Design Innovation Methodology Handbook – 2nd Edition

Book · September 2023

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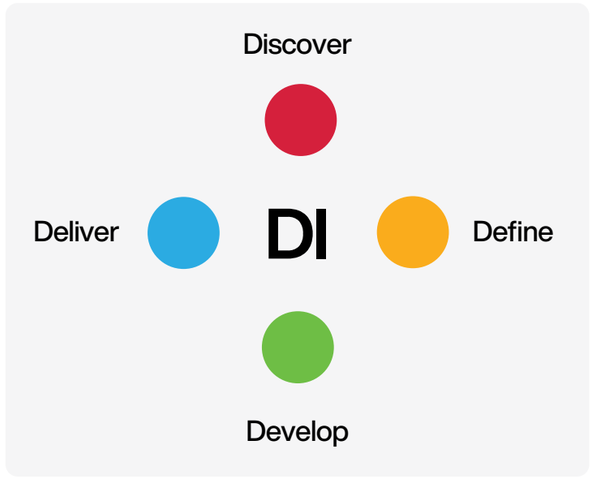
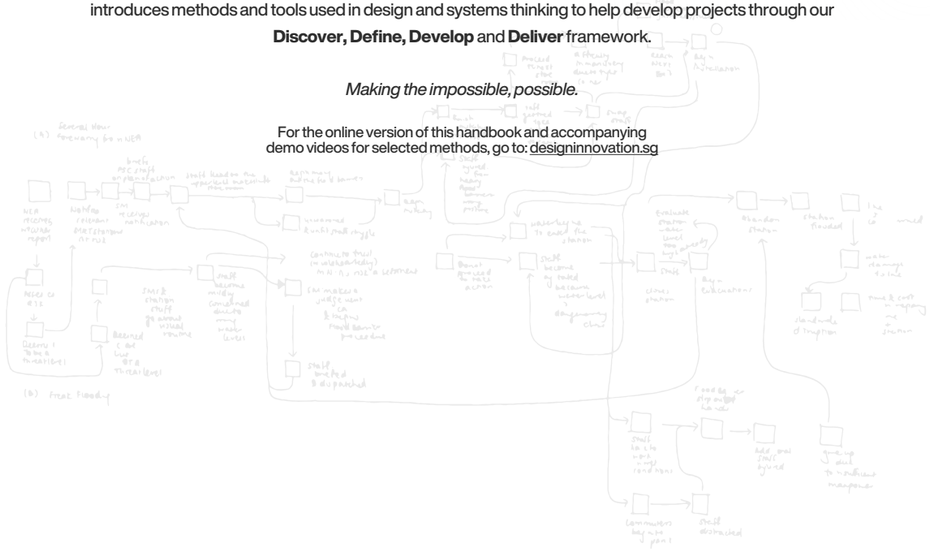


Created to help anyone design and create innovatively. The **Design Innovation Methodology Handbook** introduces methods and tools used in design and systems thinking to help develop projects through our **Discover, Define, Develop** and **Deliver** framework.

Making the impossible, possible.

For the online version of this handbook and accompanying demo videos for selected methods, go to: designinnovation.sg



Design Innovation Methodology Handbook

Second Edition

Design Innovation Methodology Handbook

Embedding Design in Organisations

Developed and designed by

Prof. Carlye Lauff, Wee Yu Hui, Ashley See, Dr. Sujitra Raviselvam, Dr. Arianne Collopy, Dr. Dan Jensen, Kenneth Teo, Sabrina Png, Amanda Swee and Prof. Kristin L. Wood.

DESIGN INNOVATION
SUTD SINGAPORE UNIVERSITY OF TECHNOLOGY AND DESIGN | DesignZ
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Design Innovation Methodology Handbook
Embedding Design in Organisations

Published by the Design Innovation Team, DesignZ Centre, Singapore University of Technology and Design

8 Somapah Road Singapore 487372

ISBN: 978-981-18-7593-9

DOI: https://doi.org/10.59977/VQPH8086

Design Innovation (DI) Methodology Handbook: Embedding Design in Organisations

Authored, developed and designed by Prof. Carlye Lauff, Wee Yu Hui, Ashley See, Dr. Sujitra Raviselvam, Dr. Arianne Collopy, Dr. Dan Jensen, Kenneth Teo, Sabrina Png, Amanda Swee and Prof. Kristin L. Wood. Book design by Ashley See.

SINGAPORE GOOD DESIGN 2022

First edition of this handbook was awarded the Singapore Good Design Awards 2022 in the Product Category.

Second Edition
June 2023

DESIGN INNOVATION

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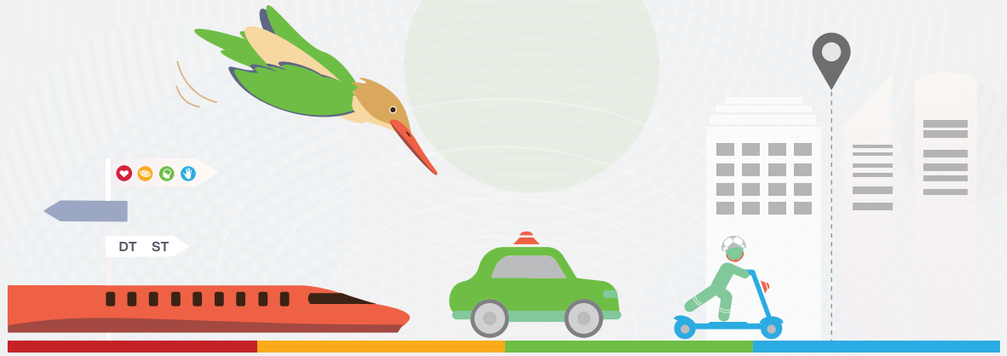
Second Edition

Design Innovation Methodology Handbook

Embedding Design in Organisations



Foreword

We are on a design journey. Business, education, society, and community are at the center of this journey. In the words of the Prime Minister of Singapore, 'Singapore is a nation by design. Nothing we have today is natural, or happened by itself... Now, as a first world country, design thinking will be critical for us to transform Singapore again, and to stay an outstanding city in the world. Actually, there are many other policies which will benefit from your design thinking. If you think about it, healthcare, education, CPF, national service and even our political system.'

The ideas expressed by the Prime Minister focus on the design journey, as a concept, known in the popular vernacular as Design Thinking, or, more broadly, what we refer to as Design Innovation. This journey is a vision for the future, no matter what country or community in which we reside. We are facing the grandest of global and national challenges, such as an ageing population, environmental crises, needs for transformation in transportation, smart and loveable cities, threats of terrorism, ethnic and religious tensions, and economic uncertainty. Design Innovation holds an optimism, an 'Also Can', and a promise to confront and overcome these challenges.

The Design Innovation Methodology handbook represents a contribution to our design journey. This handbook was developed by a number of contributors from the United States and Singapore. Through a co-creation effort and common interests to innovate together, the intent is to make a difference for all persons in our communities and society. Readers are provided with a meaningful and practical guide, reference booklet, and living document in which to engage Design Innovation at the apex of Design Thinking and Systems Thinking, and beyond.

Appreciation is conveyed to all of the contributors in developing this handbook. We sincerely hope that this guide will inspire and embolden all readers and partners to push the boundaries of human-centered systems innovation across one's entire portfolio and strategic plan. In doing so, the future will be bright, and we will have an impact beyond anything we can imagine or foresee. We wish you the very best as you embrace your personal Design Innovation journey. To Design Innovation, and Beyond!!

Prof. Kristin L. Wood
Founding SUTD Engineering Product Development Pillar Head;
American Society of Mechanical Engineering Fellow;
Director, Design Innovation Team, SUTD;
Professor, College of Engineering, Design and Computing, University of Colorado Denver | Anschutz Medical Campus

The IDC (SUTD International Design Centre) is a game changer in design and science. I am within arms reach of architects, designers, engineers, and computational analysts at my desk in the design innovation space.

Adam Gilmour

CEO of Gilmour Space Technologies

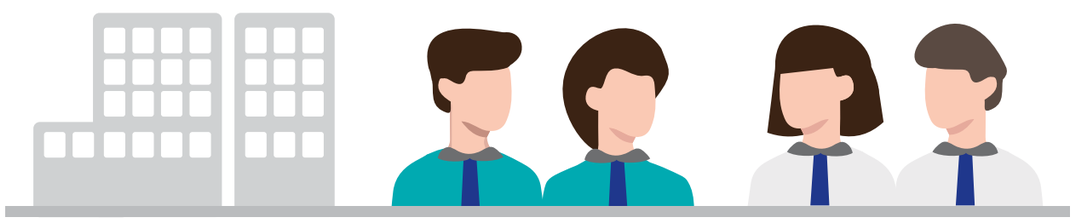
Hello there!

Preface

How Might We

impact our community, our region and beyond through Design Innovation?

A ‘How Might We’ statement is often used to question existing designs and prompt designers, engineers, and professionals for change or action.



Who is this handbook for?

- Managers and directors driving Design Innovation (DI)
- In-house design teams in approaching design
- Any innovators and entrepreneurs playing a part in design
- Any professional wishing to contribute as an innovator in their organisation or community, including roles such as design integrator, design-preneur, design specialist, or design multiplier.*

Why is this handbook relevant to me?

This handbook curates DI processes, tools, principles, mindsets and methodologies to help you solution for complex problems. Think of it as your interdisciplinary toolkit on your design innovation journey.

Not only can you use this as you need it, we hope it inspires you to develop a human centred, systematic design culture in your projects and beyond.

What can I learn from this handbook?

- Define DI and its value in the design ecosystem
- How to challenge the status quo towards innovation within the life cycle of a project
- Identify and empathise with users and stakeholders
- Remain relevant in changing times
- Creatively and effectively solving complex problems

*Reference: Agnus Quek, Design Archetypes, MindTheSystem, Founder and CEO

Contents

Methods

*The reference numbers that appear throughout the handbook follow the numbering in the 'References & Resources' section.

Guide on how to use this handbook

This shows what card number it is in the Design Method Cards

Examples with this logo are used in a website or mobile application design.

Indicates the other 4D phases for which this method may be applied

Method

Method Name

Principle | Possible use of methods

CARD 1 Empathy

DIGITAL DESIGN

Discover
Define
Develop
Deliver

Concise description of the method.

Why: Here it explains the rationale and benefit of the method.

Time: The estimated time required to complete. This is not applicable to all methods.

Materials: Materials that are needed. They can be physical or digital form. Basic materials like pen and paper are not mentioned.

Complementary methods: Here are others methods that we can use together with this method.

Applicable framework: A framework is a basic structure supporting the concepts set forth in this handbook. With the application of the Extreme-User Experience Framework, there will be more insightful outcomes. Try it out, if you see the Framework icon.

Acronyms: Here are the acronyms that are mentioned.

Scan or click here for a digital copy of the template

Best Practice

Here are some best practices

They are based on the decades of design experience and research by the authors and contributors of this handbook. Make use of them to assist you.

Template Structure

For methods where templates are provided, this section describes the overall structure of the template to assist users and readers.

Worked Example

Shows how the method is used in a design challenge or opportunity statement.

Procedure

Steps are numbered sequentially

1 **Here are some steps**

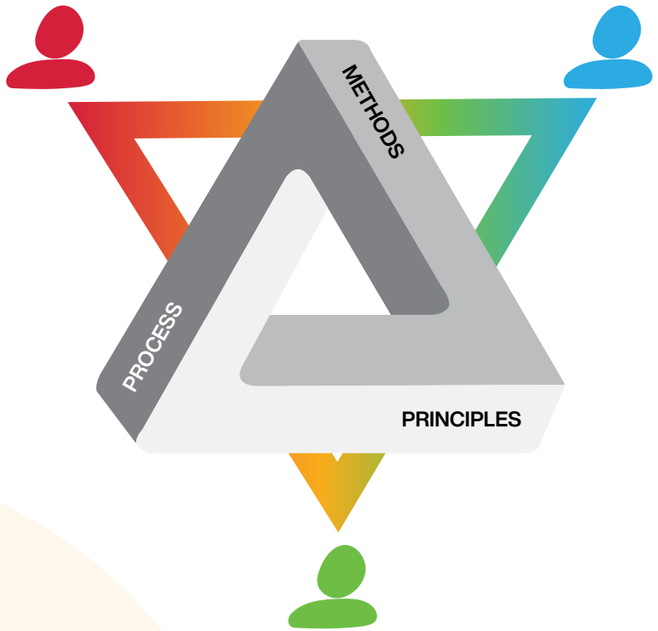
A quick way to start working on this method with a procedure

Useful Tip

We throw some tips and tricks along the way to guide you along.

References are mentioned at the end of the book and are denoted as a superscript

Design Innovation Methodology



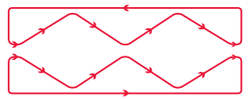
Design Innovation (DI) is a human-centred and interdisciplinary methodology to innovate on and address complex challenges in our world[1]. Designers, engineers, and professionals alike can use it to create novel and impactful solutions for users and stakeholders. The four pillars of the DI methodology are People, Process, Methods, and Principles.

DI can be engaged in designing products, services, or systems (PSS). Products are physical creations across scales, from the nanoscopic scale to the macroscopic scale (e.g. buildings, bridges, trains and roads). Services are intangible transactions performed by a person or group for the benefit of other people or groups. Complex systems are creations that include the combination of numerous elements or components with high coupling, interactions, and interconnections, ultimately delivered and evolved as a whole.

People

DI begins with people, understanding the stakeholder and user landscape which includes both internal and external teams, and striving to empathise with their needs.

Process

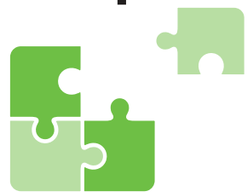


The DI process provides a flexible and customisable framework for tackling complex opportunities or challenges and allows any organisations to remain relevant in changing times. Through the 4D double-diamond (see page 11), the process creates a balance of divergent and convergent thinking, while seamlessly integrating Design Thinking and Systems Thinking.

Methods

DI methods are guided activities to help teams work towards a desired outcome. Methods provide a language for design, amplify our natural talents and skills, and help us put design into words and output. Which methods we choose and how we transition between them is governed by the DI process in the form of DI sprints.

Principles



The DI principles are the heart, mind, and soul of DI, that help to foster an innovative culture by guiding the way in which people think, communicate, and decide. These principles underpin the process and methods and act as a reminder of best practices, encouraging and enabling designers, engineers, and professionals to seek better solutions for users.

People

Stakeholder Landscape

DI begins with people through understanding both the stakeholder landscape and the internal team to complete the project.

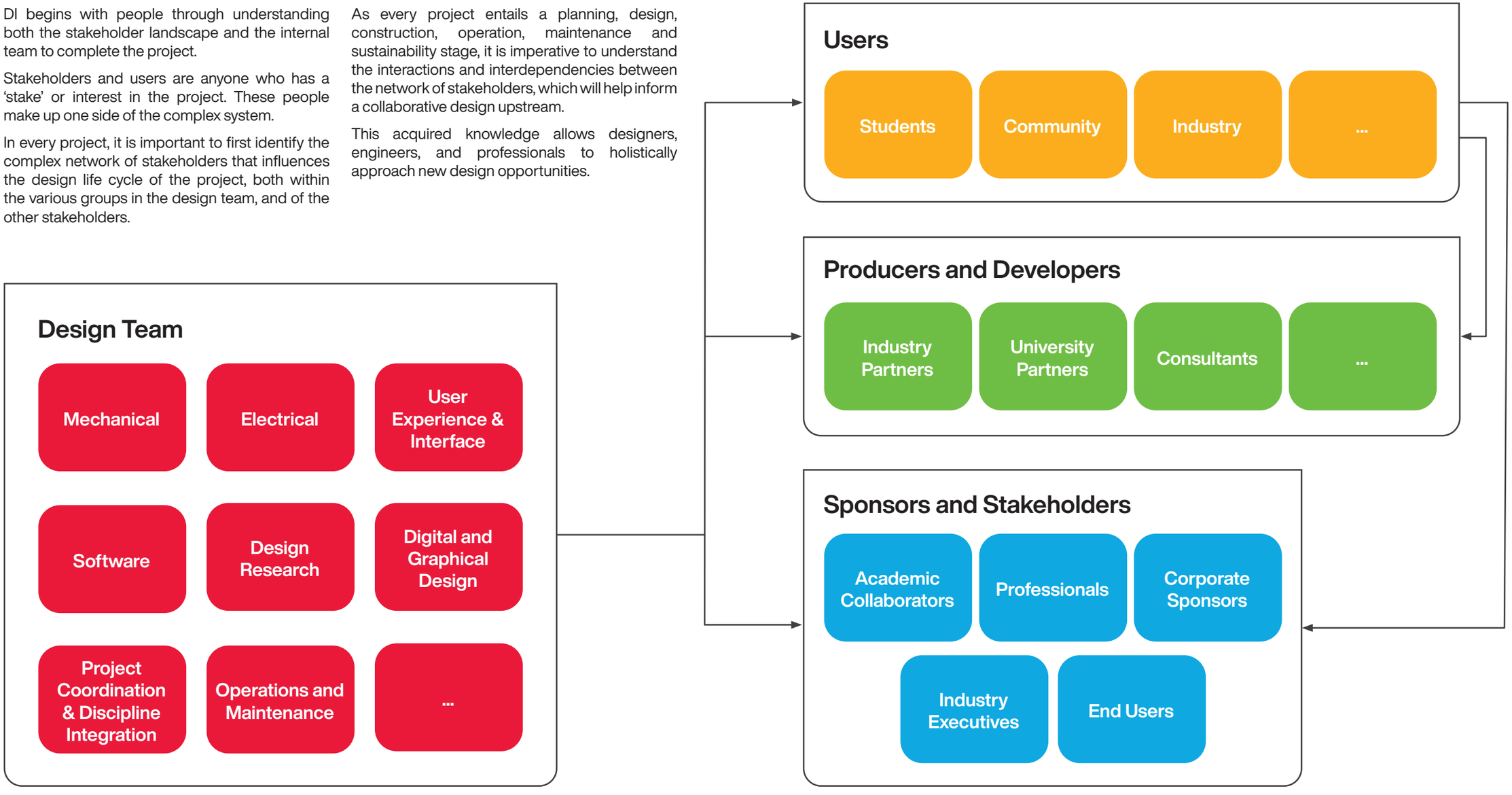
Stakeholders and users are anyone who has a ‘stake’ or interest in the project. These people make up one side of the complex system.

