains and manages the inventory of products; courier personnel, a qualified individual with vocational skill and specialised in logistics and delivery service; and customers, end-users who access the portal for maintaining the minimum stock level of grocery in kitchen, buying food items and grocery online, and track the record of food habits.

71.4.3 Service Blueprint

Service blueprint [5] defined as "a picture or map that accurately portrays the service system so that the different people involved can understand and deal with it objectively regardless of their roles or their individual point of view". Service blueprinting enables the accurate description and provides a map of a service system so that all the stakeholders can easily understand the operation of the business process [8, 18]. It has advantages of precise modelling and visualisation of the service processes, therefore the service blueprint widely used for the representation of services [11, 15].

From the service blueprint, as illustrated in Fig. 71.3, we can see customers can access the mobile application for tracking usage and ordering groceries with proper instruction and specific images to particular purchase issues. This design solves the problem of wastage of food and long waiting lines at traditional grocery shops.

From the service blueprint, as illustrated in Fig. 71.5, we can see customers can compare and purchase the grocery items for a particular brand or product issue through the information obtained from the mobile application. This design solves the problem of transparency in the cost of food items and grocery. Also, we can see the customers can make direct contact with the grocery shops and vendors for online grocery shopping services. This design solves the search and availability of grocery items in the market. Also, the support processes such as easy access to the mobile application, inventory of grocery, availability of courier personnel must be added to the solution so that the quality of the whole operational process, including onstage and backstage process, can be enhanced.

71.4.4 Data Flow Model

Data flow diagrams (DFD) are a well-known technique for structured analysis and system design [19]. DFDs are used to represent the decomposition of the system under development into processes and data stores. A DFD represents which processes and data stores can exist in the system under development and which communications among processes, stores, and external entities can exist. In recent developments, the

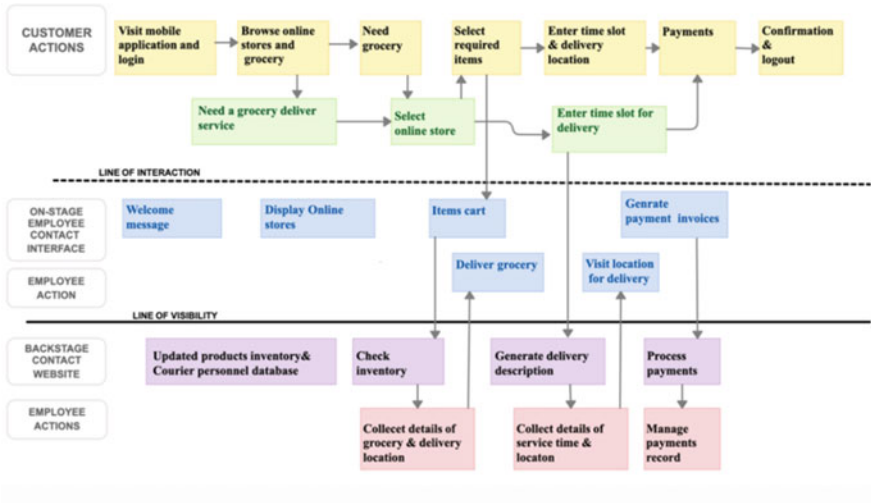


Fig. 71.5 Service blueprint of proposed service

data flow diagram process utilised in widespread domains [19]. It was introduced as a visual system to assist developers in analysing and comparing the system. In designing prototypes for software applications, data structure plays a vital role by simplifying the data keys and their relationship to other elements [1].

Considering the example of a grocery monitoring system, Fig. 71.6 depicts the model of data flows in the information system. This is the highest-level view of this system, a context diagram that represents only one process, four sources/entities, data flows, and no data stores. The arrows into and out of the processes are the data flows representing either functional transactions or structured data input or output.

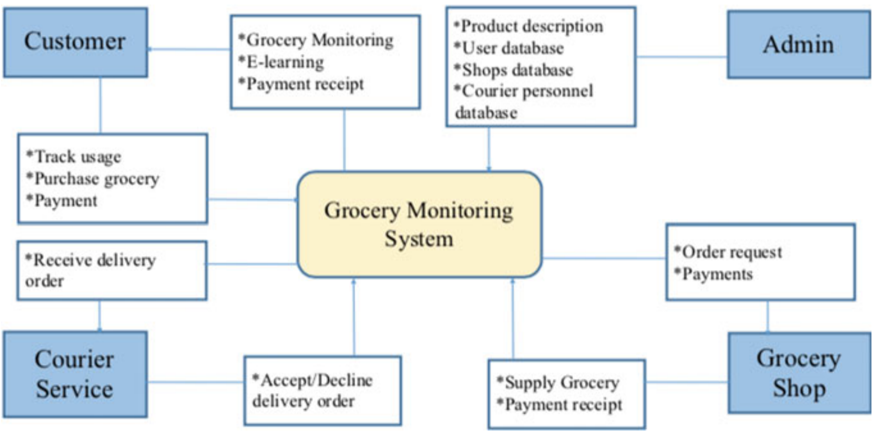


Fig. 71.6 Context diagram of grocery monitoring system

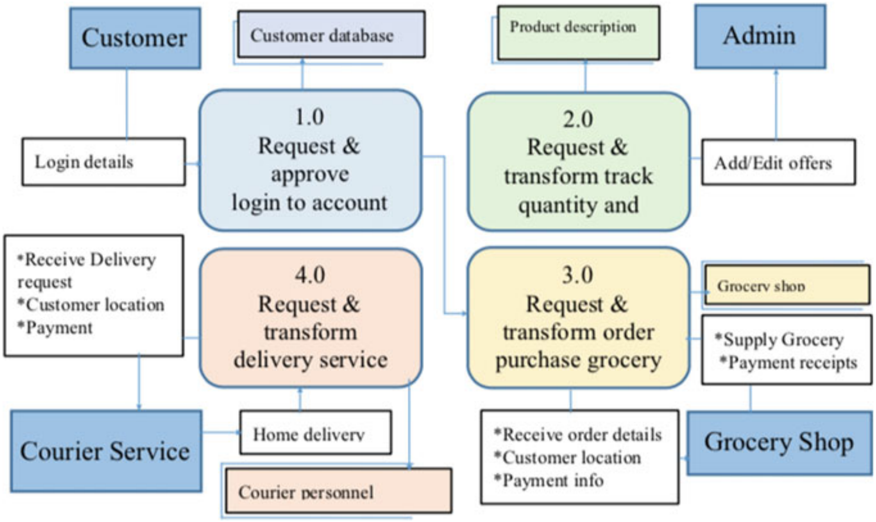


Fig. 71.7 Level 0 DFD of grocery monitoring system

Further, decomposition of the process into sub-process with data stores is illustrated in Fig. 71.7. Level-O DFD of the grocery monitoring system has four processes viz. request and approve login to account, receive and transform track the quantity and usage request, receive and transform order food item and purchase request, and receive and transform delivery service request. The output from each sub-process could have another sub-process else a data store. Data stores contain databases of customers, grocery shops, courier personnel, minimum stock level of products, and lists of available products, customers need, and distributors.

71.4.5 User Interface and Wireframe

User interface (UI) is a significant component of an information system (IS) with the task of being a translator between users and the system [10]. Research has shown that good design of a UI is a useful technique for increasing customers' trust, user satisfaction, purchase intention, and decision to buy [14].

Wireframes are a necessary first step in the process of formally establishing the interface design for the mobile application [10]. The function of a wireframe is to provide a hierarchy of user navigation, product/service information, and interface in design. Figure 71.8 depicts a structural layout for the grocery monitoring system. The layout includes viz. company logo, login screen, setup screens, online store preference, home screen, product search, minimum stock level of grocery items, shopping cart, checkout, icons to select the type of service, contact information, and terms of service.