In every project, it is important to first identify the complex network of stakeholders that influences the design life cycle of the project, both within the various groups in the design team, and of the other stakeholders.

As every project entails a planning, design, construction, operation, maintenance and sustainability stage, it is imperative to understand the interactions and interdependencies between the network of stakeholders, which will help inform a collaborative design upstream.

This acquired knowledge allows designers, engineers, and professionals to holistically approach new design opportunities.

* Notional Diagram



People

Design Innovation Catalyst

A Design Innovation (DI) Catalyst ensures that DI implementation is effective and innovative. We recommend having at least one person in each project to assume the role of a Design Innovation Catalyst.

Characteristics of a Design Innovation Catalyst:

Embodies the DI process mindsets of empathy, mindfulness, joyfulness, and non-attachment

Is not afraid to step outside comfort zone and challenge the status-quo of how things have always been done

Friendly and approachable

Has the ability to zoom out to the big picture and then zoom into the smaller, actionable details

Leads or facilitates discussions and active working sessions

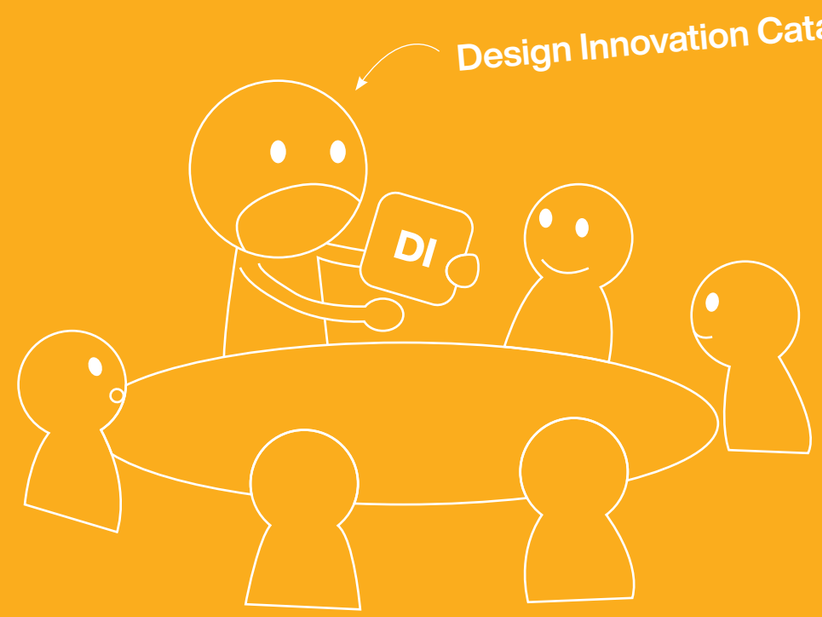
Challenges conversations from new perspectives

Is inquisitive by nature: asks lots of questions, 'Why is it this way?' and 'Could there be another way?'

Has a bias towards action – stop talking and start doing! Always sketching and co-creating

Suggests DI Methods as needed for teams and individuals, and enables them to extend themselves beyond their experiences and past capabilities

Embraces and helps in shaping a flexible, reconfigurable, agile, customisable and personalise process suitable for the individual, team or organisation.



Best Practices

- Actively listen during team meetings, picking up on pain points and opportunities to probe deeper.
- Balance Design Thinking* and Systems Thinking* approaches:

  Design Thinking: Keep the end users and key stakeholders at the centre of all conversations and decisions

  Systems Thinking: Understand the interactions and relationships between the architecture, constituents, and parts of the project/system
- If teams have been talking about the same issue for over 30 minutes, get them to stop talking and start sketching or interacting through one or more other media to change the perspective.
- Ensure every voice in the team is heard. Doing individual work followed by group discussions helps.
- Encourage team to develop Design Roadmaps for projects, seek higher-level Enterprise projects, and push the boundary of Design Futures.

*refer to page 25 for more information on Design Thinking and Systems Thinking

Creativity is piercing the mundane to find the marvelous.

Bill Moyers

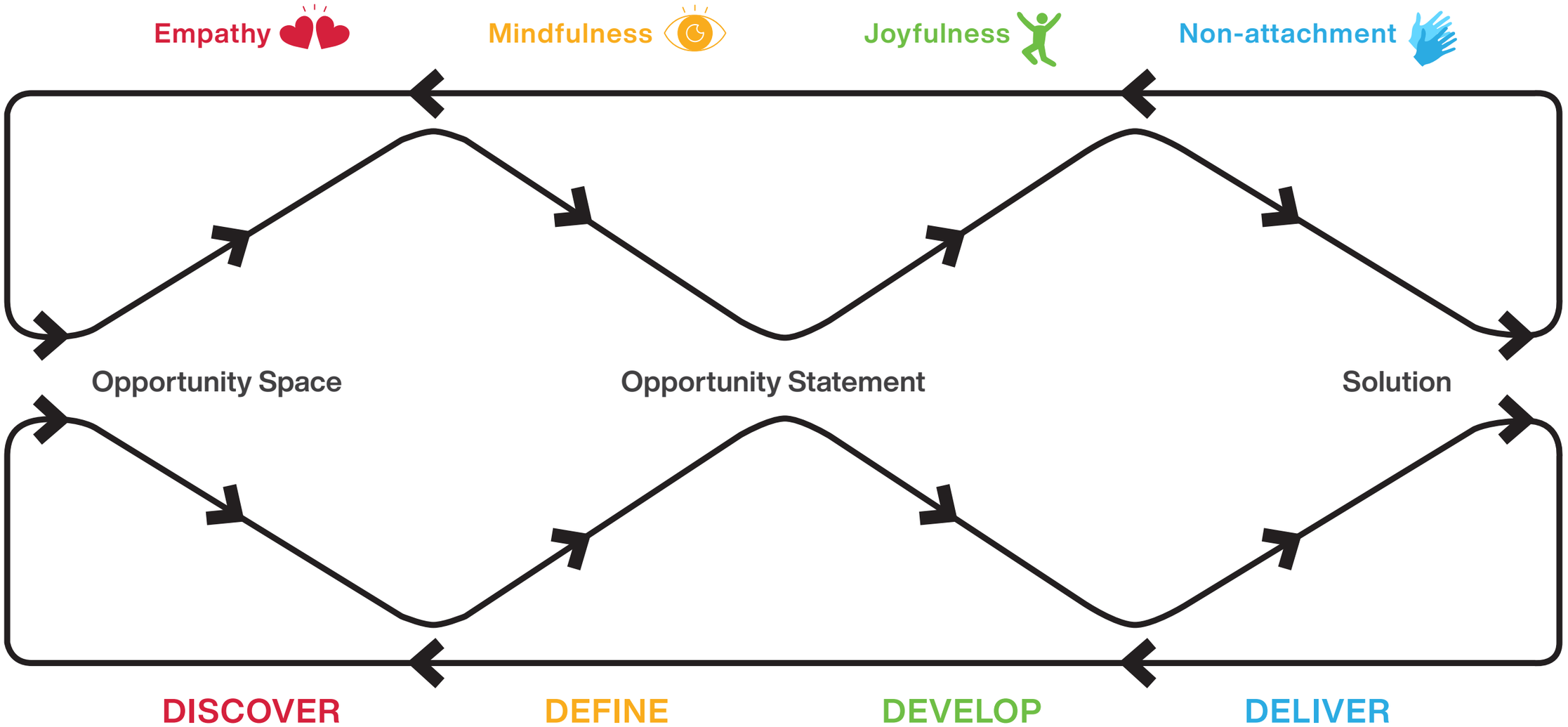
Journalist who received numerous honours, including more than 30 Emmy Awards, and a lifetime achievement award in 2006

Design Innovation Process

The DI process is an iterative approach that provides an order of action in design projects holistically. It consists of 4 phases: Discover, Define, Develop and Deliver, and its associated mindsets: Empathy, Mindfulness, Joyfulness and Non-attachment.

The process has a dual diverge-converge cycle and is built, in part, on the UK Design Council's 4Ds[1], and represents a 'sprint', where a project will constitute multiple sprints, pivots, and leaps.*

* Seow, O., Tiong, E., Teo, K., Silva, A., Wood, K. L., Jensen, D. D., & Yang, M. C. (2018, August). Design Signatures: Mapping Design Innovation Processes. In International Design Engineering Technical Conferences and Computers and Information in Engineering Conference (Vol. 51845, p. V007T06A046). American Society of Mechanical Engineers.



Empathy

Identify and understand opportunities and needs collaboratively through co-creation with stakeholders

Understand

- Who are the users and stakeholders?
- What are their needs?
- How might we delight them and enhance their experiences?
- What are their actions, reactions and emotions?
- What is the context?
- What research and user studies are needed?

Empathise

- How do users behave?
- How do they feel?
- How do we see through their eyes?
- What extreme conditions may inform us?
- How do they interact with objects, the environment, and each other?

Mindfulness

Interpret and reframe needs and map them into activities, functions and representations with a focus on innovation

Observe

- Who are the primary users?
- What activities do the users engage in?
- What are the users' journeys and emotions?
- What system functions are needed?

Analyse

- How do we make sense of these findings?
- What are the key insights and foresights?
- How might the product, services, or systems (PSS) fare in different situations?
- What are the driving social needs and technical specifications?

Joyfulness

Ideate and model concepts based on identified opportunities

Ideate

- How do we ideate?
- What are key methods we might use?
- How do we maximise quantity?
- What analogies may be used?
- How do we add depth and fidelity?

Select

- How do we down select ideas that 'wow'?
- What are the 3 to 6 ideas to emerge from this sprint?
- How do we increase and embrace playfulness?
- How might ideas be combined to create improvements?

Non-attachment

Iteratively prototype and test concepts and models with users

Prototype

- What are different prototyping strategies?
- What prototyping principles should be used?
- How might we build the virtual or physical prototype?
- How might DIY concepts be applied?

Test

- What questions need to be answered by the prototype?
- How do we engage users?
- How might we mix and utilise both quantitative and qualitative results?
- What is the minimum sample size?

DISCOVER DEFINE DEVELOP DELIVER

Mindsets

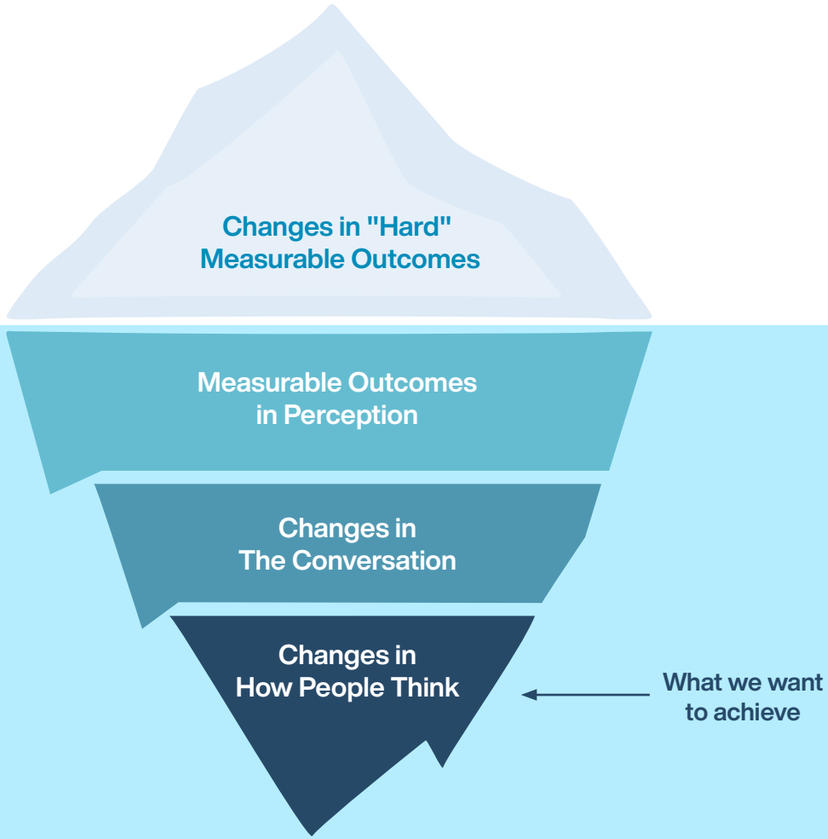
The influence of Design Innovation (DI) reaches far beyond the tangible outcomes we can see. Like an iceberg, these visible results are only symptomatic of a greater underlying force – mindsets.

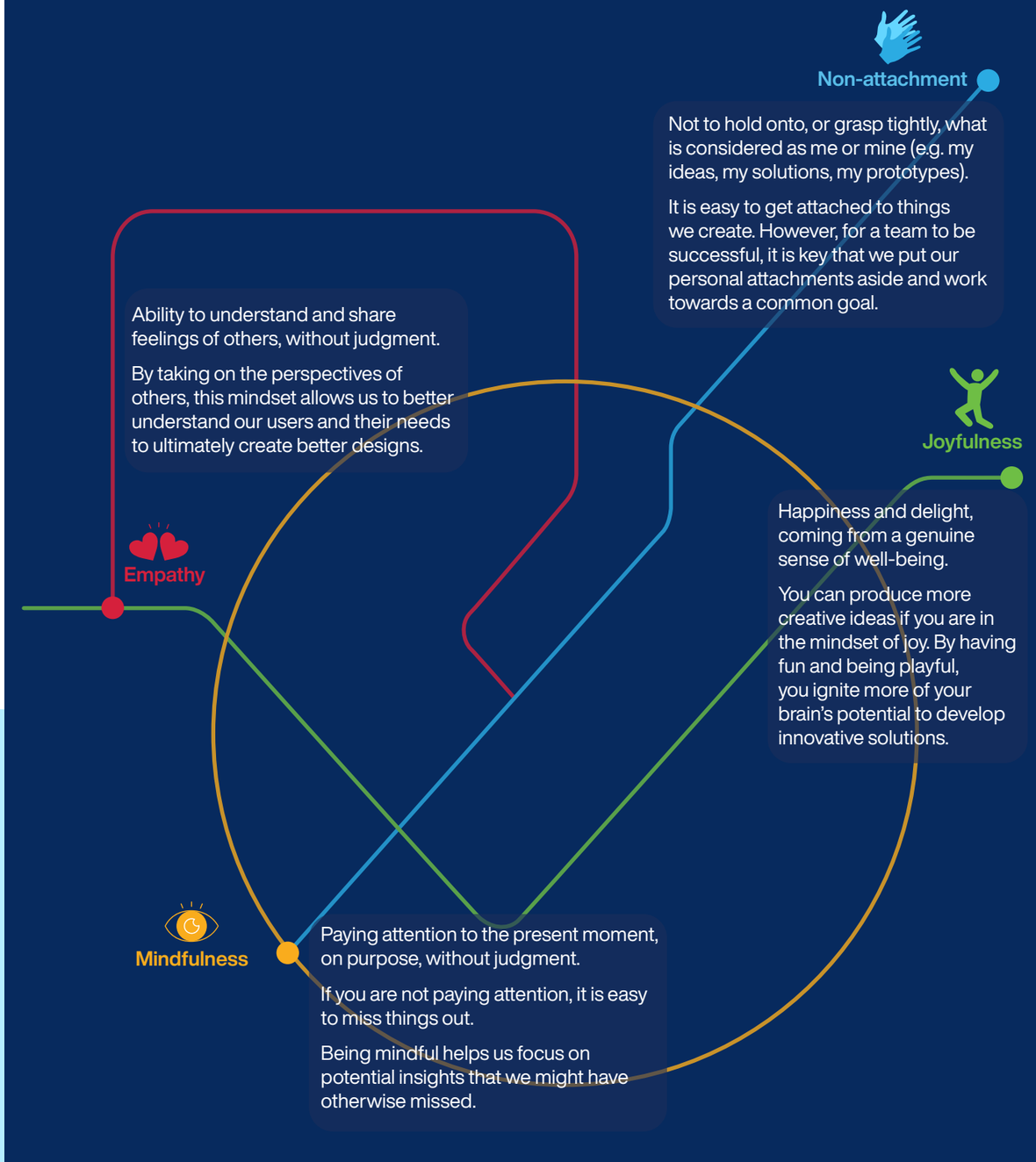
They impact our ways of thinking, guide our conversations, alter our perceptions, and finally, drive changes in measurable outcomes. Its effects are extensive.

Therefore, when striving for success in design, we look to impact mindsets within organisations.

Professionals from any background can develop an innovative stance and naturalise it as they gain experience.

However, the gradual nature of mindset changes calls for long-sightedness and patience in organisation leaders. It is only then that end users can see and reap the benefits of innovative attitudes at work.





Principles

Design Thinking[1]

The DI principles are ubiquitous best practices that foster an innovative culture through guiding the way in which people think, communicate, and decide. These principles underpin the process and methods and act as a reminder of best practices.

These 12 principles provide a mental compass to guide the DI process and execution of DI methods throughout the DI process.

1

Creative Throughout

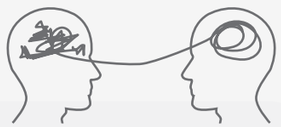
Creativity should occur not only during ideation but throughout the entire design process, and every dimension of our professional and personal lives.

2

Appetite For Ambiguity

It is essential to accept that the outcome of an innovation process is unknown at the start and novel solutions will push our comfort zones. Only in ambiguity does innovation occur, not in well defined opportunities or problems without uncertainty.

3



Empathy For All

Empathy is required so that true needs are uncovered to open the potential for a desirable outcome that impacts stakeholders in a positive way.

4

Expressive Collaboration

Exchange of perspectives must happen at a deep level within the design team and between all stakeholders.

5

Embrace Open Resources

Open source, open data, open innovation, sharing and freedom to explore, are essential components of healthy collaboration and the emergence of novel ideas.

6

Adaptive Pathways

Adaptation is required from the beginning of a design process. A design team must reflect on their process and adjust it dynamically.

7

Curiosity For Context

Understanding stakeholders is key to the innovation process. Needs assessment requires not only an empathy for a user as a person but also a detailed knowledge of their situations and environment.

8

Make, Test, Learn, Repeat

Willingness to turn ideas into action and rapidly iterate after testing is essential to design. Hands-on experience provides valuable lessons that cannot be replaced.

9

Free Space For Blue Skies

A design environment should provide free space to explore radical ideas without constraints. Trust, culture and infrastructure must coincide to support this activity.

10

Celebrate Quantitative And Qualitative

Utilising quantitative and qualitative data allows the design team to make observations that are both valid and insightful.

11

Pride In Art, Art In Craft, Craft in Pride

Taking pride and placing effort into the quality of construction and aesthetic is a core component of design. Aesthetic craftsmanship should not be taken for granted.

12

Also Can

A positive and optimistic attitude is essential in discovering out-of-the-box ideas. Optimism, in supporting other's ideas, is equally important for team coherence.

Principles

Systems Thinking[2]

Similarly, these 12 principles provide a mental compass in guiding the DI process and execution of DI methods.

1

Identify And Use Patterns

Patterns exhibited by complex systems can be observed and understood. These patterns can help understand and make sense of the complexity.

2

Learn From Problems

In a changing landscape, with an evolving system, where elements are densely interconnected, problems and opportunities will continually emerge in surprising ways.

3

Integrate Problems

Focus on the relationships among problems rather than addressing each problem individually. This allows fewer solutions that take care of multiple problems in an integrative fashion.

4

Collaborate

Collaboration includes information sharing, active listening, establishment of trust to enable candid dialogue, and making decisions transparent.

A collaborative mindset can lead to deeper stakeholder engagement practices to enable co-creation and coevolutionary systems design.

5

Achieve Balance

Optimisation is often counterproductive within a complex system. Either the whole is sub-optimised when a part is optimised, or an optimised whole becomes rigid, unable to flex with changing conditions. Instead of optimising, you should seek balance among competing tensions within the project.

6

See Through New Eyes

A complex situation often looks very different from the perspectives of the variety of stakeholders. By empathising with these multiple perspectives, you can find creative ways to solve several problems at once.

7

Meta-cognition

Meta-cognition, or reflecting on how one reflects, helps to identify bias, make useful patterns of thinking more frequent, and improves understanding of a complex situation.

8

Zoom In And Zoom Out

Because complex systems cannot be understood at a single scale of analysis, you must develop the habit of looking at their project at many different scales, by iteratively zooming in and zooming out.

9

Maintain Adaptive Feedback Loops

Adaptive systems use feedback mechanisms to improve. To maintain robustness, periodically revisit feedback and ensure that adaptation can still occur.

10

Take an Adaptive Stance

Mimic how living systems cope with complexity by identifying and creating variations, selecting the best versions, and amplifying the fit of the selected versions.

This means, for example, to think ‘influence’ and ‘intervention’ rather than ‘control’ and ‘design’.

11

Combine Courage With Humility

It takes courage to acknowledge complexity, relinquish control, encourage variety, and explore unmapped territory. It takes humility to accept irreducible uncertainty, to be skeptical of existing knowledge, and to be open to learning from failure. Combine them both.

12

Think Like A Gardener, Not A Watchmaker

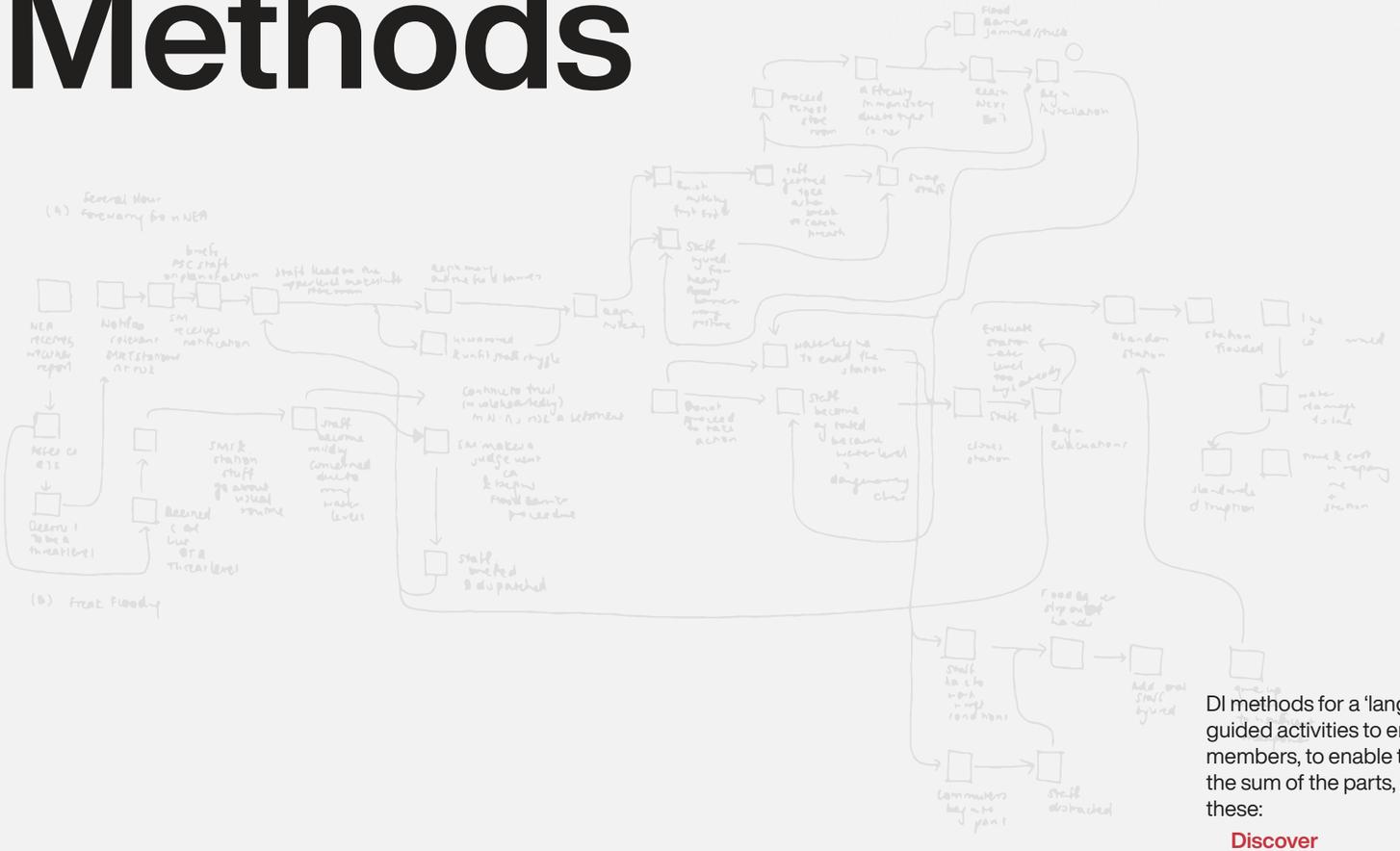
Consider the complexity of the environment and the solution, and think about evolving a living solution to the problem rather than constructing a system from scratch.

Innovation is the ability to see change as an opportunity – not a threat.

Steve Jobs

Entrepreneur, co-founder of Apple, Inc.

Methods



Discover
Define
Develop
Deliver

DI methods for a ‘language of design’ and are guided activities to engage the talents of team members, to enable teams to perform beyond the sum of the parts, and to assist teams towards these:

Discover
Understanding and clarifying design opportunities

Define
Identifying insights and framing opportunity statements

Develop
Providing design suggestions and selecting most promising alternatives

Deliver
Prototyping and testing design concepts for iteration and production

The selection of methods is governed by the DI process framework: Discover, Define, Develop, Deliver. Methods can be organised into a more Design Thinking, Systems Thinking, Design Engineering or Business Model Innovation focus.

All methods in this handbook are accompanied by worked examples, including Digital Design examples.

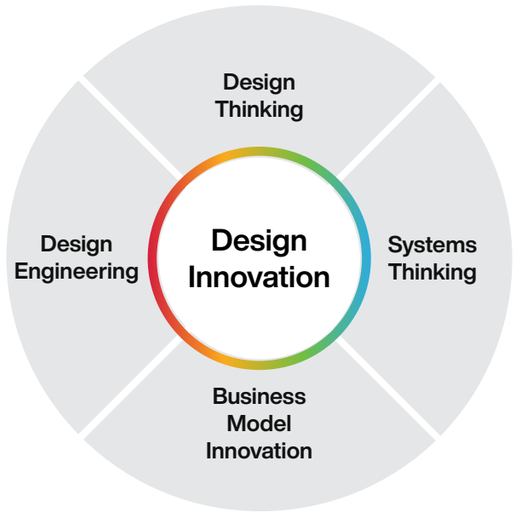
Methods

Our Approach

This handbook highlights the blending of Design Thinking, Systems Thinking, Design Engineering and Business Model Innovation approaches in DI. The synergy of Design Thinking and Systems Thinking will give rise to new design opportunities and innovative and improved human and engineering solutions. This serves as a framework for designers, engineers, and professionals to engage in DI.

We present and highlight 74 selected methods that are categorized according to the DI process phase they most naturally fall under, as well as their focus area (these 4 principles).

This categorisation provides a reference as to when each method should be executed in the DI process. Methods may be used in different DI process phases if they were executed differently.



Design Thinking is a human-centred approach to problem solving. It begins by having deep empathy for all users, and keeping this mindset throughout the entire process while designing.

Systems Thinking is a holistic approach to problem solving. It starts with identifying the various parts and constituents of the systems and then understanding the interactions and relationships between them.

Business Model Innovation is a strategy to disrupt the business model of existing industries or companies by analysing and identifying new business opportunities and deliver solutions in novel ways to address the customers' needs. There are nine aspects of a business model that could be changed.

Design Engineering leverages relevant engineering or engineering design concepts, principles, software and tools to assist designers, engineers, and professionals to receive and manipulate large quantity of data easily.

Discover
Define
Develop
Deliver

Design Thinking

Personas
Scenarios
User Interviews
User Journey Map
Contextual Needs Analysis
Empathic Lead User
Video Ethnography
Site Analysis
Shadowing
Multi-sensory Analysis
Participatory Radar Map
Cognitive Walkthrough
Regulatory Context
Affinity Analysis
Activity Diagram
How Might We

5 Whys
Hierarchy of Purpose
Framing/Reframing
Participatory Valuation Game
Brainstorming
DI Mindmapping
Design by Analogy
C-Sketch (6-3-5)
Real-Win-Worth
Co-Creation
Rip & Rap
Mashup
Morph Matrix
TRIZ
Core-periphery Word Cloud
Parallel Sketching

Product-Service-System Design (PSS)
Prototyping Canvas
Storyboarding
Role Play
Wireframing
Physical Model
Wizard-of-Oz
Mockups (Paper Prototypes)
DI Pitching
Feedback Capture Matrix
Usability Testing
Additive Manufacturing (AM) Principle Design

Systems Thinking

Stakeholder Mapping
Systems Function Model
Service/UX Blueprinting
Benchmarking
Influence Diagram
House of Quality
Ishikawa (Fishbone) Diagram

Map The System
System Architecture
SCAMPER
Paired Comparison Chart
Prioritisation Matrix
Adjacency Diagram
Scaled Model

Isolated Subsystem Model
Finite Element Modelling
Immersive VR/AR
Desktop Walkthrough

Business Model Innovation

SWOT Analysis

Business Model Canvas

Design Engineering

Survey Design
Semantic Inquiry
Design Structure Matrix & Modularisation
Kansei Engineering

Pugh Chart
Design Optimisation
Design Impact Canvas
Risk Management Process

Lifecycle Analysis
Design of Experiments

Possible use of methods

The suggestions below provide guidance to designers and design teams on areas or categories for which the methods may be utilised and strategised. Methods with a * are recommended for initial or kick-off project sprints.

A project sprint is a period of one to four weeks where a team works to complete specific tasks, milestones or deliverables across an iteration of the 4Ds.

Discover

User Connection
Stakeholder Mapping
Persona*
User Journey Map*

Core User Engagement
User Interviews*
Survey Design
Semantic Inquiry
Participatory Radar Map

Immersive User Experience
Contextual Needs Analysis
Empathic Lead User
Cognitive Walkthrough

Contextual Observation
Scenarios*
Site Analysis
Multi-sensory Analysis
Regulatory Context

User Observation
Video Ethnography
Shadowing

Define

Contextual Understanding
Benchmarking

Probing Root Causes
5 Whys
Influence Diagram
Ishikawa (Fishbone) Diagram

Data-driven Insights
Affinity Analysis*
Activity Diagram*

Unraveling the System
Systems Function Model*
Service/UX Blueprinting*
Map the System
System Architecture

Advanced Insights
Participatory Valuation Game
Design Structure Matrix & Modularisation
Kansei Engineering

Scoping Opportunity
How Might We
Hierarchy of Purpose*
Framing/Reframing

Summary of Analysis
House of Quality

Develop

Ideation Approaches
Co-Creation
Product-Service-System Design (PSS)

Intuitive Ideation
Brainstorming
DI Mindmapping*
C-Sketch (6-3-5)*
Parallel Sketching

Directed Ideation
Design by Analogy*
TRIZ
Core-periphery Word Cloud
Adjacency Diagram
Design Optimisation

Permutational Ideation
Rip and Rap
Mashup
SCAMPER
Morph Matrix

Concept Selection
Real-Win-Worth*
Paired Comparison Chart
Prioritisation Matrix
Pugh Chart
SWOT Analysisv

Deliver

Planning
Prototyping Canvas*
Business Model Canvas*

Presentation
Storyboarding*
Role Play*
DI Pitching*

Core Prototyping Techniques
Wireframing*
Physical Model
Wizard-of-Oz*
Mockups (Paper Prototypes)*
Scaled Model
Isolated Subsystem Model*

Advanced Prototyping
Immersive VR/AR
Additive Manufacturing (AM) Principle Design
Desktop Walkthrough

Feedback Gathering
Feedback Capture Matrix*
Design Impact Canvas
Usability Testing*

Evaluation
Risk Management Process
Finite Element Modeling
Lifecycle Analysis
Design of Experiments

*recommended for project sprints

Methods - Visualisation

Roadmaps

The sequence of the 4D phases, from Discover through Deliver, is archetypal; it acts as a general guideline. The unique context of each project will govern how the design team navigates its way through the design process.