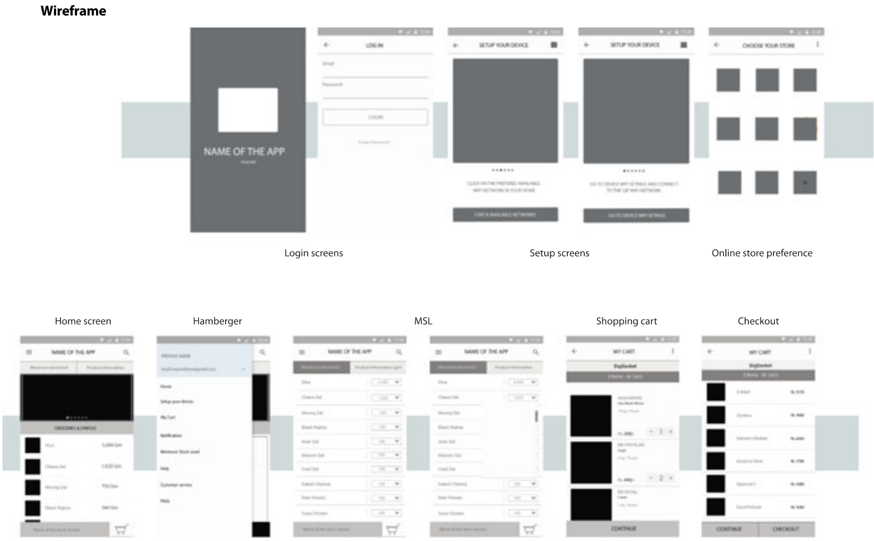


Fig. 71.8 Wireframe of grocery monitoring system

Explorations were done for the interface of the mobile application according to the need of the product and the user. It was necessary to provide a setup procedure, to link the product with the application on the phone. Once that is done, one needs to set the minimum stock limit for the contents in the containers according to your preferences/ shopping habits. Once the same is done, the app will study the patterns of your minimum stock level and will set automatic preferences. The application wireframes were made on android mock ups according to the user needs to sign in / sign up before entering the app. After signing into the application, they need to connect their weighing machine to their phone through Wi-Fi. After setting up the phone to the weighing machine, one needs to setup the weighing machine to his home Wi-Fi connection. One needs to check the available Wi-Fi connections and fill in the required data to setup the weighing machine to your home Wi-Fi. After connecting the weighing machine to your home network, the phone is to be connected again to the home Wi-Fi network. The mobile application will save the required data and join the Wi-Fi network available to it. Once done with the setup of the app, user needs to choose the store of his choice. Home screens display advertisements from the other apps with the shopping cart and the available contents in the house.

71.5 Conclusion

This study primarily concentrates on the application of DT through stakeholder mapping, service blueprint, data flow, and wireframe approach in planning for the service design and business model. The purpose of this study is to illustrate the mapping of stakeholders, visualisation of the service process, data flow and wireframe with a practical case of grocery monitoring system. This methodology can act as a guideline for service providers, designers, developers, and project managers for implementing service design and business models. It would finally contribute to design for development. Future research may be conducted in implementing and measuring readiness of the grocery monitoring system. This paper elucidates the new product development for monitoring of grocery levels. A wireless sensor network is built with multiple nodes transmitting the weight of different grocery items. On uploading the grocery level over Internet, the acquired data can be remotely accessed. Implementation of a network with multiple central nodes can help aggregate the data from a large geographic area and further analyse it based on the application. With immense future scope, this system can be employed in kitchens, supermarkets, and other storage spaces for smooth management of commodities.

Machine learning algorithms can then be employed on the server to elaborate the usage patterns by applying monetary, ethnic, demographical, or dietary filters to it. The data could be processed on the Raspberry Pi, thus evading the need for sending the data to an external server for processing, hence saving time and improving reliability. It can be customised to a greater extent for developing the applications. The data could provide insights into the average usage of the kitchen commodities and can be used to improve the process of grocery procurement. Data gathered from multiple sources can be analysed to understand the consumption patterns based on various geographic areas, economic sections, or communities in the society. This demographic information could be vital in the development of the food industry. The data could play a very important role in the preparation of healthier meals on the basis of the consumption averages recorded, depending upon seasonal changes in the consumption pattern. Machine learning algorithms can be implemented for predictive analysis. This has to be facilitated by periodic notifications given to the user. The data could provide insights into the average usage of the kitchen commodities and can be used to improve the process of grocery procurement.

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Chapter 72
Why Storytelling Should be the Medium of Design Education

Sugandha Jain and Abhishek Srivastava

Abstract Design education is a modern discipline. However, like storytelling, design has been a way of expression for human beings since the beginning of civilization. In fact, the earliest recorded stories by humankind in the form of cave drawings draw on both the skills–storytelling and designs. Stories evoke powerful emotions in us, staying with us for a long time. Similarly, a good design experience, which connects with us through strong emotions and an engaging storyline, has staying power. A story connects multiple characters and contexts through a single narrative. Similarly, a seamless design experience straddles across diverse domains, such as psychology, technology, marketing, art, among others with a compelling narrative. The aim of the paper is to probe the need for design education and establish its strong connection with storytelling. Through literature review, we have concluded that stories can enhance the design process in diverse forms at multiple levels and help fortify the skills of designers. Storytelling can effectively complement the other tools and techniques used in the design process. The paper establishes a strong case for incorporating storytelling as a medium in design, and as an integral and inherent skill set of a designer.

72.1 Introduction

The paper investigates the current state of design education in India and lists some of the requisite skills for designers (both aspiring and professional) based on various literature studies. The paper also explores the role of storytelling in design and its inclusion as a requisite skill set for designers. Stories can enhance the appeal of designs by making them more engaging. We examine various case studies, where

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A. Chakrabarti et al. (eds.), *Design for Tomorrow–Volume 3*,
Smart Innovation, Systems and Technologies 223,
https://doi.org/10.1007/978-981-16-0084-5_73

storytelling has played a critical role. These case studies reinforce the importance of storytelling in the design process.

72.2 Methodology

We did an extensive literature review to analyze the role of storytelling in all formats of design, including service design and instructional design, as well as design education. As part of our literature review, we studied journals, academic papers, and books related to the topic. To understand the role of storytelling in designs, we also examined YouTube videos on the topic and listened to TED talks. This gave us a wholesome perspective on the inclusion of storytelling as an effective medium for any mode of communication, including visual.

72.3 Design Education

Design education can empower lives by considering aspiration, culture, and values [1]. India, with its large population, needs innovative design solutions to basic problems and hence possesses a strong potential for the power of design [1].

72.3.1 Requisite Skills for Designers

The designers of today are responsible for shaping tomorrow's world. It is, therefore, of utmost importance to identify the key skill sets for designers. Based on an exhaustive and extensive literature review, the paper focusses on the following primary skills sets for designers (Refer Fig. 72.1):

- Cross-disciplinary work and collaboration skills

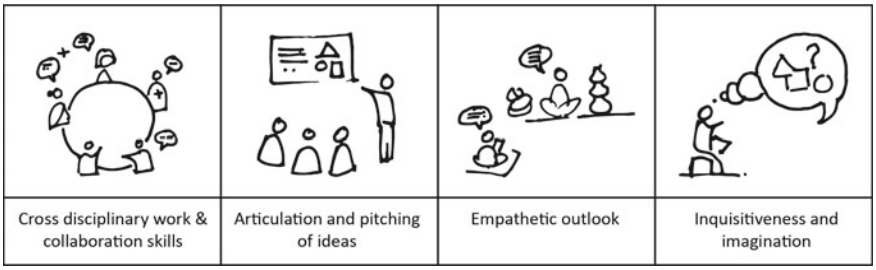

Fig. 72.1 Requisite skills for designers. *Source* Author

- Articulation and pitching of ideas
- Empathetic outlook
- Inquisitiveness and imagination

Cross-disciplinary work & collaboration skills. According to Practicing Design: Rethinking Design Education[2], today's designers need to collaborate with people from diverse disciplines and backgrounds like architecture, science and technology, ethnography, philosophy, sociology, marketing, and many more in order to create holistic enriching experiences. Due to technological advancements, the lines between disciplines are diminishing and multidisciplinary experiences are being generated more often. Hence, it is of utmost importance for the designers to be equipped with cross-disciplinary work skills to be able to collaborate with diverse groups of people and come up with innovative solutions. A fresh design graduate is not restricted to a design job. New ventures like marketing, business strategy, human resource management, and many more are opening up for designers [1].