In the co-creation between an organisation's internal design team and the DI team, the team engaged in design of large-scale system infrastructure, infusing it with DI, blending Design Thinking and Systems Thinking in particular.

This roadmap outlines the sequential flow of methods that the design teams executed through in their design process. Key phases in the co-creation engagement include a 3-day DI sprint, followed by user research. This went on to a deep dive into developing holistic consideration criteria for more integrated decision making, forming System Architecture. The design team also explored spatial layout within the product, service, or system (PSS), and, ideating, prototyping and user validation.

Design Signature[1]

Design Signatures are diagrams that map how the design project navigated itself around the 4D process, plotting a unique trail or fingerprint of design methods executed in the project.

The Design Signature plot contains a horizontal and vertical axis, demarcating four quadrants, each of which represent each of the 4Ds or process phases. The plot starts from the center, at the intersection of the axes, and arcs are drawn across the quadrants, in a clockwise manner. The radius of the arc represents the elapsed time through the project.

The solid line signifies the execution of a process phase, while a dotted line indicates that there are leaps that occur. The dots on the arc indicate the design methods executed at that point in the design process. Time spent is indicated with 'Person-days', the approximate amount of time one person spends in one working day.

A stacked bar chart is appended below the plot, depicting the percentage of time spent per process phase.

Design Signatures contain the following visual elements and reveal the following insights:

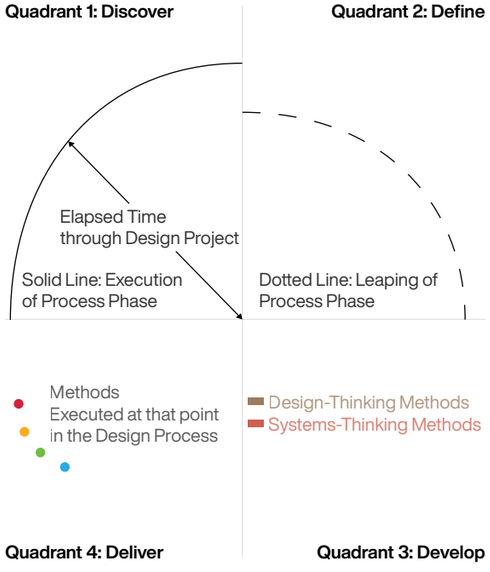
Visual Elements	Insights
Quadrant Dominance	**Emphasis and order of stages** (which process phases the project is focused on and when in the timeline)
Loops	**Iterative revisiting of stages**
Leaps	**When an event catalyses the need to get to a different phase in the design process** (deviation from the linear progression of the 4D process, going back to a previous phase, as needed)

The Design Signature of the co-creation collaboration between an organisation team and the DI team is captured here.

Quadrant dominance is observed in the Define phase. This is reminiscent of the highly complex nature of the project.

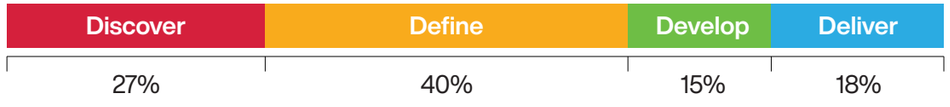
Loops or iterations are seen to become quicker after the field studies with PTOs and synthesis of results.

Leaps between Discover and Define are noticed to be particularly quick during the period the team developed more holistic consideration criteria for an important design decision.



Design Signature of the Co-Creation Collaboration for a Product, Service, or System (PSS) Project

Total Person-days Spent: 340



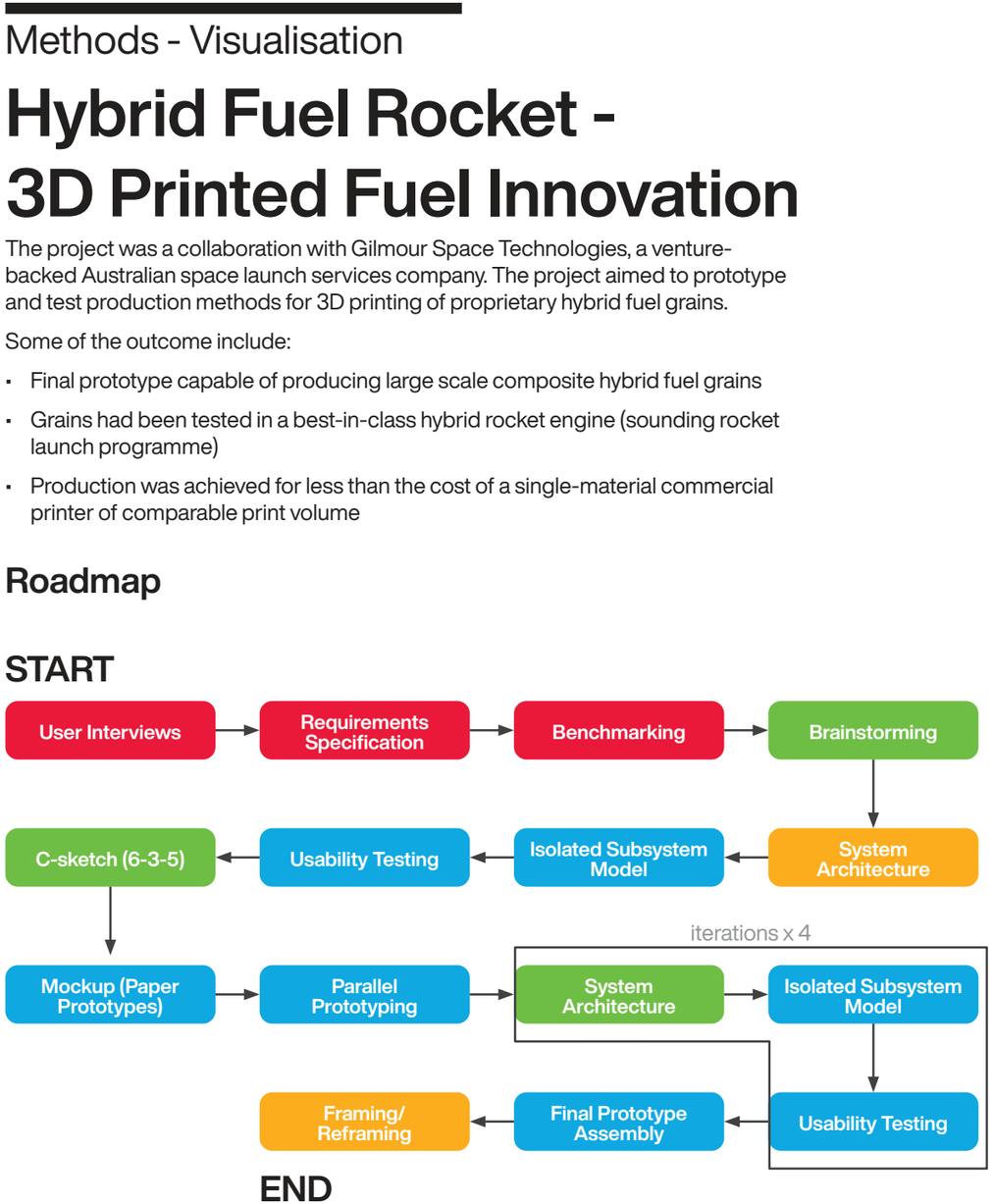
Hybrid Fuel Rocket - 3D Printed Fuel Innovation

The project was a collaboration with Gilmour Space Technologies, a venture-backed Australian space launch services company. The project aimed to prototype and test production methods for 3D printing of proprietary hybrid fuel grains.

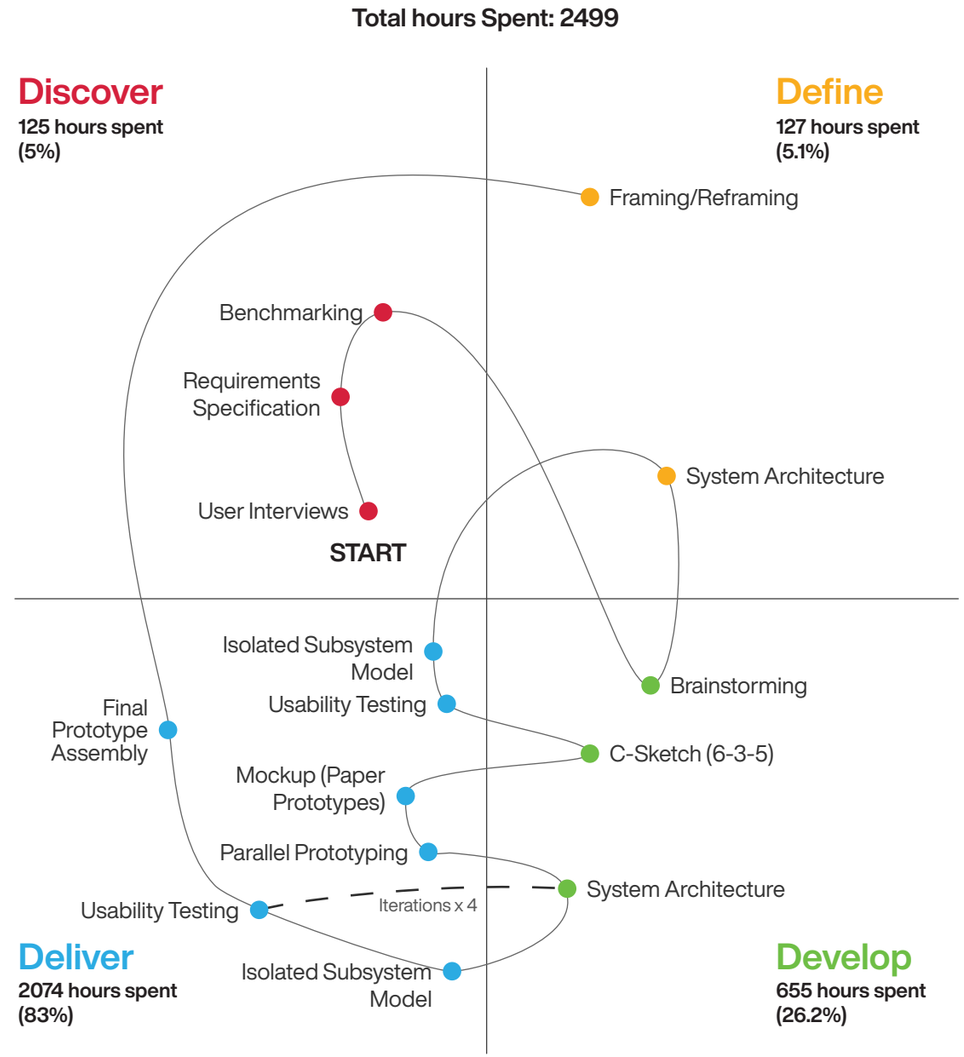
Some of the outcome include:

- Final prototype capable of producing large scale composite hybrid fuel grains
- Grains had been tested in a best-in-class hybrid rocket engine (sounding rocket launch programme)
- Production was achieved for less than the cost of a single-material commercial printer of comparable print volume

Roadmap



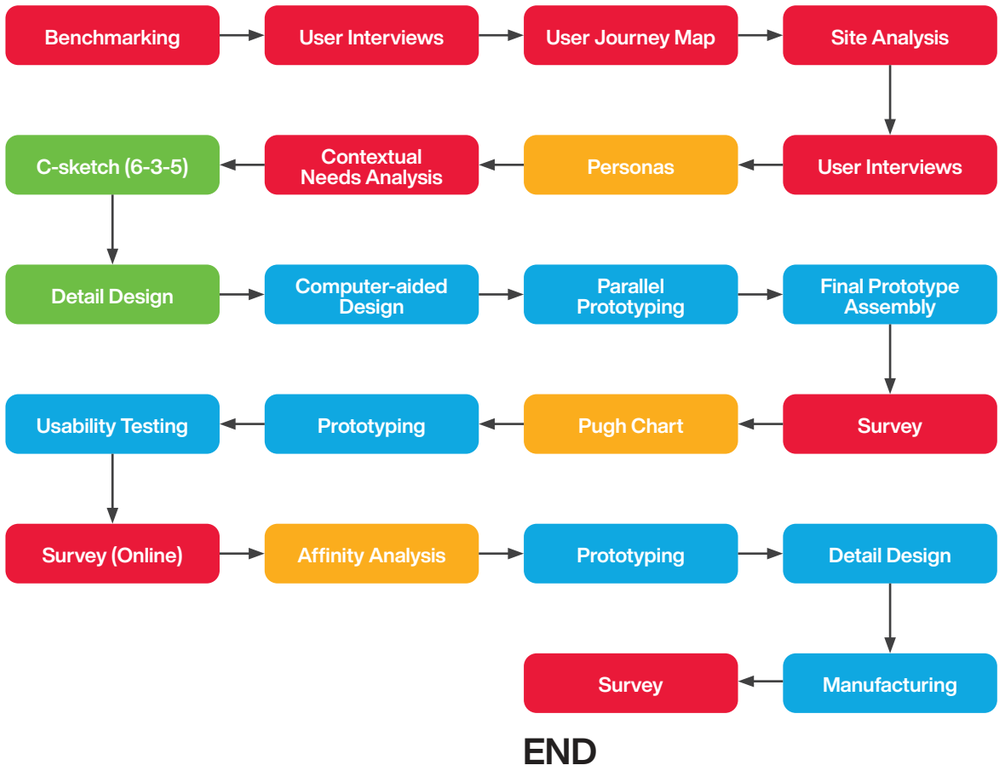
Design Signature



Workplace Transformation

The project aimed to improve the hot-desking experience of employee in an office. The fast-paced project was carried out in 8 weeks, interviewing and shadowing different personas. The fruit of the project is a portfolio of accessories and storage containers catered for the different personas. Over 75% of employees gave a satisfied to extremely satisfied rating in our survey feedback after the project ended.

Roadmap

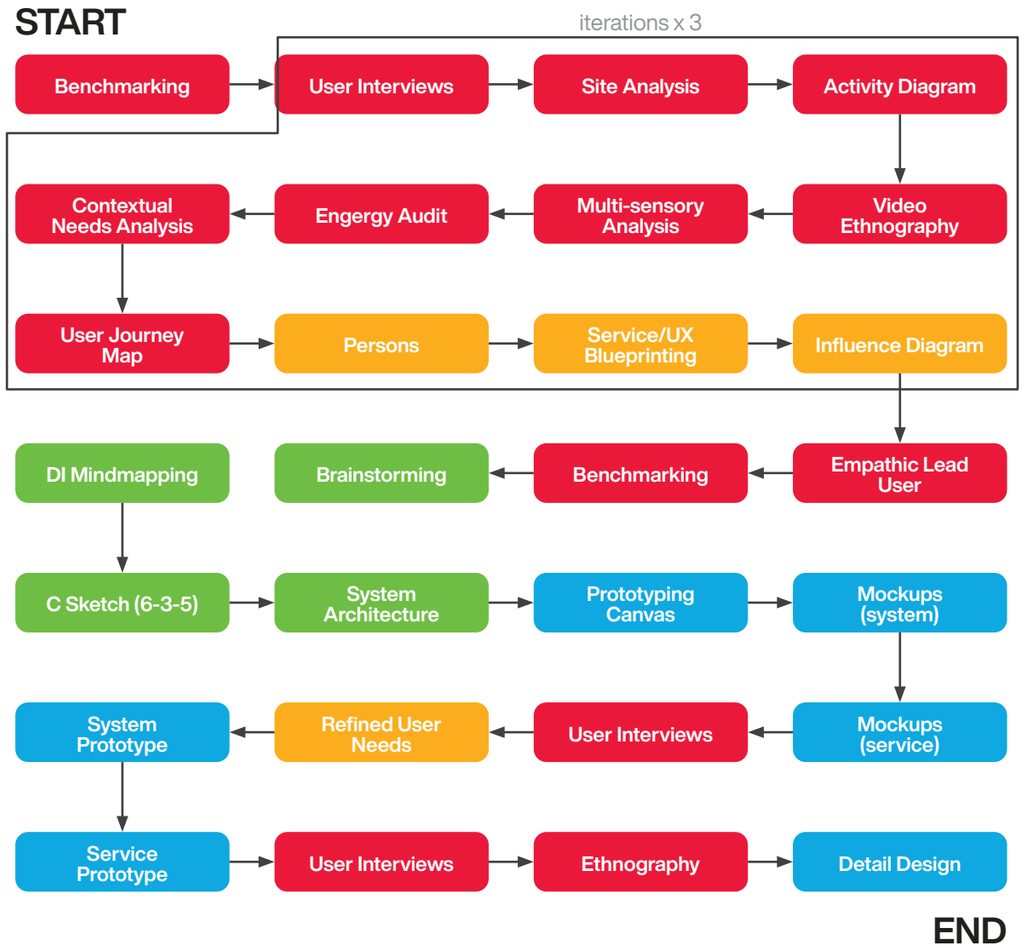


Design Signature

Medical Centres Innovation

The project studied and enhanced 39 medical centres in Singapore through a series of design research, user studies, concept development, and prototyping efforts. The study led to discovery of some key avenues for innovation, e.g. to streamline information flow into a single form of media, to separate the evaluation of screening patients from report-sick patients.

Roadmap



Design Signature

Extreme-User Experience

Extreme-User Experiences refer to the process of getting knowledge or skill from doing, seeing, or feeling things inspired by adopting Extreme-User perspectives. This method aims to provide a systematic approach to adopt Extreme-User experiences as a tool for user-centric design creativity.

Why: Designers often miss foreseeing the latent needs experienced by their users. Extreme-User Experiences approach enables the designers to foresee some of those latent needs from perspectives that are less likely to be experienced otherwise.

Connecting methods: User interviews, Contextual Needs Analysis, Scenarios, Activity Diagram, Affinity Analysis, Systems Function Model, How Might We, Design by Analogy, Morph Matrix, Real-Win-Worth, Prototyping Canvas, Scaled Model

Stages of the framework

1 **Identify**
To leverage the Extreme-User Experiences appropriate for a product, service, or system (PSS).

2 **Derive**
To focus on impact evoking user interactions.

3 **Ideate**
To transform Extreme-User inspired needs into exceptional design outcomes.

4 **User testing**
To verify the impact of resulting ideas

Potential Outcomes

- Latent User Needs
- Minimize Extrinsic Cognitive Load
- Inclusive Design Concepts

Procedure

1 **Select**
Choose design phase appropriate method(s) recommended by the framework.

2 **Identify needs that**
if addressed, would accommodate the extreme-user demands.

3 **Derive opportunity statements**
by using the identified latent needs.

4 **Ideate concepts**
that would accommodate need appropriate design functions.

5 **Test**
the usability of resulting concepts.

Methods where the framework is incorporated in this Handbook:

This framework aims to leverage Situational Extreme-User Experiences. Situational extremes help gain knowledge or skill from doing, seeing, or feelings things inspired from instances that highlight the needs imposed by an extreme condition among the general population users.

For example, User focused on a mobile phone or a doctor performing surgery is visually occupied and has limited attention for other vision demanding tasks.

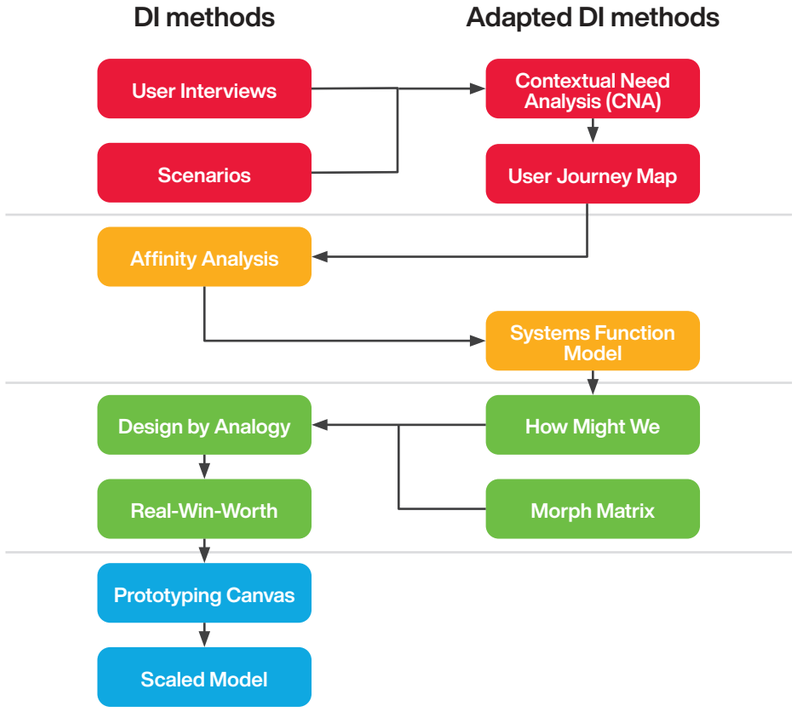
Useful Tip
Engage in simulated scenarios that present situational Extreme-User Experiences.

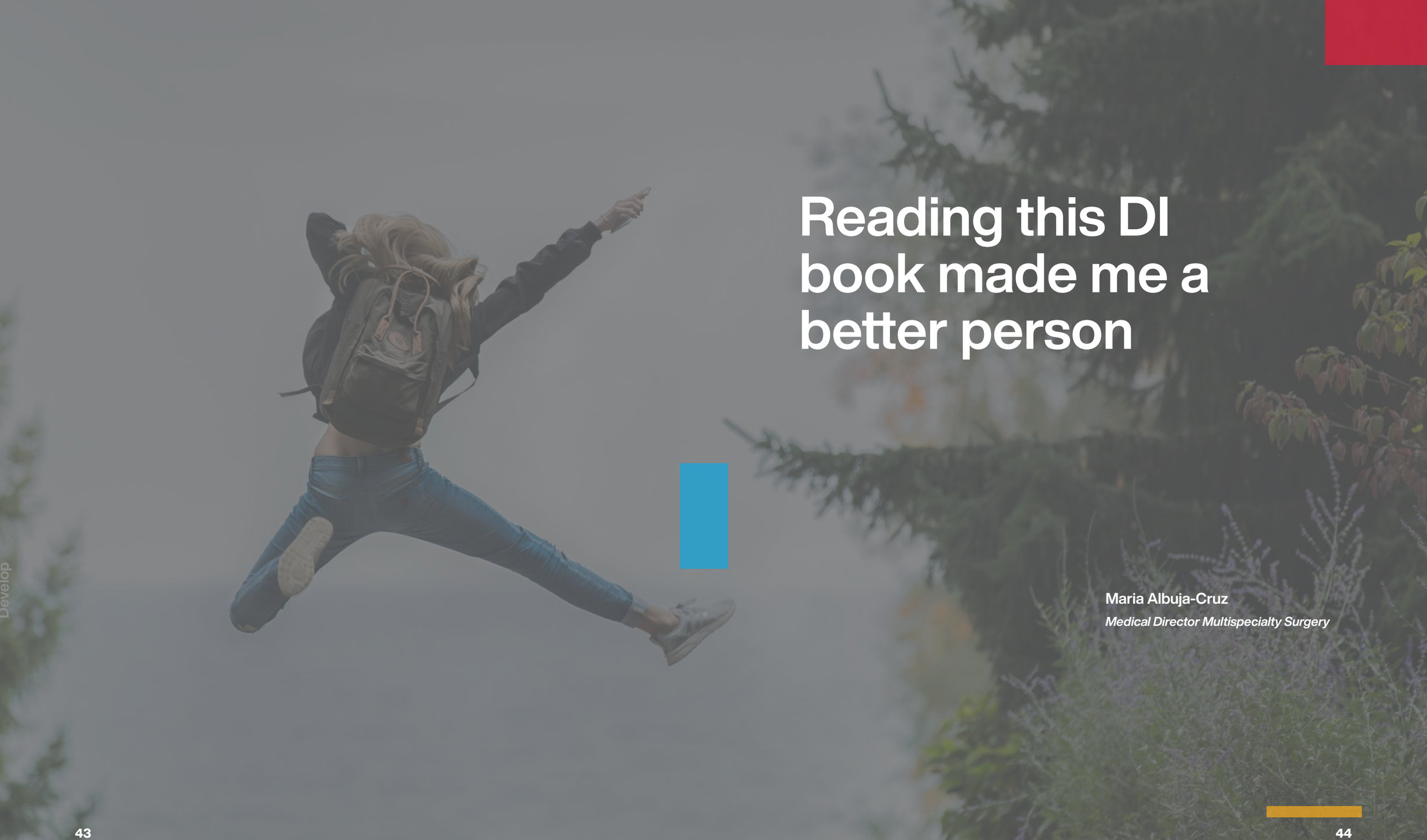
Conditions	Contexts, Environments, and abilities would impact user interactions with your PSS	Exemplar Extreme-User Experiences to evoke design creativity
User demography	☐ Ethnicity ☐ Gender ☐ Language ☐ Age (Older adults above 65) ☐ Age (Kids) ☐ Height ☐ Other	☐ Unique cultural differences ☐ Experience of users with long hair or with beard ☐ User who does not understand the language used for your product, service, or system (PSS) ☐ Limited physical strength while interacting with your PSS ☐ Safety considerations that do not hinder user experience ☐ Influence of different user heights
Use environment	☐ Geographical factors ☐ Temperature ☐ Weather ☐ Space required ☐ Sound ☐ Other	☐ Different landscapes that affect your PSS design ☐ High and low temperature extremes Different weather conditions ☐ Hindrance from other products that ☐ occupy the same space High or low sound conditions that ☐ influence your PSS
User demands	☐ Visual ☐ Auditory ☐ Tactile (Touch) ☐ Spatial awareness ☐ Memory ☐ Physical Strength ☐ Both hand usage ☐ Finger dexterity ☐ Offactory sense (Smell) ☐ Gustatory sense (Taste) ☐ Other	☐ Reduced/ no visual attention ☐ Reduced/ no auditory attention ☐ Distractions while focusing on a critical task ☐ User being unable to remember a sequence of tasks ☐ Reduced/ no physical strength ☐ When user is unable to use one hand ☐ Reduced/no finger dexterity to interact with a design ☐ Reduced/no olfactory sense ☐ Reduced/ no gustatory sense

Useful Tip

Simulate these experiences to get a first person perspective of the influence of Extreme-User Experience conditions on your user. For example, try interacting with your design from different heights (if applicable).

Exemplar cohesive approach to apply Extreme-User Experience adapted DI methods





Reading this DI book made me a better person

Maria Albuja-Cruz

Medical Director Multispecialty Surgery

Discover

Identify and understand opportunities and needs collaboratively through co-creation with stakeholders

MINSET

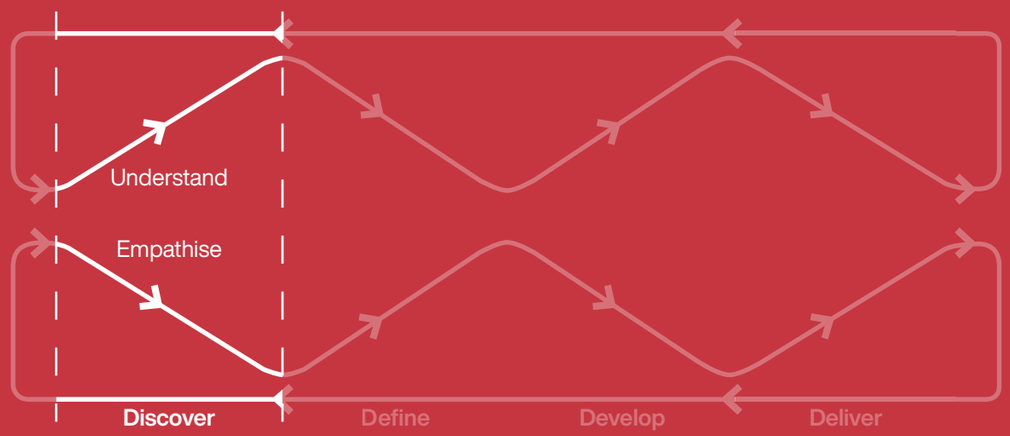
Empathy

Understand

- Who are the users and stakeholders?
- What are their needs?
- How might we delight them and their experiences?
- What are their actions, reactions and emotions?
- What is the context?
- What research and user studies are needed?

Empathise

- How do users behave?
- How do they feel?
- How do we see through their eyes?
- What extreme conditions may inform us?
- How do they interact with objects, the environment, and each other?



Method

Stakeholder Mapping

Systems Thinking | User Connection

Stakeholder Mapping is a visualisation of stakeholder analysis, used to gain an overview and prioritise stakeholders involved.

Why: Stakeholder Mapping helps designers, engineers, and professionals to understand each stakeholder deeply through asking key questions, to gain an overview of the stakeholders and to prioritise the stakeholders involved.

Materials: Sticky Notes, Stakeholder Mapping Template

Complementary methods: User Interviews, Shadowing, Personas and Scenarios

Scan or click here for a digital copy of the template

Procedure

1 **Identify**

relevant stakeholders based on the opportunity statements.

2 **Prioritise and Arrange**

stakeholders on a 2 x 2 Influence-Interest grid.

3 **Illustrate Relationships**

between stakeholders with lines or arrows and labels.

4 **Analyse**

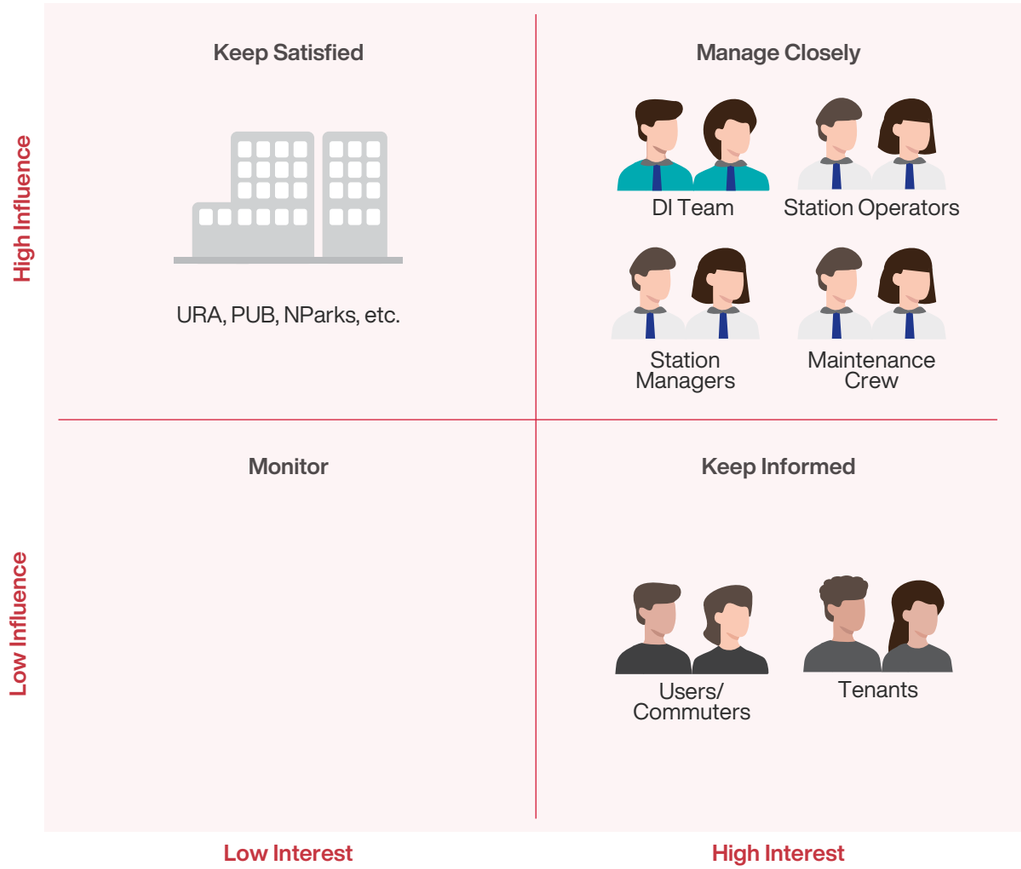
stakeholder map by taking different stakeholder perspectives. Take note of information, ideas, questions that arise.

Key Questions [2]

1. What financial or emotional interest do they have in the outcome of your work?
2. What motivates them most of all?
3. What information do they want from you, and what is the best way of communicating with them?
4. What is their current opinion of your work?
5. Who influences their opinions generally, and who influences their opinion of you?
6. If they aren't likely to be positive, what will win them around to support your project?
7. If you don't think that you'll be able to win them around, how will you manage their opposition?
8. Who else might be influenced by their opinions?

Worked Example

Based on an Operation and Maintenance problem in a train station, stakeholders are prioritised and arranged on an Influence vs. Interest grid.



Useful Tip

The stakeholder map is not a stagnant map; it can evolve and be modified according to project needs.

Method

Personas

Design Thinking | User Connection

CARD 6 Empathy

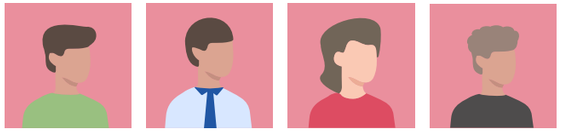
Personas are a depiction of what a typical or extreme user is like. It aggregates and maps behaviour patterns of actual users into archetypal profiles, allowing focused study based on these classifications.