Articulation and pitching of ideas. Designers should be able to convey the value of a product or services through their designs. For effective execution of a project, a designer should be able to not only comprehend the needs of the client but also articulate ideas. Pitching of ideas is one of the most important traits of a designer [2]. Designers should understand the concept, demonstrate the value of their ideas, and stimulate critique about a design concept for better acceptability in the real world [3]. Only then will they be able to face the challenges of the changing world.

Empathetic outlook. Designers should be able to connect with the client to be able to design for them. A user-centered approach, and understanding the real needs of people and society poses a great challenge to designers [2]. Terms such as user-friendly design, environmental-friendly design, community-friendly design, design-for-all, etc., signal a strong empathy on the part of the designer [2]. For a better tomorrow, designers need to drop a unilateral approach and be considerate of all beings [2]. All the stakeholders in the design process should be able to generate value by understanding the existential, cultural, and social needs of their environment.

Inquisitiveness and imagination. In today's time, designers should be able to act strategically, by being inquisitive and proactive [4]. They should be able to seek opportunities to engage with a wider business and be able to spot areas for improvement and innovation using their design expertise [4]. Designers should be able to visualize, discuss and work toward the future using imagination [5]. Imagination is essential for designers to figure out the unknown solutions [5]. In design enterprise, there is a need for imagination and judgment [6]. Through imagination one is able to create the 'not yet existing' through a process of composing parts, structures, processes and forms in a way that is suitable for design and through judgment, one evaluates how well it fits [6].

72.4 Storytelling

Storytelling is the art of narrating stories. For generations, stories have been one of the key mechanisms through which human experiences have been shared [7]. Stories represent 'a powerful and an accessible means of sharing knowledge, and their value and pervasiveness in conveying knowledge is well-recognized' [8].

72.4.1 About Storytelling and Linkage to Design

According to a postulate by Donna Lichaw [9], people are by nature story-driven, they communicate with and understand the outer world through stories. Whether the designer intentionally uses a story for the product or not, the user will experience the product as a story and will share the experience of the product with their own version of story [9]. Also, Quesenbery and Brooks point out that there are many ways of using stories in design, like gathering and sharing information, putting a human face on the data, generating new ideas and design concepts, sharing ideas, fostering understanding, and as a tool for persuasion [10].

72.4.2 Why Storytelling Could be a Strong Medium for Design Education

Through literature review, we have observed a strong connection between storytelling and design. Going forward, we will be reflecting on the requisite skills for designers and how it can be strategically aided using storytelling as a medium.

Storytelling aiding in cross-disciplinary work & collaboration skills. When it comes to cross-disciplinary work, storytelling can be used as a good tool for communication. Stories about the users can help in understanding them better [10]. It is easy to remember a story and communicate it with the team, resulting in a shared vision among the team members [11]. Stories are easy to articulate, thus allowing stakeholders of diverse backgrounds to contribute to the development of a design [12]. To foster this, we looked at 'The Shopping Cart IDEO Case study.' It is among the widely acclaimed redesign projects documented and showcased by ABC Nightline TV [13]. The importance of cross-disciplinary approach and collaboration was evident from the fact that the team formed for this project was composed of engineers, designers, linguists, marketing experts, etc. All the members were made to share their knowledge through stories, drawings, and prototypes, which helped everyone to be on the same page despite their diverse backgrounds [14]. The case study is an example of IDEO's design process and a demonstration of its innovation, which facilitated its journey from an idea to a product in barely four days with the help of a multidisciplinary team using effective collaboration skills.

Storytelling aiding in articulation and pitching of ideas. A designer must be able to articulate and pitch ideas to the various stakeholders. The design pitch should be able to generate the following impacts as listed below [3]

1. Deliver an understanding of the product
2. Demonstrate the value of the product
3. Stimulate critical thinking about the product.

The design pitch should convey an understanding of the product by the designer and should demonstrate its value both instrumentally and intrinsically for the investor to invest in it [3]. When a designer acknowledges user perspective and cultural beliefs weaved into a story, the impact and value is greater [3]. The design pitch should also be able to stimulate critical thinking (stimulating critique denotes opening up critical conversations about how a design concept has been, and can be further developed) [3]. When a subtle evolution in a series of design artefacts (such as sketches) is featured through storytelling in a design pitch, the audiences are able to analyze rationally [15]. Because of the transparency and familiarity brought to the design process through storytelling, audiences are able to take crucial decisions [3].

The following story illustrates a design pitch by Unilever Household Care [3], 'A concept for a spray applicator was presented in the Chinese market. Throughout the story told at this pitch, different colors and their meanings in Chinese culture were shared with the audience, revealing motivations behind key decisions made in terms of color selection on the product and pack. This quality was heralded by the audience as crucial to delivering understanding due to the contextual information it provided.' Here we can observe that when designers use different/ diverse storytelling modes, the delivery of understanding (due to the pitch being intriguing and memorable) is greater; the demonstration of the value (being rare) is impactful [3]. When audiences are taken through the stages of the design concept, revealed through storytelling, critical dialogue can flow. This happens because audiences are able to relate to design insights and product features [3]. The case study is an example of how the pitch could be made impactful through storytelling.

Storytelling aiding empathetic outlook. In any design process, designers gather contextualized insights about the user that is grounded in real-life situations [11]. Stories can help designers gain empathy with the users [11]. Persona scenario helps the designer to develop understanding about the product (including understanding of concept development, its form, and function) [16].

The following story by Quesenbery and Brooks suggests how sharing the stories of intended users during concept development can align understanding [10].

'The Open University (OU) is the largest university in the UK. Its programs are offered through distance learning, so its Web site is critical to connecting students to the university and helping potential students find out more information. One of our ongoing projects is the online prospectus, the catalog of academic programs offered by OU. Originally, this prospectus was presented like a typical catalog or database, starting with a list of departments and drilling down to specific courses. This design assumed that most people would be looking for the details of a particular course. But we were wrong. We found out instead that students wanted to talk about their dreams.

In one usability test, an older Pakistani woman, Priti, had put off her own education to raise her family. Now, she wanted to get the university degree she'd missed when she was younger. Her first course, she thought, should be the one that would help her with her English reading skills and get her back into good study habits. She and a friend worked diligently, reading each page carefully. They talked through each decision and had good reasons for each link they chose. But in the end, they selected an upper-level linguistics course, which would have been completely wrong for her. The cues about the level and content of the course that seemed so obvious to us were just invisible to them. It happens that the OU has a program specifically for people like Priti. Opening courses are a gentle introduction to university study skills like re-learning how to write essays, and they would have been a perfect match. So it wasn't just that she had picked a bad starting point; she had missed a really good one. The site just wasn't speaking her language. This story, and many more that we collected, convinced the team that we needed to engage people in the idea of the subject before pushing them to choose their first course. We started talking about needing to tell the story of the subjects that you could study at the OU.'

Storytelling aiding Inquisitiveness and Imagination. While listening to a story, the listener creates mental images [10] Thus, storytelling can be used by designers to spark each other's or their own imagination and discover new perspectives [10]. When we create fictional stories, we use imagination to develop scenarios, which helps us learn about the context of the problem, that would not become apparent through analysis. Stories act as a form of inquiry in which we bring together different elements and discover the potential of their interaction. This quality of a story renders itself as a powerful tool for designers to formulate their designs [17].

72.5 Conclusion

As established through literature study in the paper, the primary requisites of design education can be addressed through storytelling. Using storytelling as a medium could be extremely beneficial for designers.

The following table (Refer Table 72.1) lists the requisite skills for a designer and explains how storytelling can aid in addressing these skills.

As the rigid lines between different disciplines of design are diminishing, with multidisciplinary experiences being generated more often, storytelling can emerge as a powerful tool for a designer. The implementation of storytelling as a medium in design education is an area that requires further exploration and research. This will require a deeper understanding of diverse mediums of storytelling, which will vary based on the subjects in tandem with the teaching pedagogy of the faculty. We believe this paper will play a crucial role and support further investigation of the use of storytelling in design education.