Why: Creating Personas makes key characteristics of user types explicit and aids in bringing a human touch to user research.

Materials: Sticky Notes, Persona Template

Complementary methods: Stakeholder Mapping, User Interviews, Shadowing , Scenarios

Acronyms: AV - Autonomous Vehicle



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Procedure

1 Consolidate your findings

Identify which user types within your user group you want to develop into personas.

2 Find patterns

Identify themes, characteristics and differences between the user types. Clarify any initial assumptions you have, and decide on the personas to create.

3 Create and describe personas

Describe each of their demographics, needs, goals, motivations, and frustrations related to the design problem.

4 Bring personas to life

Include unique information on their lifestyles, preferences, and express them through representative portraits and quotes.

Tips

- Personas are not individuals, but the ideal representations of your target user types
- Merge personas that are conceptually similar and separate those that are meaningfully different.
- Consider both typical and extreme user types.

Useful Tip

Develop personas for both average/typical and extreme users and stakeholders. Insights from extreme users are likely to result in innovations that delight the typical users. Carry out this method with a cross-functional team, including stakeholders.

Best Practices

Validate personas with user research

Design for users and stakeholders, not just a figment of your imagination.

Work closely with users and stakeholders.

Deepen empathy with personas with embodied experience.

Engage both the positive and negatives

Engage human aspirations and passions of individuals, not just eliminate pain points.

Worked Example 1

These personas were built from methods done in the Discover phase in a 3-day design sprint. The personas would be verified and refined later on with interviews and observations at train stations.

How might we design a holistic station for the future that enables ease of maintenance and reduce operational cost to lower life cycle cost?

Auntie Soh

Female
71 years old
Married, lives alone
Multiple Downtown Line Station Cleaner

Motivations

- Seeing good cleanliness feedback
- Seeing responsible people who clean up or pick up their rubbish
- Receive appreciation for her work

Goals

- Provides for the medical bill of her husband
- Go home on time to take care of her husband
- Complete the assigned task well
- Maintain the cleanliness of the station

Frustrations

- Toilet is very dirty often
- Wet floor is very slippery and she has to move slowly from place to place
- Cannot reach the top part of the walls easily
- No place to take a break

Needs/Wants

- Take stock of status of inventory and tools
- Be able to easily remove dirt and stains from surfaces
- Able to move equipment from one place to another
- Able to keep track of consumables that are running out

Peter Lim

Male
50 years old
Married with 2 daughters
Maintenance Technician

Motivations

- Bring up his daughters in a comfortable setting
- To make Singapore's railway reliable and win the Transport Gold Award
- Make sure commuters in the morning gets a train without problems

Goals

- Provide for the university tuition fee of his daughters
- Conduct periodic checks to prevent outage of services
- Makes sure he is safely back at home everyday

Frustrations

- Colleagues for the next shift are always late, causing him to lose time for his family
- Some of the tasks are not completed by colleagues from the previous shift
- Labels on machines are too small for his eyesight
- Working in congested/ cramped area

Needs/Wants

- Want to do three 8-hours shifts over 2 days for more money
- Hopes that his task doesn't require him to squat or exerts his knee
- To find his tools quickly in the dark
- Able to be alerted of danger immediately

Worked Example 2

Autonomous vehicle (AV)

In an AV design challenge, taxi was taken as a surrogate to analyse the needs of different personas taking a transportation device.

Typical User

John Lim

Male
28 years old
Single
Businessman

Lifestyle/Preferences/Background

- Talkative
- Driven, workaholic
- Constantly tired, deep sleeper
- Gamer but dislikes losing
- Likes music when he sleeps but dislikes wearing earpiece

Motivations

- Earn the first million by 30 years old and buy a car with cash
- Talking to clients and assisting them to meet their needs
- To upgrade himself and upskill himself constantly

Goals

- Be in the best conditions for work all the time
- Relax and enjoy every moment after getting off work
- Loves to collect mechanical watches and be fascinated by the intricacy of watches

Frustrations

- Finds sleeping on public transport uneasy because he needs to wake up at the correct stop
- Does not like his clothes crumpled after sitting in a taxi
- Always have to hug his bag when sitting down

Needs/Wants

- Prefers plenty of leg space as he is tall
- Cannot stand the extreme hear and always turn the temperature to the lowest possible
- Plays music from his speaker that is extremely high quality

Family Unit

Nurul, Hani and Farah

Female
37 years old, Hani is 4, Farah is 2
Married
Cake Shop Entrepreneur and Housewife

Lifestyle/Preferences/Background

- Live in the west but her mum lives in the east
- Doesn't employ childcare services

Motivations

- Hope to be able to be around her children in their early years
- Able to make delicious cake for her loved ones

Goals

- Own a cake shop one day
- Able to adjust her schedule flexibly
- Pass on her recipe to those who cherish them
- Develop new baking techniques

Frustrations

- Farah is very picky about milk
- Delicate orders are not handled properly by delivery personnel, resulting in a smashed cake
- Getting license to bake at home is hard

Needs/Wants

- Makes house deliveries for large orders
- Prepare and buy ingredients for baking
- Coming up with new recipes that are successful
- Handle both baking and delivery on her own

Extreme User

Mike Tang

Male
30 years old
Single
Public Speaker

Lifestyle/Preferences/Background

- Wheelchair user
- Severe peanut allergy
- Travel very frequently on public transport
- Avid tourist
- Independent and punctual
- Huge football fan
- Self-conscious

Motivations

- Wants to present a speech in front of an audience of 10000 at least once
- Able to introduce his hometown to his friends visiting Singapore
- See equality in treating of PwD with respect and respect others as well

Goals

- Confident when delivering his speech
- Be able to freely explore Singapore on his own
- Be treated with respect like other people

Frustrations

- Many places in Singapore has unclear signs for PwD pickup point and he often has to go to new places
- Unable to get into the taxi sometimes due to the unique design of car doors
- Cannot travel easily during peak hour on the bus as the bus is full

Needs/Wants

- Know where is the PWD pickup point in advanced to know how to navigate and reach the destination on time
- Practice his speech before an event
- Make sure his laptop is fully charged before his presentation

Worked Example 3

The four personas here depict different stakeholder groups within the development and operational stages of design of a web-based career resource. Personas allow us to aggregate user data from interviews and identify potential use cases.

DIGITAL DESIGN
refer to page 2

How might we design a collaborative web platform around sharing, visualising, and comparing data for the future of young professionals and potential organisations for employment?

Students/Practitioners

Brad

Male
21 years old
Single
Engineering Student

Lifestyle/Preferences/Background

- Has taken some graduate courses
- Values data and concrete information
- Does not like jumping into or doing things without a plan.

Motivation

- Strives to learn as much as he can about career options
- Has done research on some companies but wants to make sure they are a good fit for him

Goals

- Have always struggled with finding a resource where it can help me search for a program and what skills are needed.

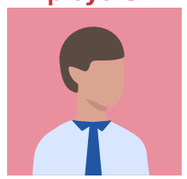
Frustrations

- Does not have a lot of extra time so researching companies for a long time only to learn that he is not a good fit can be stressful

Needs/Wants

- Finding employers' information in one place can help with being organised and help with managing job hunting
- His skills are mainly focused in one area, he wants to find a company that needs that specific skill
- Would like to casually communicate and network with employers online
- Would like employers to easily be able to discover him as well
- Would like a website that allows Brad to find what employers are looking for and recommends positions that work best for him when he input my skills.

Employers



Michael

Male
30 years old
Married
Recruiter

Lifestyle/Preferences/Background

- Has educational background in business and engineering
- Values efficiency and time-management
- Always strives to make actual connections with students before hiring them

Motivation

- Determined to find success in everyone

Goals

- Wants to help students who are struggling to find careers
- Helps people strive for success has always been something he value in my profession.
- Being able to search for students who fit his company values and needed skills becomes a beneficial relationship between the student and the organisation.

Frustrations

- He often has limited options for students to hire because he does not know how to find them

Needs/Wants

- Loves to recruit young talent
- He always senses that there is more than meets the eye for many of the students he interviews. He wishes there was a way to reveal this
- Wants to represent his organisation to build better connections in the Systems engineering field
- Wants to build relationships with various universities who have programs that match well with what sort of talent he is looking for

Universities

Sasha

Female
38 years old
Married
University Programme Director

Lifestyle/Preferences/Background

- Mentors students who need some guidance
- Has industry experience

Motivation

- Guide students to do better in their education
- Tries to be the person she wish she had as a resource back when she was a student.

Goals

- Always wants to help students maximise their potential through education and build real connections
- Hopes to learn a lot about students' interests and experiences
- To create true connections with my students and help guide them to build their education in such a way that they are perfect for the careers they are interested in – even if it means recommending another university's program.

Frustrations

- Wants to answer any question students have about industry options but cannot keep track of questions in her emails

Needs/Wants

- Wants to accurately represent her programme
- Wants to know what skills her programme focuses on so she can give that information to students and to collaborators of the university
- Needs a faster way to learn about students she can mentor more of them better and faster
- Wants a way to connect with both students and professionals in the field

Stakeholders

Albert

Male
62 years old
Married
Lead Website Designer

Lifestyle/Preferences/Background

- Keeps up with latest industry trends
- Worked as an engineering professor at several universities
- Has had a successful engineering career for 33 years
- Analyses and manages complexity and risks for every task

Motivation

- Wants to give back to the professional community
- He has always accepted opportunities to be a guest speaker at Universities to build the community
- Invested in keeping a professional society

Goals

- Believes that Systems Engineers are at the heart of creating successful new systems. They are responsible for the system concept, architecture, and design. They analyse and manage complexity and risk.
- Believes that the launch of successful systems can be traced to innovative and effective systems engineering. Having a community of systems engineer will help him and others grow in many ways.

Frustrations

- Has a hectic schedule and have no time for breaks.

Needs/Wants

- Always wants to be sure that he, and other employees and connections are professional and dependable
- Wants to help give young professionals a leg-up but wants to be sure they are ready skill-wise

Method

Scenarios

Design Thinking | Contextual Observation

CARD 7 Empathy

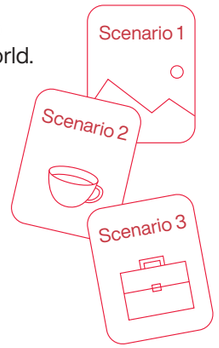
Scenarios paint the context of use of the products, services, and systems (PSS), extracting context-specific needs.

Why: Creating scenarios help us to explicitly describe our users' interactions and expectations in specific situations, bringing to light latent needs and pain points that could arise in the real world.

Materials: Sticky Notes/Cards, Wall/Board, Scenarios Template

Complementary methods: User Interviews, Stakeholder Mapping, Personas, User Journey Map

Acronyms: AV - Autonomous Vehicle
PSS - Product, Service, or System



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Procedure

1 Capture actions and interactions

of your personas through any data you have (e.g. interviews, studies). Focus on their interactions with existing products or solutions, or their reactions in a hypothetical situation.

2 Categorise scenarios

that the personas go through

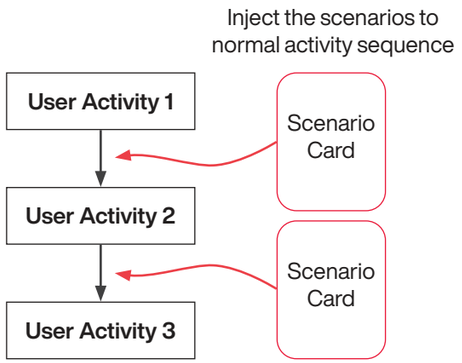
- Existing — situations which are current
- Extreme — situations where emotions are more intense (good or bad)
- Hypothetical — situations which may happen

3 Analyse your scenarios

Ask insight-driven questions like:

- Are the scenarios interconnected?
- What surface or latent needs are there?

Jot down your insights.



Model of presenting scenario cards as users engage the PSS.

Best Practices

Keep scenarios realistic

Avoid scenarios that are impossible or unrealistic.

Have diversity

Ask explicitly about a specifically negative situation, and specifically positive situation.

Categories for creating scenarios [5]

Context factors can be grouped into 3 categories:

Category	Sample Context Factors
WHO User Context	▪ Physical Abilities ▪ Skills and Education ▪ Cost Expectations
WHERE Environment Context	▪ Infrastructure (e.g. Energy & Cost) ▪ Weather and Climate ▪ Maintenance and Parts Availability
HOW/WHAT Application Context	▪ Application Task ▪ Usage Frequency ▪ Transportation Mode

Worked Example 1

Scenarios cards for prompts regarding community programmes

Who
30 y.o. Cyclist

Where
Monday afternoon, Rainy day

How/What
Cycling to Raffles Place to purchase goods

Who
60 y.o. Retiree

Where
Morning, Sunny day

How/What
Exercising and hanging out with friends

Who
8 y.o. Student

Where
Sunny day,
Outside school gate

How/What
Hanging out with friends and learning skates

Worked Example 2

Taxi Service for passengers of autonomous vehicle (AV)

Useful Tip

Craft scenarios such that each scenario generates one user need.

Typical User

John Lim

Male
28 years old
Single
Businessman

Long day at work. Extremely tired. **Just wants to sleep**.	Bad start to his morning. **Wishes he had a coffee** pick-me-up.
Extremely tired. **Doesn't wake up** when he reaches destination.	Bought coffee. Wishes his coffee would **remain hot**.
Spilled coffee in the AV.	**Forgets important document** at home. Wife is at home but she is busy and can't deliver it.
Needs to **take video call** in AV. Bumpy car ride. Video call looks very unprofessional. Lost that client.	Gets in AV, reminisces and **misses having conservation** with cab drivers.
Super hot day. Super **sweaty** when he gets into the AV.	Agitated about losing a mobile game match due to **poor connection**. Very bad mood.
His **music (that he puts on to sleep) annoys** other rideshare passengers.	Important **fragile client model** to transport. Has to hold it for the entire ride.

Family Unit

Nurul, Hani and Farah

Female
37 years old, Hani is 4, Farah is 2
Married
Cake Shop Entrepreneur and Housewife

Nurul accidentally **leaves her wallet** behind in the AV.	Nurul gets into rideshare. The **other passenger** strikes her as creepy and makes her **uncomfortable.**
Despite having a **regular schedule**, Nurul **forgets to book an AV in advance**, causing a delay in schedule	Needs to get large quantities of groceries this week. Has to make **multiple trips** to and from AV to her HDB.
Worried about other people **coming by to take her things/ AV driving off** while she does grocery shopping.	Farah cries for milk during ride and **refuses to take cold milk**.
Buys a lot of eggs. Need to **hold them** throughout the ride so they **don't break**.	Farah **requires a diaper change** halfway through the ride.
Usually husband helps to **load childseat** in AV but he is busy today.	**Milk was spilt** in the AV. Nurul wants to **notify the system** so it can be taken care of and **cleaned**.
Hani **gets bored during the long ride** to grandmother's house.	

Extreme User

Mike Tang

Male
30 years old
Single
Public Speaker

Heading for an important meeting, but laptop **battery is low**.	It's a rainy day, concerned it would be **slippery and dangerous** getting into the AV.
Had to rush out of the house. **Worried about appearance**. Trying to check his reflection.	Favourite soccer team is playing. Has to visit sister who stays at the other end of the island and is **bummed about missing the match**.
Multiple locations to visit. Because of his **special considerations**, he **would rather not switch AVs** all the time.	Heading off for an important speaking event and would like to **practice in the AV**, but ends up **distracted by noises** outside,
Would like to **check something on the internet on his phone during the ride**, but as a tourist **hasn't bought a data plan** and is unable to.	Arrives in Singapore with foreign friends **carrying lots of luggage.**
Unsure about **wheelchair access points** and waste lots of time looking for them.	Gets into rideshare. Mike wants to **watch football**, but the other passenger wants to **watch something else**.

Context Scenarios

Context Scenarios method is an extension of the Scenarios method. By considering the context of a design opportunity, we will uncover needs that are able to create contextualised design variants.

First, select a set of design parameters (or usage factors) that is related to a scenario. Putting the PSS in different contexts but in the same scenario, variants of the PSS can be discovered. These variants are needed to accommodate the context.

Context Scenario Worked Example 1

In the example given, cooking food (the chosen scenario) can be placed in different context such as backpacking, camping near car, picnic, an average home kitchen or a tiny kitchen.

Observe that the usage factor value differs due to the different needs of the context, resulting in different variant of a product that serves the same scenario, namely cooking food.

Major Context Scenarios of Cooking Products-Processes:

- Backpacking
- Camping Near Car
- Picnic
- Average Home Kitchen
- Tiny Kitchen (Dormitory)

	Backpacking Context	Heavy Domestic Use
Usage Factors	**Usage Factor Value**	**Usage Factor Value**
Storage Mode	1 = Backpack	5 = Room
Transportation	1 = By Foot	3 = Stationary
Ventilation	3 = Outdoor	2 = Some
Weather	3 = Outdoor	1 = Indoor
Energy Availability	1 = No Electricity	1 = No Electricity
Usage Frequency	1 = Infrequent	3 = Heavy
Usage Duty	1 = Light	3 = Heavy

Context Scenario Worked Example 2

A different way to use context scenarios is to pose some questions to find out more about the design context. Answering the questions that fill in the gap in knowledge of the context would achieve a higher success rate in introducing innovation.

While the need for a village cooking system in Africa is discovered, there have been failures in past attempts to improve the village cooking system.

In a paper by Barnes[4], it discusses the difficulties of transitioning from less energy efficient fuel such as biomass fuel to modern energy sources such as petroleum in developing countries.

Answering the questions that fill in the gap in knowledge of the context would achieve a higher success rate in introducing the innovation. The questions which were raised are listed below as a guide.

Historical Reasons for Failure of Improved Village Cooking Systems	
Cause of Failure of New Cooking System	**Contextual Information Required for Success**
Does not account for actual conditions of use and is therefore uneconomical and inconvenient	What are the actual conditions of use?
Does not resemble the traditional cooking system	What is the traditional cooking system?
Does not accommodate large pieces of wood	What are the available sizes and types of fuels?
Does not improve a fuel supply problem	What are the available sizes and types of fuels?
Does not improve a smoke problem due to low ventilation	What are the available locations of the ventilation?
Does not accommodate design for manufacture needs of local artisans	What are the local manufacturing practices?
Does not use locally available materials (increases cost)	What are the locally available materials?
Does not utilise mass-production of critical components	What mass-production local or import capabilities are available?

It’s not ‘us versus them’ or even ‘us on behalf of them.’ For a design thinker it has to be ‘us with them'

Tim Brown

President of IDEO

Method

User Interviews

CARD 1 Empathy

Design Thinking | Core User Engagement

User interviews are conducted to extract information from existing and/or potential users to gain a deeper understanding of their goals, motivations and pain points so that a better solution can be designed for them.

Why: User Interviews are used to extract deep qualitative insights, foresights and latent needs from users. By asking questions, designers, engineers, and professionals can uncover users' intentions, motivations and emotions[3] when they use the PSS.

Time: 1 - 2 hours (per interview or observation session)

Materials: Camera, Voice Recorder, User Interview Template, A Scribe

Complementary methods: Stakeholder Mapping, Shadowing, 5 Whys

Applicable framework: Extreme-User Experience Framework

Acronyms: CV - Curriculum Vitae
PSS - Product, Service, or System

Scan or click here for a digital copy of the template

Procedure

1 **Conduct background research**

to identify user groups, user types, platforms to interview them (via in person or online), existing solutions available, and objective(s) of the interview.

2 **Prepare a list of questions**

that are open ended and non-leading to avoid response bias from your interviewee.

3 **Introduce yourself and the objectives**

of the interview to start things off.

4 **Go with the flow of the interview**

and be unafraid to ask questions that were originally not in the list if they seem like they will be promising leads.

5 **Observe & record the interview**

whether by audio, video (with permission), or have a teammate take notes. This will allow you to focus on the interviewee.

6 **Summarise your findings**

to clarify key points with your interviewee, and ask them if they have questions for you. The questions they ask may raise interesting points you may not have originally considered.

Best Practices[1]

Do not ask leading questions or suggest answers

Leading questions or suggesting answers might influence and bias the response of the interviewee, compromising on the accuracy of their responses.

Seek what the PSS must do, not how

Be open to explore alternative ways to how the PSS might be able to do what it should.

Go with the flow

Wherever the user/customer takes you, follow along, and ask why and how questions.

Use visual stimuli and props

Bring models of new concepts, competitors' PSS, related or analogous PSS. Ask about all of these.

Have the customer/user demonstrate

Don't just ask about the PSS; human language is only so expressive. Seeing the need in action will permit much better understanding.

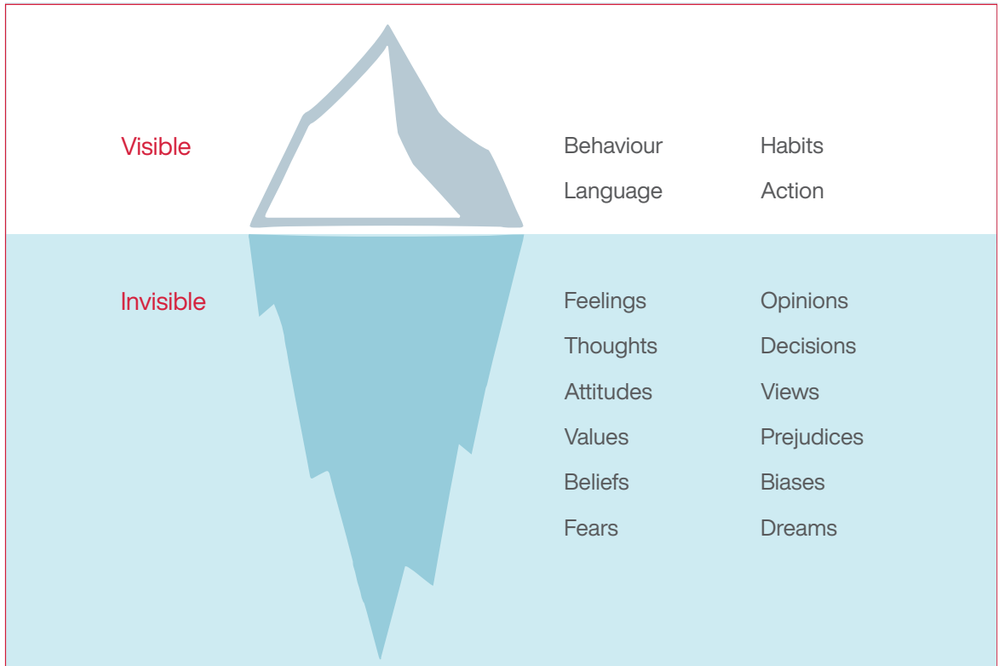
Be alert for surprises and latent needs

Pursue any surprising answers with follow-up questions until we understand the need completely. This additional level of inquiry usually uncovers the latent needs.

Watch for non-verbal information

Human language cannot communicate all sensation modes and feelings about a product. Non-verbal information includes body language, facial expressions, emotions, values and beliefs.

DI team members conducting interviews with stakeholders



Information Gathered from Interviews[4]

Interviews are like diving into the ocean to observe beyond the tip of an iceberg. While digging for more information about the users, be mindful of any need beyond the surface that is valuable for the design opportunity or problem. Seek to discover latent needs, which are not obvious and not indirectly expressed by users.

Request the users to be open to share their feelings, thoughts, attitudes, values, beliefs or even fears.

Useful Tip

Interviews are most effective when held in the environment and circumstances, or as close as possible, to where the PSS will be implemented.

To encourage more sharing in the interview, you can plan to conduct follow-up interviews and gradually build up the rapport between the interviewee and you.

Sample Questions

The sample questions below may be contextualized and rephrased in terms of the Enterprise-level or Project-level opportunity statement(s) of the team. These questions are proven through extensive research and application across domains and disciplines.

Who (Characteristics/Personas)

‘What is your occupation?’
‘Describe yourself _____ ?’
‘What tools do you use the most at work?’
‘What do you usually prefer, _____or _____, why?’
‘How familiar are you with _____ ?’

Jobs To Be Done (Social/Emotional/Functional)

‘How often do you _____?’
‘How much/often do you _____?’
‘How many time have you _____?’
‘When do you have to complete _____?’
‘Walk me through your responsibilities...’
‘When do you have to _____?’

Look for Specific Stories and Contextual Needs

‘Can you tell me about the first time you _____ ?’
‘What do you remember about _____ ?’
‘What kind of day was it?’
‘Could you tell me the story of how you _____ ?’
‘Where did that happen?’

Likes and Dislikes

‘What do you like about _____?’
‘What do you dislike about _____?’
‘What was your best experience with _____?’
‘How do you compare this and that?’
‘When was the last time you shared _____ with your friend?’

How they Feel (Pains/Gains, Emotional/Social)

‘Walk me through how you felt . . .’
‘What were you thinking at that point?’
‘Why do you say that? . . . Tell me more.’
‘Could you tell me why is that important to you?’

Worked Example

User Interviews are used to extract deep qualitative insights, foresights and latent needs from users. By asking questions, designers, engineers, and professionals can uncover users' intentions, motivations and emotions when they use a product, service, or system.

In these interviews, questions are designed to allow interviewees express their needs and aspirations by articulating how they engage with a process similar to our opportunity statement. This will inform the discovery of insights and identify opportunities for design improvement while empathising with user needs.

How might we design a collaborative web platform around sharing, visualising, and comparing data for the future of young professionals and potential organisations for employment?

Jobs To Be Done

- Have you searched for employment within your discipline? How did you do this?
- Have you searched for graduate programmes in your discipline? How did you do this?
- What does a successful job search look like for you?

Too much social upkeep is required	Likes a consolidated resource for specific field	Wants a unified location to upload resume, CV, and other resources
Likes having access to contacting companies with questions	Needs resources on how to get noticed	Read receipt for resumes
Hard to get response from employers	(Interviews) felt inadequate for the job	Likes the idea of having a display that shows job recommendations

Stories; Contextual Needs

- How would you connect to someone who specialises in the field you want to pursue?
- Can you share a story of a successful or unsuccessful connection?

Likes connecting with people their age	Likes matching skills with companies	Likes openness of information
Dislikes how much work it is to make connections and build a profile	Employment search is daunting	Dislikes how performative it is
Likes connecting with people in field easily	Advice from the actual department they are applying for	Job recruitment involves lots of back and forth emailing

Who

- What is your major?
- What year are you in?
- What is your ideal graduation date?

Likes/Dislikes

- What do you like about searching for employment?
- What do you dislike about searching for employment?
- What employment search platforms have you used, if any? What do you like or dislike about the platforms you have used?

Wants more kindness from employers	Lack of consistency between job websites	(Glassdoor) reviews are great to look at from work places (salary + job specifics)
Programs are not easy to find	More up-to-date details of programs	Hard to learn where to get information
Likes that there are learning courses	Available to work option	Networking capabilities

Feelings; Pains, Gains, Emotional, Social

- How did your search for employment make you feel? Did you have any struggles or fears?
- Do you have advice for employers or university programmes relating to the job search process?
- What kind of advice would you like to receive?

Dislikes lack of guidance or support	Likes notifications and reminders	Make strengths career test mandatory
Dislikes that programs are not specific enough on expectations	Struggled finding program that fits schedule	Better website design to get attention of user
Feels ignored	Opportunity to rebrand themselves	Likes to easily get a sense of what employment is like in various companies

Method

Survey Design

Design Engineering | Core User Engagement

Surveys are an asynchronous data collection technique that can complement other data collection methods (interviews, observation). The asynchronous mode means you don't have access to non-verbal information, but users are free to respond on their own time.

Why: Surveys are incredibly flexible with multiple types of structured and unstructured questions and visual interactions possible. In addition, a survey can allow reaching a much wider audience than interviews.

Time: 1 - 2 hours preparation, 1 - 2 weeks to collect responses, 1 - 2 hours analysis

Materials: Survey platforms (see opposite page)

Complementary methods: User Interviews, Shadowing

Acronyms: CIT - Critical and Inventive Thinking
DBL - Design-based Learning
MBL - Maker-based Learning
MOE - Ministry of Education

Procedure

1 **Determine topics**

for exploration. What are you trying to learn?

2 **Develop questions**

that are a mix of open (free response) and closed questions.

- **Open questions** are open-ended, and users can respond freely. This kind of question is best for learning about a user's experience.
- **Closed questions** force the respondent to choose from a set of options you provide. This kind of question is best for user evaluations.

3 **Select a survey platform**

that will allow you to reach your intended audience, and use that platform to customise response formatting and question flow.

4 **Pilot your survey**

by asking a small group representative of your audience to take the survey. Update questions that are confusing, vague, or too specific.

5 **Distribute your survey**

Thank participants for their time.

6 **Analyse responses**

Open questions could be analysed by looking for common themes or phrases, and closed questions could be analysed with descriptive statistics.

Best Practices & Tips

Introduce your survey

Surveys are asynchronous, so a short text introduction is your way of explaining the survey and why a participant's input is valuable.

Ask demographic questions at the end of the survey

This avoids potentially negative effects of priming or bias.

Avoid leading questions

Phrase questions to not assume people will interpret something in a given way, or respond in a given way. This minimises bias.

Always include 'none of these' or 'other' options

In a closed response survey, these options allow survey takers to accurately respond.

Ensure responses will be useful

In a Likert-style (-2...0...+2) or scale question, include no more scale points than is meaningful for you to make decisions from. In general, 5 or 7 scale points is usually sufficient.

Keep it short

An ideal length for a survey is about ten minutes, or no more than 25 questions. Depending on the audience or circumstances, your survey could be longer.

Survey Platforms

Typeform
Google Forms
Qualtrics
Survey Monkey
Microsoft Forms

Worked Example

Critical and Inventive Thinking in Singapore General Education

Research Questions

What is Critical and Inventive Thinking to school leaders, educators, students and based on the academic literature, business leaders, and government leaders worldwide?

What are the existing Singapore MOE and school programmes that address Critical and Inventive Thinking, including learning objectives, pedagogical approaches, programmes, and assessment?

How pervasive are these programmes in their implementation? How effective are these programmes? What are the systemic and resource constraints involved in these programmes?

What are MOE's future plans to address Critical and Inventive Thinking?

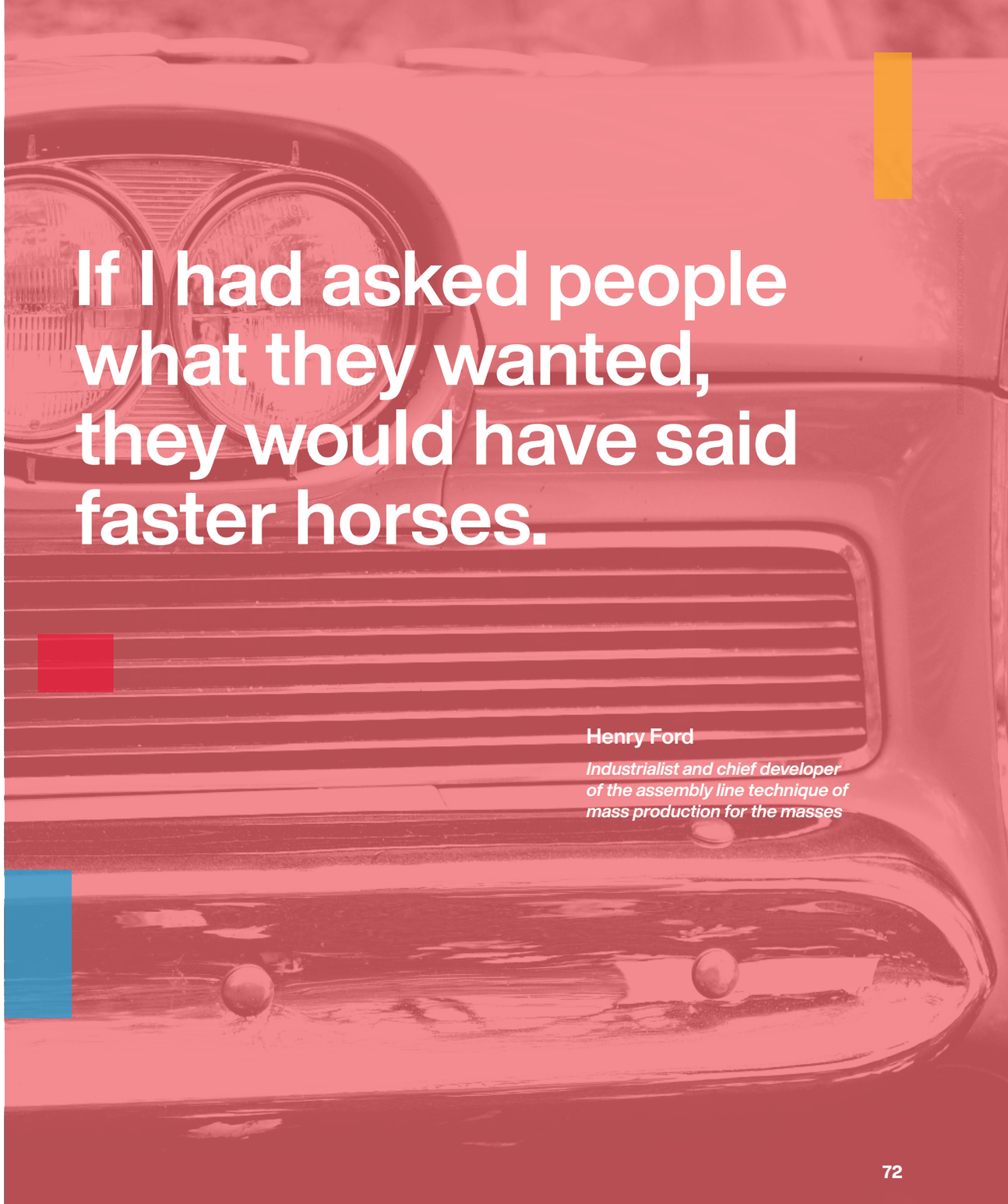
What are other countries and educational systems doing to address Critical and Inventive Thinking, including learning objectives, pedagogical approaches, programmes, and assessment?