Table 72.1 Mapping how storytelling aids in designer requisites

Designer requisites:	How storytelling aids:
Cross-disciplinary work and collaboration skills	• Easy to remember and communicate, resulting in a shared vision among the team members • Easy to articulate, thus allowing stakeholders of diverse backgrounds to contribute
Articulation and pitching of ideas	• Audience connects to user perspective and cultural beliefs better through a story, and is thus able to understand the product and its value better • Critical discussion regarding the evolution of design concept using design artefacts during storytelling makes audience analyze things better
Empathetic outlook	• Helps in gaining empathy with the users, thus a better understanding about the user and context • Results in an user-centered design of products or systems
Inquisitiveness and imagination	• In sparking the designer's imagination and discovering new perspectives • By acting as a form of inquiry by bringing different elements together and discovering new avenues

Acknowledgements We wish to thank our institute, U.P. Institute of Design, Noida, for support. We also acknowledge our gratitude to

Dr. Ravindra Singh and Ms. Srirekha Pillai for their valuable suggestions. We also place on record our gratitude to the references mentioned below.

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Chapter 73
Twenty-First Century Entrepreneurship and Innovation Management in the Garment Manufacturing Industry

Meeta Gawri and Shweta Sharma

Abstract Fashion is said to be monitored across the continents through cyclic trends in rejuvenation and re-establishment of innovations across the color palette and design board. The twenty-first century has added an entirely new dimension to the mechanisms of garment manufacturing, the garments being manufactured as also the demand for these and newer forms of garments. There has emerged a wide gap in the world of yarns, fabrics and clothes. The expectations of the consumers have touched the zenith with their demands for bio-tolerant, eco-friendly and environment conducive clothes that are suitable for varying climates and varying situations of human occupation and endeavor. The consumer in the current century is as conscientious of fashion and its trends as the people in the past centuries. There is, however, a tremendous gap in the functionality, embellishments, sourcing and sales of the creations of designers then and now. Another change that has taken the fashion world by storm is that prêt-a-porter has become as significant as haute couture with brand exclusivity being the new coinage of the fashion realm. The crème de la crème of society are increasingly following the brand band wagon as world class names like Chanel, Nike, Adidas, Pyramid and the likes are taking large strides on the fashion ramp walks across the globe. The concepts of outwear being replaced by innerwear comfort wear and casual wear are currently fast displacing the erstwhile formals. This is also true because a large part of the traditional, natural materials like silks, cotton and such like are constantly being replaced by rayons and their chemically created counterparts with Spandex and Lycra being the temporally recent additions. It has been observed that the twenty-first century stands poised to witness an unprecedented revolution in fashion and its manifestations right down to the grass roots level. There are numerous innovation taking place.

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A. Chakrabarti et al. (eds.), *Design for Tomorrow–Volume 3*,
Smart Innovation, Systems and Technologies 223,
https://doi.org/10.1007/978-981-16-0084-5_74

73.1 Introduction

The Prime Minister, Shri Narendra Modi, announcing a special package of one hundred thousand crore or thousand million, is at once, mind boggling and yet it opens up vast vistas of resurrecting the country's lost heritage. The exquisite craftsmanship which was under constant threat of being wiped out may well receive the proverbial shot in the arm for the country's dwindling population of varied craftsperson. This paper examines the possibility of rejuvenation of a lost but essential craft. This is the craft of the "rangrez" or the dyer, the expert who fills resplendent hues in the attires off young and old alike.

India has always led several nations in the trades including those dealing in dyed textiles. Indian dyeing has surpassed the textile crafts of the world in many ways. The dyers of India have harmonized and contrasted the colors for resplendent turbans, saris, ghagra skirts and shirts that formed the brilliant dress wear of the Indian people. They are the embodiment of the dyer's art and skill. Color plays a vital part in Indian textile designs. The colors have tremendous significance. Indians have borrowed colors from nature for centuries. These colors have had intense social, spiritual and even cosmic connotations. Every color has its own in-depth meaning. The design and color palette have mythological, natural or human history-related mysticism. Indians have derived colors naturally from flora and used them extensively.

The purpose of this study is to carry forward the exclusive revival of floriculture dyes with the floriculturist using the leftover floral waste. This will further help in developing sustainable fashion fabric—with the eco-friendly fabric dyeing and printing, thereby creating medicinal, skin-friendly organic fabric.

In the current scenario, severe damage has been reported to the environment and also those wearing dyed fabrics. There is a worldwide ban on azo-based dyes. Thus, natural dyes are the workable solution.

Historicity of Dyeing in India and the World

The oldest known dye is indigo blue, obtained in Europe from the leaves of the dyers woad herb, Isatis tinctoria, and in Asia from the indigo plant, Indigofera tinctoria. Till date, both alizarin and indigo have excellent dyeing properties. Indigo is a favored dye for denim but synthetic indigo replaced the natural for commercial purposes.

The Phoenicians had developed a derivative of indigo, Tyrian purple, which could be extracted in very small quantities from the glands of a snail, Murex brandaris which is indigenous to the Mediterranean Sea. This dye was called royal purple because kings, emperors and high priests alone had the exclusive right to wear garments dyed this hue. The 1450s saw the decline of the Eastern Roman Empire and the Mediterranean purple industry died out with it (Table 73.1).

Table 73.1 Sources of dyes shows the groups of dyes and their sources that have contributed to the dyers repertoire across time and space

Sr. No	Color/Class	Name	Source and Binomial Identity
1	Yellow/Flavonoid	Weld Quercetin Safflower	Seeds, stems, leaves of reseda luteola North American oak bark, quercus tinctoria nigra dried petals of carthamus tinctorius
2	Red/Anthraquinone	Kermes Cochineal Alizarin	Insect, coccus ilicis Insect, dactylopius coccus Madder plant roots, Rubia tinctorum
3	Blue/Indigoid	Indigo, Woad	Indigo plant leaves, Indigofera tinctoria l
4	Purple/Indigoid	Tyrian purple	Mollusks, Murex brandaris
5	Black/Chroman	Logwood	Heartwood, Haematoxylon campechianum l

73.2 Scholarly Inputs on Natural Dyeing Processes: A Review of Literature

Several experts in the fashion industry have been seized with the problem of natural dyes. There has been tremendous experimentation in the field of natural dyes currently. This is because of the rising concern for the environment as also the severely adverse long-term effects of chemical dyes made of synthetic components and processes. The attraction of brilliant chemical dyes has gradually worn off.

Aggarwal, Paul and Gupta (1993) examined the "effect of mordants on natural dyes" and explained the effect of mordants and mordanting on the color obtained when dyeing silk fabric using red sandal wood powder. Vandana (1995) also conducted a "study on extraction of natural dyes from selected plant source and its application on wool." Similarly, Aggarwal (1996) carried out a "study on extraction of natural dye from selected plant source and its application on wool and silk." It was Karole [2] who examined the "dyeing of pineapple leaf fiber using natural dyes extracted from the rind of pomegranate." Pandey and Tiwari [6] looked at "eco-friendly processing" in textile processing. They gave the recent developments in energy preservation techniques used in durable press resin finishing. They advocated the minimization of energy wastage. Subramanian, Nadiger and Singh (1998) asserted that awareness of eco-textiles has increased in recent years. Verma et al. [7] in their study, "eco-friendly, biodegradable less allergic," demonstrated the use of eucalyptus and wattle bark colors. Radhika and Jacob [4] extracted dye from jatropha seeds and applied it to silk fabric using myrobalan as a fixing agent and mordant.

Vernekar et al. [8] worked on "scouring and dyeing effect on yarn" and found that tenacity increases as uniformity improves for single and double yarn, while snarling decreases after scouring and dyeing. Devi et al. [1] conducted a study on "peltaphorum bark—a new source of dye for silk and cotton." Mahale et al. [3]

conducted a study on "natural dyeing of silk with teak leaves and its fastness." They concluded that a silk sample premordanted with 2% potassium dichromate showed better results for washing, rubbing, sunlight and perspiration in acidic media in a teak dye solution. A study on the "fastness properties of natural dyes by Seerangarajan and Jayabal [5] observed the fastness properties of natural dyes (chavalikodia, katha, ratanjot and annatto) with alum, $CuSO_4$, $FeSO_4$ and K_2CrO_7 on cotton, jute and silk. They found that alum and potassium bichromate gave bright and excellent shades with fastness properties of washing and rubbing.

There is ample scope for conducting a number of dedicated research-oriented studied in the field where a lot of resources are still waiting to be discovered.

73.3 Data Findings, Analysis and Discussion

The authors conducted experimentation to discern the possibility of bringing about low cost efficient solutions in dying. Color brightness, fastness and durability are the desired attributes of any good dye. The current paper details the possible avenues for bringing about the total extermination of harmful chemical dyes.

The research for this study involves natural dyes

- Extraction of dye from rose petals.
- Determination of optimum time for extraction of dye.
- Standardization of dye, thickening agent and mordant concentration.
- Determination of color fastness properties (washing, ironing, rubbing, perspiration and light properties) of the printed silk samples.

For final prints, five different concentrations viz. 1, 4, 6, 8 and 10 grams were tested. The printing paste prepared with synthetic thickener 2 and 4 grams were quite dilute while those with 8 and 10 grams were found to be light as compared to 6 grams of synthetic thickener. As a result, 6 grams were selected because it showed the required viscosity and color for printing.

Mordanting with ferrous sulfate was done with five different concentrations viz. 1, 2, 3, 4 and 5% of ferrous sulfate which was taken while carrying out the printing with ferrous sulfate. The sample printed with concentration 1, 2 and 3 percent gave lighter shades while patchy print was obtained with 5 percent concentration. The best prints were obtained by using 4% ferrous sulfate as far as the hue, color absorption, color fastness and the tactile quality of the printed samples was concerned.

Properties Expected and Obtained

After the exposure to various color fastness tests, the change in color of the printed samples and the staining of the white material was evaluated against gray scales. For each of the test samples, five readings were taken and then the average was considered as final for completing laboratory testing (Table 73.2).

Table 73.2 Results and Findings

Sr. No	Result Characteristics	Result
I	Colorfastness to Ironing Dry ironing Wet ironing	Good Good
II	Colorfastness to rubbing Dry rubbing Wet rubbing	Good Good

Source Compiled by Researcher

The Allure and Fallacy: Natural Dyes Revisited

The eco-friendly trends have been fuelled by increased public awareness about environmental issues over the past few decades. There are strict global restrictions that give stringent precautions for the use of substances to be used as a dye. They must have a number of properties like:

Intensity of color.

Solubility, dispensability or capability of being made soluble in a (usually aqueous) medium permanently or during dyeing.

Ability to be absorbed and retained by the fiber.

Fastness post-washing and exposure to light.

Natural dyes can be classified into four broad categories on the basis of: source, methods of dyeing, colors produced and chemical structures of the dyeing compounds

These categories have been given in details in the following paras.

Source

Vegetable dyes: These dyes are derived from roots, leaves, bark, trunk, wood, flowers and fruits of plants.

Animal dyes: These dyes are extracted from animals like cochineal, kermes and lac

Dye prepared from the dried bodies or exudates of certain insects. Animal dyes are, however, relatively unexplored.

The insect groups that are dye producers are: Cochineal scales (found on opuntia)

Lac insect found on lac host.

Lac insect found on lac host.

Gall like coccids found on oak.

Mealy bugs, especially those having red bodies, many garden plants have been known to be the hosts of such mealy bugs.

Chemical structures' categorization has:

Indigoid dyes: Two important natural dyes have indigoid structures namely, indigo and Tyrian purple. Indigo is the oldest natural dye but another ancient vat dye is Tyrian purple derived from Mediterranean shell fish of the genus Purpura and also Murex. This dye is fast and gives a brilliant purple shade.

Anthraquinone dyes: These are red dyes based on insects and animals and characterized by good fastness to light. These are:

- Madder: These are hydroxyl-anthraquinones, extracted from the root bark of various Rubiaceae like madder root. Madder (common chemical name alizarin) is among the most ancient of natural dyes.
- Lac dye: Used in South East Asia and India, since the origins of recorded history.
  Yields scarlet and crimson shades.
- Cochineal: Obtained from an insect of the same name, which feeds on the cactus *Nopelea cochinellifera*. Cochineal produces beautiful crimsons, scarlet's and pinks on wool and silks especially when mordanted with alum or tin in addition to tartaremetic. With chrome, copper or iron mordants the colors range from purple to gray. The brightest colors are seen in the combination of tin and an acid, such as acetic, tartaric and oxalic acid.

Alpha Naphthoquinones: It is henna obtained from the leaves of *Lawsonia inermis*, which is cultivated mainly in India and Egypt. Henna is an excellent substantive dye used for centuries as a beauty aid particularly for hair and skin. It imparts an orange shade to silk and wool.
Flavones: A colorless organic compound. Most of the natural yellows are derivatives of hydroxyl, methoxy substituted flavones or isofalvones.
Dihydropyrans: Closely related in chemical structure to the flavones. They are substituted dihydropyrans, viz. Haematin and its lenco from haematoxylin. These are the principle coloring bodies of logwood. Important natural dyes historically for imparting dark shades on silk, wood and cotton.
Carotenoids: These are derived from the orange pigment found in carrots. Two other sources are:

- Annatto: A prominent natural dye based on carotenoid structures. Obtained from the pulp Bixa Orellana seeds.
- Saffron: A major chemical constituent of saffron is crocetin and is obtained from the pistils of the crocus plant sativus.

Mineral colorants: Derive their name from natural sources that produced these colorants.

73.4 Sanctions Against Chemical Dyes

Germany was among the first to impose a ban on the export of textiles goods dyed with azo dyes. This was because on reduction they tend to release certain harmful amines. Most chemical dyes have been known to be based on coal tar and petroleum. They have proven to cause harm by continuous contact with human skin. They have also been acknowledged to be causative of all forms of environmental pollution.
Transferring Prints in Natural Dyes on Silk

Table 73.3 Dyeing properties of silk

Sr. No	Properties	Description
1	Shape and appearance	Silk filaments are very fine and long. They frequently measure about 1000 to 1300 yards (915–1190 m) and can be as long as 3000 yard (2750 m). The width of silk is from 9–11 microns. The fibers are smooth, and have a high natural luster or sheen. They are off white to cream in color. Sometimes they are yellow or light brown. Usually wild silk is uneven, having less luster and is tan to medium brown in color
2	Luster	It has very high luster after the sericin has been removed
3	Tenacity (strength)	Silk is the strongest of natural fibers and loses 15–25% of its strength when wet. Its dry strength is 2.4–5.1 g/d and wet strength is 2.0–4.3 g/d
4	Elasticity	Silk fiber is very elastic. It stretches upto 20% of their original length, with 92% recovery at 2% extension
5	Resilience	Silk ranks next to wool in resilience. Wrinkles hangout fairly readily
6	Moisture Absorption	It absorbs 11% relative humidity and 70° F water does not affect silk
7	Heat	Silk can withstand finishing temperatures of upto 370° F for short periods of time

Source Compiled by Researcher

The physical properties of silk determine the depth, quantity and quality of color transference as well as accuracy of printing being done. The intensity and sharpness of the printing process on silk is dependent on a number of factors. These are delineated in the following (Table 73.3):

- Chemical properties of silk also determines its potential for being dyed and printed as shown in Table 73.4.
- On the basis of its origin silk has been categorized into these four varieties of silk (Table 73.5):

73.5 Conclusions

Rose petals can be used as a rich source of natural dye for dyeing and printing of silk. The natural range of color produces harmonies that seem simple and obvious at first glance but which reveal a clever use of chiaroscuro effects on closer examination. The petals provide enticing, fascinating shades with good colorfastness properties.

Higher color qualities of traditional textiles will enable them to create more interest of the consumers in textile dyes and thereby in the preservation of the magnificent textile heritage of India.

Table 73.4 Chemical properties of silk for dyeing purposes

Properties	Description
Resistance to Acids	Silk is not damaged by most acid solutions
Alkalis	Silk is more resistant to alkalis
Chloride Salts	Silk fibers are damaged by substances containing chloride salts found in perspiration, deodorants and salt water
Organic Solvents	Silk is not affected by dry cleaning solvents
Bleaches	Silk is damaged by oxidizing bleaches
Mildew	Silk has high resistance to mildew
Moths, insects	They do not affect clear silk fiber
Light	Silk is not very resistant to strong light
Dyeing	Silk absorbs dyes more readily and at lower temperatures than any other natural fibers

Source Compiled by authors

Table 73.5 Varieties of Silk

Sr. No	Properties	Description
1	Mulberry Silk	It is called cultivated silk as it is produced by a silk worm called Bombyx mori
2	Tasser Silk	It is obtained from the silkworm Antheraea mylitta which is fed on asan terminalia Tomentose and oak
3	Eri/Endi or Errendic Silk	It is obtained from the silkworm called philsomiacricin, which are fed with the leaves of castor, tapioca or kesseru plants
4	Muga Silk	It is obtained from the silkworm Antheraca assamesis which is fed with the leaves of Som and Soalu plants

Source Compiled by authors

The findings of the paper open up vistas of design for the realm of fashion technology. India has been the hub of indigenous methods for use of natural elements. Bringing two natural elements of roses and silk together can result in the resurrection of truly Indian overtures in the field of fashion design technology.

There is tremendous further scope of the study. In India, a developing country, a huge proportion of the unskilled population could be encouraged to seek livelihoods in the vegetable dyeing and printing industry besides providing economic benefits to the country as an income generating activity in agriculture and non-agriculture sector. This study also promotes the use of organic floral waste.

Such experimentation is the need of the hour to supplement India's efforts in establishing its supremacy in the field of dyeing and printing of textiles in the world of fashion in the twenty-first century.

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Chapter 74
Investigating Surface Finishing to Develop an Advanced Process for Super-Finish, Highlighted by Benchwork and Polish Lathe in Jewellery Making

Parag K. Vyas and Nitya Vyas

Abstract Indian jewellery manufacturing scenario is rapidly evolving and changing in recent times, compared to the traditional way of working. It is slowly approaching an organized shop floor like that of a precision engineering division. Work is becoming more methodical and precise. There are merits in using abrasive processes minimally, as it has a direct relationship with human effort and material loss in jewellery designing. Moreover, as there is lack of standardization and nomenclature of process, this paper addresses the very need of the industry that requires a matrix through which methods that gives an acceptable finish with the least possible removal of material which can be designed. Further, this paper also proposes a structure by which a process best suited for a specific article can be designed and horizontally deployed through the shop floor.

74.1 Introduction

The Indian jewellery manufacturing scenario has rapidly changed its way of working, and the trend is expected to continue for times to come. Diverse factors are responsible for bringing about this change, such as evolving technology and demand for affordable as well as cost-effective products. As compared to the traditional ways of an artisan's lodge, where a few people worked collectively; it has taken shape of an organized shop floor with a systematic, organized and precision engineering division. In this environment, the work is defined and articulated, and results are delivered driven by deadlines.

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A. Chakrabarti et al. (eds.), *Design for Tomorrow–Volume 3*,
Smart Innovation, Systems and Technologies 223,
https://doi.org/10.1007/978-981-16-0084-5_75

There are different departments in a manufacturing set-up. At the onset, the casting department arranges miniature articles around a central armature—called the ‘tree’ in common parlance, by the lost wax casting method. This stage is followed by sprue cutting activity, where a solidified and cooled cast tree is cut that separates an article from the central tree. This is followed by the ‘De-Sprueing’ method before beginning the benchwork. During the benchwork, the article is refined at the outer form, and gemstones are set in. Finally, the article progresses to the polishing lathe, called a buffing machine in local dialect. Although each stage demands one expert artisan handling the small segment of the manufacturing chain, the artisan needs to be well aware of the full process and the aligning stage requirements of the complete process chain. This contributes commendably towards achieving productivity and efficiency of time.

The finish for an article of jewellery is most impacted by the two most sensitive finishing stages—Benchwork and polish lathe.

In benchwork, the sub-components and components are put together, assembled and given a semi-finish. At the polish lathe stage, the final finish is achieved. The method of giving a finish to a jewellery surface in both these stages is termed as ‘Mechanical Removal’ of surface material that reveals the ‘nascent metal’ surface. Here, the application involves use of an abrasive tool, to scrape the surface. The abrasive tool requires abrasive particles to be loosely applied to a rotary mop to achieve a target finish parsimoniously. It is called a buffing wheel in common parlance. A lot of emphasis is given to the surface material removal and collection of polishing dust for recovery and recycling of precious material. For any jewellery set-up large or small, minimizing of material loss whilst making and finishing is most essential. As the jewellery industry is particularly sensitive to recovering and recycling precious metal scrape and grinding dust during making of an article, it continues to be one of the most efficient industries to recycle more than 80% of its metal scrape during the manufacturing processes.

There are also the merits of using minimal abrasion at finishing of an article, as lesser the precious metals removed from the surface, lesser are the operational losses. Therefore, there is a need of an efficient selection process that gives an optimal as well as acceptable level of finish of surface while involving minimal operational losses. In jewellery, minimization of material removed to achieve target finish is well appreciated as it results into direct savings.

74.2 Need Statement

As jewellery industry has transformed from traditional to modern processing, some of the practices have evolved over time. For example, lost wax casting can be done in reasonably sized batches with minimal operational losses along with relative operational ease. This side of production line is well evolved and developed to match the international norms and practices.

However, owing to particular and peculiar forms of Indian motifs, mass finishing techniques well suited for European designs and continental style of jewellery are not effective in achieving a homogeneous and defect free surface that is aesthetically pleasing. In the experience of various bench workers and shop floor managers, hand process such as filing and hand sanding is best suited for finishing of Indian motif jewellery. As these motifs involve a greater curvature/lyrical complexity to their form, each unit needs to come under observation. These finishing techniques lack normalization and standardization for Indian motifs and similar jewellery making.

Outcomes of benchwork and work on a polish lathe to achieve a continuous defect free surface as a result of a process such sanding and buffing, therefore, are not predictable [1]. The way artisans and bench workers are operating on the shop floor presently which is a classic example of precise behaviour from imprecise knowledge. They do the work somehow but it is not repeatable or reliable. It is hence the need of time to bring objectivity and repeatability/predictability in hand work procedures. This standardization of process is the present need of the industry. This is plausible once a standard operative procedure or a process is laid down and adhered to, for the entire operation.

Articulation of a process, specifically a hand operated one, needs to be done with care and sensitivity. It needs to accommodate individual hands and yet collectively deliver consistent results, as expected from a procedure.

Presently, there is lack of standardization and calibration of process as different people approach the target finish result differently. This often leads to non-concurrence between bench workers and shop floor supervisors as well as quality assurance departments. This situation leads to loss of work and loss of time.

However, different stakeholders can differentiate between two articles of different finishes, by evaluation through simple observation and touching the surface. These evaluation methods are specific to textured surfaces created by particular tools such as engravers.

This paper attempts to study and develop a structured framework, through which a method best suited for a specific article as a whole or a segment under observation can be designed. This, thereafter, can be deployed through the whole shop floor. This learning can be extended to the surface finish of various articles sharing the same features of form.

74.3 Background Study

A process by its definition is a means to an end (with repetitive accuracy). A process entails a series of steps or actions taken in order to achieve a particular end result or outcome. Once the process parameters or constraints are set, predictability of the desired outcome is certain.

Adherence to a process, therefore, mitigates negative impacts of an individual's condition, state of mind, physical strength, etc. and gives fairly consistent results.

This requires following a set of instructions and using a predetermined set of tools to accomplish objectivity.

Finish as understood broadly is low surface roughness and waviness in primary and secondary textures. A process at bench or polish lathe, therefore, is expected to progressively reduce surface roughness and control waviness.

In the domain of engineering, defining and adhering to a process are relatively easy. A probable solution is simple, as material removal is not restrictive, and removal of a little more material to achieve a good finish is acceptable. But in the domain of jewellery, it becomes critical, as the result has to be achieved with 'minimal material removal'. Even a fraction of a percentage of more material removal leads to correspondingly more irretrievable loss. Therefore, a designed process needs to give optimal results with minimal material removal. Adapting from two of Taguchi's functions, it can be summarized as:

- Minimization of material removal
- Optimization of surface quality (primary and secondary texture, cumulatively)

This can further be elaborated as:

The process is that it needs to be effective in achieving a continuous, homogeneous and uniform surface with efficacy of minimal material removal.

It is pertinent to note here that if a product moves from its target finish, according to Taguchi, it leads to a loss of function. Over finishing or continuous polishing beyond the optimum point removes more and more material from the surface. This is known as low-grade scrape in jewellery. This grinding or polishing dust is precisely collected using a vacuum system. As a practice a vacuum system is started even before a polish lathe starts, to build a directional flow of air. As a result, there are two machines running in parallel to fulfil the same function of improving surface finish. A human hand delicately manoeuvres an article of jewellery against a cotton wheel with loosely applied abrasive to achieve a high level of lustre and reflectivity. The operator observes an article several times during this operation to assess the quality of surface and levels of reflectivity.

With the help of the above example, it is self-evident that effect of loss function in this case is particularly amplified, owing to two machines running while the operator is simultaneously pursuing the intermittent operation.

74.4 Methodology

The undertaken study was exclusively done in two jewellery producing establishments in India, in the towns of Hosur in proximity of Bengaluru and Pantnagar near Rudrapur. The study elaborated in the present paper is an opening step in devising research methodology for consistent surface quality. The data has been collected over a period of five years by meticulous observations of jewellery benchwork, along with combined meetings and interviews with departmental heads as stakeholders [2].

Meticulous notes were taken on simple notepads to avoid startling the operators. They serve as a record and reference. This method has been acknowledged for research in the domain of jewellery [3]. Videotaping and photography were mostly restricted inside closely guarded factories. In this domain, attempts to record electronically lead to the expected/normative answering that impedes an anticipated flow of authentic information. The data has been collected during ten planned visits and multiple sessions of interviews and observations during each visit.

The general duration of the factory observation period was between three to five working days. Key points emerged were as follows:

- People approach work in different ways and may take varied paths to achieve the same quality [4, 5] of surface on an article of jewellery. Often, this creates a difference in appearance of the same design when produced in many numbers.
- Subsequently, the literature was looked up to find if any relevant prior knowledge existed. The literature was scarce and silent.
- There was lack of authoritative work by jewellery professionals and practitioners with direct applications of such processes on the shop floor.
- Inferences and deductions were based on interviews and then cross-checked with simple observations. The cycle of experiential learning as expounded by Kolb [6, 7] was also found to be useful. This propounds four sequential steps: first the experience about an event, incident or occurrence leading to reflection on experience by drawing conclusions using sorting, understanding and generalizations to provide an overall framework and finally, testing new experiences using the proposed framework.
- Phenomenology is grounded on the way people observe phenomenon, in the world they live in. Observations and the following deductions became the basis of proposition of a matrix [8]. In a domain that is a relatively an uncharted area, this method was well suited for the beginning and later on to further build upon itself.

74.5 Proposition of a Process Cloud

A human hand is best suited to do mental calculations, akin to multivariate analysis in real time and quickly respond to these conditions and challenges presented by intricacies of form. This is an area, where machine-based processes face tough challenges and meet impedance at a point beyond which it becomes ineffective [9]. It is at this point that the response of a human hand is far superior in swift understanding of an ever-changing form. This conjecture becomes key to the inference that diverse approaches and procedures are adapted by individuals to achieve a quality surface on jewellery. Therefore, there is a need to evolve a process that is inclusive and accommodates different sizes, styles, intricacies and peculiarities of design in its fold.

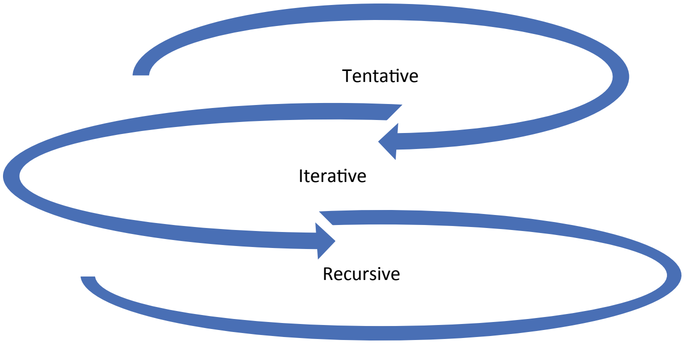

Fig. 74.1 A jewellery process is tentative, iterative and recursive

A jeweller's approach towards an article in terms of work is cautious and full of apprehension. This is not a lack of clarity in a bench worker's mind but due to the multiple complex objectives that need to be fulfilled all together at the same time.

Processes are applied according to decisions taken on the form and its intricacies. They are sequential in nature so that they reduce surface roughness in two to three steps. Thus, it progressively making a difference between peaks and valleys of the article-surface smaller and smaller. The artisans observe and visually evaluate an article from several angles before proceeding to the next step, and at times, it may come back to the previous step before satisfactory results which are achieved. This makes the finishing process tentative, iterative and recursive. This process has been visually depicted in Fig. 74.1. This procedure also begets the best surface finish results on an article of jewellery. In comparative contrast, an engineering process is linear and straight forward. A comparison of the two gives us a perspective and the limited world view essential for comprehending. [10]

Tentative—approaching with apprehension, not sure whether the desired result would be achieved.

Iteration—understood as a procedure or operation applied to as a consequence of a previous procedure. This is done as a means to obtain closer approximations in order to achieve an aesthetically pleasing surface finish in minimum steps with minimal wastage of material like bullion metals. Especially, the irretrievable part of material loss to which industry is particularly sensitive.

Recursion—is repeated application of a definition, rule or procedure to achieve successive results.

These concepts are similar, but not the same although all of them mean implementations of a set of desired directions.

Recursion aids in taking decisions for applying the necessary method according to the situational requirement for every piece of jewellery. Like an assessment, for example, to apply a little more buffing in a small spot for a particular piece.

Iteration on the other hand involves a loop executed repeatedly, until a certain condition is met. This can be understood by the instance of filing needed in a small area before further buffing.

Tentativeness also plays an important role here as it allows time for the human mind to resolve problems mentally and lucidly avoiding costly rework.

Close observation of work over the shop floor has revealed three key processes adapted by master craftsmen and accomplished bench workers. These are, namely:

Decorative Filing

Involves using a file to remove fine amount of material from the exterior to reveal a fresh surface. Various shapes are used by jewellers to achieve an effect that is decorative and pleasing to the eye. Common jewellery shapes used are: triangular, half round and flat. It is a favourite technique adapted by master jewellers to quickly and effectively remove metal from specific locations. As a general rule, coarser the file, faster the work and better the quality of scrape. Mastery lies in accomplishing as much work as can be done using coarse files.

This work is also done by rotary files, using a micromotor. Rotary files are commonly known as burrs. They carry out work faster but require considerable mastery. A slip in work is expensive as a rotary tool can do a lot of damage within a fraction of a second.

Some tools, implements and devices used in progressive reduction of surface roughness are briefly touched upon with help of indicative pictures. These may change from time to time and may vary according to a specific tool manufacturer (Fig. 74.2).

Buffing Sticks

A buffing stick is a special purpose tool developed by watchmakers and extensively used by jewellers. It is a piece of graded abrasive paper stuck to a piece of shaped wood. It is used in a similar manner to that of a file, giving a finer control over metal removal. It is an intermittent step between filing and polishing. It is called buffing stick in common language, but an abrasive stick would be a more appropriate nomenclature. Similar work can be carried out by rubber bonded abrasive wheels. Similar to the use of rotary files, mistakes are expensive (Fig. 74.3).

Polish Lathe

Commonly referred to as 'buffing machine', it is a favourite tool of jewellers. It uses a rotating flop wheel to which a loosely bonded abrasive is applied. A piece of jewellery is presented to this wheel to remove miniscule amount of material. This reduces surface roughness and gives surface reflectivity (Fig. 74.4).

It is pertinent to note here that surface reflection may vary with the incident angle and polarization of light. It is the sum total visual appearance as a result of this reflection. Reflection determines lustre that is easily observed but it is rather subjective and therefore complex to articulate objectively. On the shop floor, both words are used interchangeably, to describe approximately the same effect. By this

Fig. 74.2 Files [11]

Fig. 74.3 Buffing sticks [12]

explanation, this study factors out the quality of light and thereby brings in objectivity in discussions.

Verbally, three adjectives are used to define tool roughness in an ordinal scale

Rough—indicates an aggressive cutting tool, used for fast and efficient removal of bulk material. This is used for form giving and shaping. A coarse file gives '***lamels'***, or thin shavings which are easy to recover and recycle.

Fig. 74.4 Polish lathe [13]

Medium—indicates a moderate cutting tool that is milder in comparison to an aggressive tool.

Fine—indicates a very light cut as compared to medium. This is used for final touches to the complete form and to achieve a general, homogeneous and uniform appearance overall. A fine file gives fine dust which is difficult to collect, control and recycle.

It is a general practice to carry out the largest part of the work with the coarsest tool possible, so as to carry out work faster and have an easy to recycle scrape. This is critical to the domain of jewellery as material scrape holds as much commercial value as the raw material.

Actual roughness though may have a more accurate description, e.g. an abrasive paper as per FEPA [14], Europe, namely P220, 400 and 600 can be termed as rough, medium and fine for a set of process. The same can be understood for files, second cut, medium and dead smooth that carry the same thought.

74.6 Proposition of a Process

Processes need to be human centric for the benchwork and polish lathe stages that accommodates individual working styles and yet consistent in achieving the expected target finish [15].

It can be achieved by deploying processes in a predetermined sequence of steps. The following tables illustrate schematic plans of a proposed jewellery manufacturing process to get a super finish (Tables 74.1, 74.2, 74.3, 74.4 and 74.5).

Table 74.1 Showing coarse, medium, fine tools and abbreviations used

Tool	Process		
	Coarse	Medium	Fine
Filing	FL(C)	FL(M)	FL(F)
Buffing stick	BS(C)	BS(M)	BS(F)
Polish lathe	PL(C)	PL(M)	PL(F)

Table 74.2 Example 1 of process design for a specific product

	Process		
Tool	**Coarse**	**Medium**	**Fine**
Filing	FL(C)	FL(M)	FL(F)
Buffing stick	BS(C)	BS(M)	BS(F)
Polish lathe	PL(C)	PL(M)	PL(F)

Table 74.3 Example 2 of process design for a specific product

	Process		
Tool	**Coarse**	**Medium**	**Fine**
Filing	FL(C)	FL(M)	FL(F)
Buffing stick	BS(C)	BS(M)	BS(F)
Polish lathe	PL(C)	PL(M)	PL(F)

Table 74.4 Example 3 of process design for a specific product

	Process		
Tool	**Coarse**	**Medium**	**Fine**
Filing	FL(C)	FL(M)	FL(F)
Buffing stick	BS(C)	BS(M)	BS(F)
Polish lathe	PL(C)	PL(M)	PL(F)

Table 74.5 Example 4 of process design for a specific product

	Process		
Tool	**Coarse**	**Medium**	**Fine**
Filing	FL(C)	FL(M)	FL(F)
Buffing stick	BS(C)	BS(M)	BS(F)
Polish lathe	PL(C)	PL(M)	PL(F)

This kind of table hence becomes a reference point for the designing of a process cloud. As evident from the above, an article is filed from coarse to medium to fine to give form and has a homogeneous surface finish. The jewellery article is then rough, medium and fine sanded to get a surface ready for buffing.

This article is then taken to a polish lathe, and it is roughened using a bobbing compound such as Tripoli. Followed by rough, medium and then finally fine, buffing is done almost with using no compound.

It is proposed that by following the nine sequential steps systematically, any article can get a desired finish. A surface which is free from any material removal process defects is considered to be continuous, homogeneous and reflective. Achieving such a surface in the domain of jewellery is rather rare and privy of few. In common language, it is called 'super finish'. It is similar to but not the same as use of words super finish in the domain of engineering. Though, a suitable number from N1 to 12 can be found for and assigned to this quality; however, it is better to have a different scale for jewellery finishes. This proposition would be in the scope of another paper and not in this present paper.

In the light of this discussion, we can understand that it is possible for some steps to be omitted in this three-by-three matrix to achieve the required finish results. The expertise of a process designer lies in recommending which steps to skip without compromising on the overall desired surface quality.

74.7 Limitation

Formal and methodical research in the domain of jewellery is miniscule as compared to engineering processes especially metrology. Theory and practice in these domains need to go hand in hand for clarity/formalizing processes/productivity on subject. There exists a knowledge chasm herein that needs to be bridged. Shop floors lack robust theory to back their practices as in this field particular attachment to old ideas and emotions, cloud factual assessment of intricate procedures. Also, guarded communication and secrecy make exploratory research challenging in this field.

This study faces limitation due to lack of scientific literature in the domain of jewellery and also due to a dearth of authoritative reviewed material. There is an absence of alternative contemporary views and shortage of knowledge which makes conclusions difficult and challengeable.

74.8 Merits

This study provides a firm theory to.

- Give a detailed account of jewellery surface finishing processes and offers its documentation with tools and technology used.
- Develops scientific definitions and articulation of complex and intricate procedures like, surface finishing methods used in jewellery.
- Methodically explains each process stage, with a jeweller's/artisans perspective.
- Lays out a procedural, schematic framework to various stages of design, a process hitherto deemed undoable.
- Opens pathways for further research in the domain of jewellery.

Jewellery manufacturing in the present set-ups strive to gain productivity and efficiency with a standardized super finish through proficient methods. This study provides a well-defined framework to achieve the same. The most prominent contribution of this paper is articulation of process details, terminology and definition building, along with devising a standardized framework that accommodates/retains unique handwork and adding to the body of knowledge of the jewellery finishing processes. Thereby allowing designers and jewellery makers to understand, investigate and develop design systematic processes. So far, neither process design nor investigation of these features in the jewellery domain were deemed possible and were considered to be too difficult to put in place.

74.9 Future Directions

This research was tested out in a leading jewellery manufacturer, Titan industries, Jewellery Division Hosur in the country. Processes designed were verbally explained as well as physically demonstrated to a batch of tool ambassadors, as the select group of bench workers was named internally for easy of identification. The initial response of bench workers was positive and early adaptations were appreciated by shop floor managers. A photo documentation is requested for purposes of deeper study and further refinement. It is also worth mentioning that the processes guided thus are still ongoing in the above jewellery unit.

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Correction to: Understanding Emotion in Design Inspiration Contexts Through the Core Affect Model

Vimalkrishnan Rangarajan, Prasad S. Onkar, Alison De Kruiff, and Deirdre Barron

Correction to:
Chapter 6 in: A. Chakrabarti et al. (eds.), *Design for Tomorrow–Volume 3*, Smart Innovation, Systems and Technologies 223, https://doi.org/10.1007/978-981-16-0084-5_6

The book was inadvertently published with chapter author's incorrect family name. The author's name has been corrected from "Vimal Krishnan R" to "Vimalkrishnan Rangarajan".

The updated version of this chapter can be found at
https://doi.org/10.1007/978-981-16-0084-5_6

A. Chakrabarti et al. (eds.), *Design for Tomorrow–Volume 3*,
Smart Innovation, Systems and Technologies 223,
https://doi.org/10.1007/978-981-16-0084-5_76