What are the strengths, gaps, challenges and opportunities based on the afore-mentioned findings?

What are the recommendations, building on the results from Q1-Q5, for design-led creative thinking and doing (design-based learning – DBL, and maker-based learning – MBL) to value add to existing programmes?

Survey Questions for Teachers

1. How would you define Critical and Inventive Thinking (CIT) in terms of your school?
2. Does your school use Design Thinking and Maker Spaces? If so, please describe.
3. What activities have integrated CIT / Design Thinking / Maker spaces in your school? Explain.
4. For your school, how does CIT, Design Thinking and Maker Spaces integrate with and across the core subject areas? Explain.
5. Provide a brief story or vignette for your favourite CIT / Design Thinking / Maker Space - integrated activity in your school.
6. What issues or challenges (including systemic and resource constraints) exist or have existed in your school's CIT / Design Thinking / Maker Space - integrated activities?
7. What strengths exist, and what improvements and opportunities do you foresee or desire in CIT / Design Thinking / Maker Space - integrated activities in your school?
8. What might be some creative ways you envision for overcoming issues or challenges for adopting CIT / Design Thinking / Maker Space - integrated activities in your school?
9. How do you see the future of education, the classroom, and learning environment changing over the next five years or so?



Method

User Journey Map

Design Thinking | User Connection

CARD 3 Empathy

User Journey Map charts out an archetypal journey of a user's interaction with the product, service, or system (PSS), over time and across channels, fleshing out the user's emotions.

Why: User Journey Map helps teams visualise and story-tell users' journeys for deeper empathy, enabling more integrated sense-making of needs and identification of specific opportunity areas for innovation. It also creates a shared reference frame around the user experience across stakeholders.

Complementary methods: User Interviews, Activity Diagram

Acronyms: AV - Autonomous Vehicle
PSS - Product, Service, or System

Procedure

1 Choose a persona and a scenario

Clarify the persona's needs, expectations and goals within a defined scenario (refer to 'Personas' and/or 'Scenarios' cards)

2 Map the journey

Chronologically plot the relevant points of action between the user and the PSS.

3 Identify gaps and insights

Analyse the Journey Map. Identify the interactions that are pain points and note areas where the user experiences delight. Draw insights to improve on the user experience.

Framework

Apply Extreme-User Experience Framework

read more about the framework on page 39

a. Determine the physical abilities/demands needed to interact with each touchpoint

b. Use wearable situations that eliminate specific physical demands

c. Use user emotions to identify critical points for improvement.

d. Test with users and discuss experiences. Check how similar or different are they from what you anticipated.

Key Elements of a User Journey Map

- Touchpoints[3]: Instances of interaction between a user and the PSS
- Channels[3]: Mediums of interaction between a user and the PSS

Best Practices [1]

Involve different stakeholders

Co-create the journey map with different stakeholders, to align and sharpen their perspectives on the user journey.

Content first, visuals later

It can be easy to be distracted by the visual aspect of a journey map. Ensure you build a solid foundation with the content before trying to communicate the story.

Build and support it with data

Be mindful of assumptions made in developing a journey map. Strive to ground them on data.

Test and refine it with users

Show the journey map to users and get feedback from them on how representative it is in depicting their actual journey.

Worked Example

A User Journey Map is created to address the opportunity, 'How might we design and integrate an Autonomous Vehicle System for the future of Singapore?' The current travel experience of taking taxis is mapped as a proxy to the experience of taking Autonomous Vehicles.

It begins by selecting the persona and scenario involved, as seen in the topmost row. If personas are not yet created, key stakeholders can be picked.

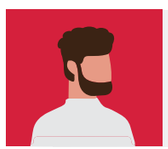
With reference to the Scenario, touchpoints and channels are then identified and listed chronologically in the next rows.

The emotional level of each touchpoint is rated, sketched and labelled with facial expressions, empathising with the Persona.

Insights and opportunities are extracted, asking, 'How can positives be amplified, and negatives turned into positives?'

How might we design and integrate an Autonomous Vehicle System for the future of Singapore?

Persona



Adam

- 32 years old
- Newly married
- Financial Advisor
- Doesn't own a car
- Has an active lifestyle with lots of appointments with clients
- Exercises regularly to keep fit
- Loves dogs
- Wishes traveling can be more fun

Scenario

Travel Experience Taking Taxis

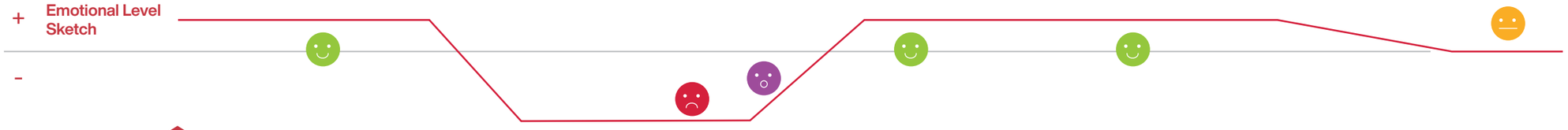
- Travels by taxi to meet a client on a regular workday in Singapore
- Carries a briefcase with a laptop and work documents
- Needs to reach destination promptly

Touchpoints

Arranges/ Confirms meeting with client	Book Taxi	Travel to Pick-up Point	Waits at Pick-up Point / Looks out for Correct Vehicle	Vehicles Arrives, Boards Vehicle	Rides in Vehicle, Waits to Arrive at Destination	Alights Vehicle	Gives Rating for Ride	Walks to Destination

Channels

Emotional Level Sketch



Insights and Opportunities

How to book vehicle without looking at the screen?	Option to book vehicle with dog inside	Minimise taxi waiting time	Display "Welcome (user name)" for easier recognition	Customisable Rides	Ensure nothing left behind
	Option to book vehicle with exercise equipment inside		Vehicle to identify user	Make vehicle interior more conducive for exercise and rest	Give directions to walk
			Option for easy boarding if user has a lot of items	Give recommendation on places to meet client	

Extreme-User Experience Framework
refer to the previous page

Method

Contextual Needs Analysis

Design Thinking | Immersive User Experience

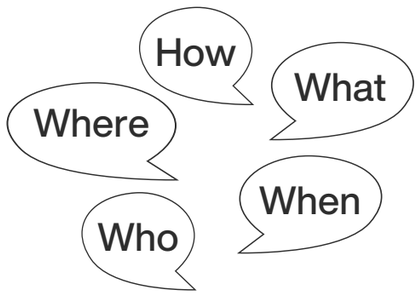
Discover the context surrounding products, services, or systems (PSS) to understand and account for context in the design process.

Why: User satisfaction with a PSS critically depends on the context it is used in. By considering the context, the function is integrated and harmonised with its surrounding.

Note: To be present in the context of the PSS.

Complementary methods: User Interviews, Site Analysis

Acronym: PSS - Product, Service, or System



Context setting questions

Procedure

1 **Ideate interview questions**

What do we need to know about? Where? How? and Who?

2 **Context questions template**

Add, delete and modify questions as needed.

3 **Interview users**

While using product, service or system in a realistic context.

4 **Form a user needs list**

Translate voice of user - combine and prioritize needs.

5 **Form scenarios In context**

by combining contextual answers to each question.

Framework

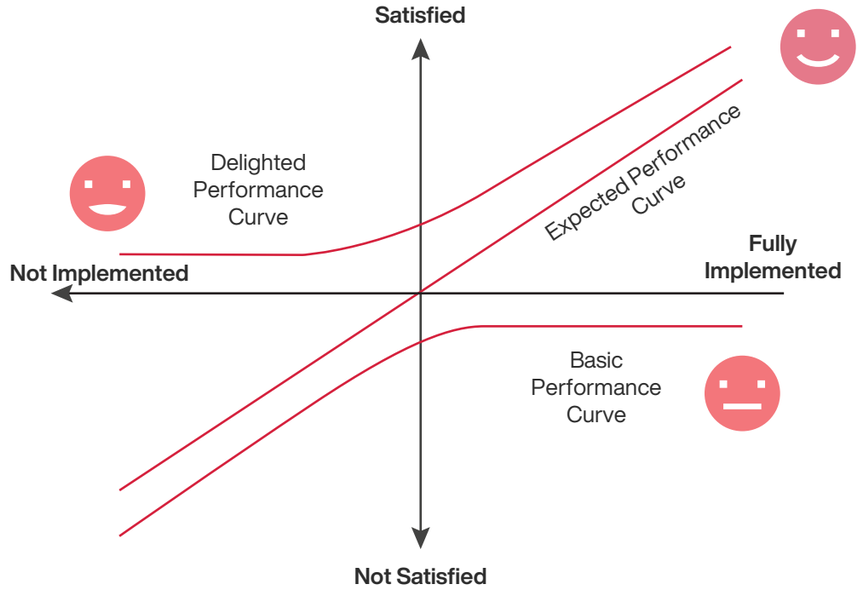
Apply Extreme-User Experience Framework (Optional)

read more about the framework on page 39

User with [Extreme-User demand] [interacting with product, service or system] [environmental/spatial extremes]

Measure context against: Kano Model

Users will always have certain expectations of products, services and systems based on what they are used to. That can be viewed as the Expected Performance Curve. Should our new products positively exceed expectations, we can delight consumers. Conversely, should our products fail to deliver on what consumers have come to expect as the 'norm', they will be upset even if our design is super polished and fully implemented.



5 categories of customer preferences

1. Must-be	Expected and taken for granted
2. One-dimensional	Satisfaction if fulfilled, vice versa
3. Attractive	Satisfaction if achieved, does not cause dissatisfaction if unfilfilled
4. Indifferent	Neither good nor bad
5. Reverse	High degree of achievement resulting in dissatisfaction

After defining the context(s) of use, measure the user satisfaction of a product, service or system (PSS) against a Kano Model.

Method

Empathic Lead Users

Design Thinking | Immersive User Experience

CARD 12 Empathy

Empathic Lead User enables a Lead User* experience by simulating extreme conditions in using the products, services, or systems (PSS).

*Lead users are users whose present strong needs will become general in a marketplace months or years in the future.[5]

Why: It encourages new perspectives on user interactions with the PSS, and identifies needs that are latent among a wider population of users.

Materials: Empathic Lead User Template, Lead Users, Extreme-User Experience Framework

Complementary methods: Stakeholder Mapping, Personas, Scenarios, Affinity Analysis

Acronyms: DI - Design Innovation
MRT - Mass Rapid Transit
PSS - Product, Service, or System

Framework

This method follows Extreme-User Experience Framework
read more about the framework on page 39

Procedure

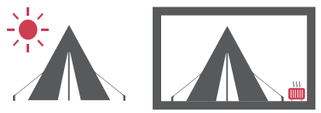
1 Develop list of extreme usage conditions

that are likely to occur and deviate from typical experiences. Consider the physical, sensory and cognitive demands that might occur during the use of the PSS.

2 Simulate extreme conditions

in a controlled and/or creative environment.

For example:



Setting up a camping tent in a dark room to simulate the perspective of users with visual impairments.

3 Collect simulation data

Get users to think aloud as they use the PSS. Observe interactions and record insights.

4 Identify latent needs

based on data collected and follow-up interviews.

Useful Tip

Use the Extreme-User Experience Framework to guide your Empathic Lead User method.

Best Practice

Use Situational Extreme-User Experiences

Situational Extreme-User Experience refers to getting knowledge or skill from doing, seeing, or feelings things inspired from instances that highlight the similarity in needs experienced by the extreme and general population users.

For example, someone listening to music on a noise cancelling earphone experiences a situational extreme that overlaps with the experience of someone with hearing impairment (direct extreme).

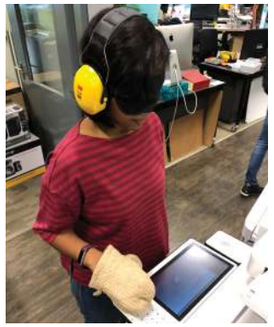
Be willing

to experience the life of the Extreme-User instead of talking about their experience. Extreme-User conditions may need to be repeated many times in different scenarios to understand the Extreme-User well.

Emulation and Simulation Tools

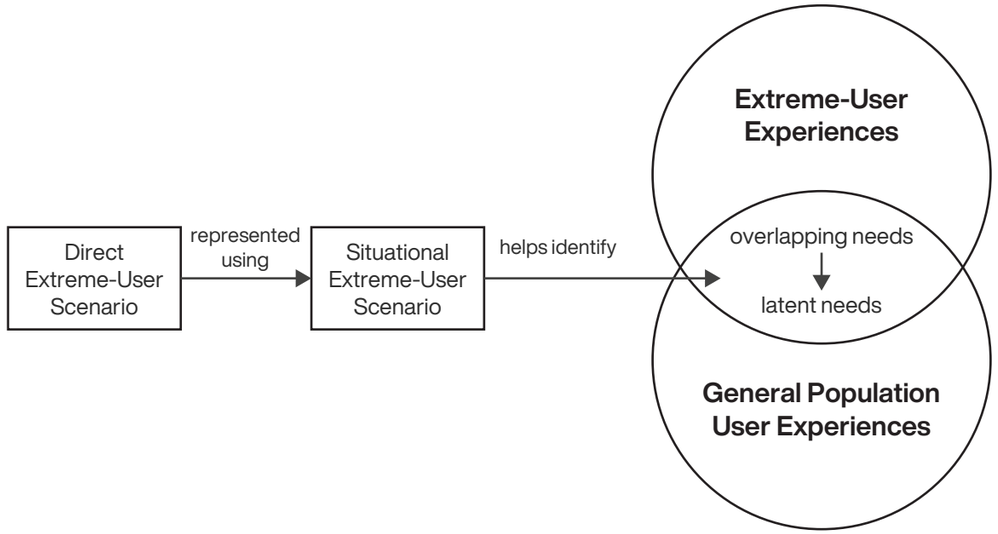
Use the corresponding simulation tools to eliminate the parameters. People can get creative with these tools!

Identified Physical Demand	Simulation Tool
Vision	Eye mask, blindfold or dark glasses
Both hand usuage	Hand band
Dexterity	Low dexterity glove or mitts
Listen	Noise canceller, ear plugs or background noise
Standing on feet	Your chair
Limited strength	Strap-on weights or joint wraps



An eye mask, ear muff and oven glove were used to simulate visual impairment, hearing impairment and slowness in dexterity respectively.

Role Of Situational And Direct Extreme-User Scenarios



Useful Tip

While these simulations are never a replacement for actual users, they play an efficient role in challenging designer perceptions and expectations.

Worked Example

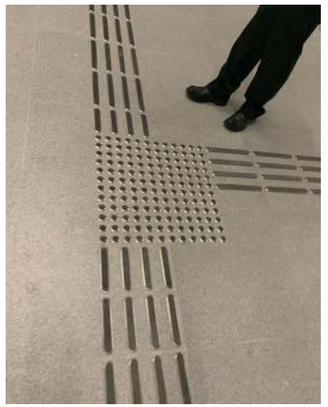
DI team members paired up and took turns to attempt to navigate the station, putting on different aids to enhance their sensitivities to the needs of extreme users of MRT station such as the visually and audibly impaired.

How might we enable the public and visually impaired to navigate a station more confidently?

A

Extreme usage condition

Visual impairment:
Using tactile flooring for navigation



B

Performing simulations

DI team member takes on the role of a user, putting on blindfolds to simulate visual impairment, while a designer guides him and observes the way navigation is done.

C

Identify latent needs

The DI team identifies the following latent needs:

- Wider corridor leading to the lift (congested flow around lift was felt acutely by the blindfolded DI team member).
- Easily noticeable alert to train passenger load information. (Would enhance the experience of users who would prefer to avoid crowded train journeys)

Method

Video Ethnography

CARD 4 Empathy

Design Thinking | User Observation

Video Ethnography is a visual data recording tool that focuses on precise recording and review of documented footage from user observations.

Why: Video Ethnography supports user studies and user needs method by providing user information that are graphical and dynamic.

Materials: Phone, Video Camera, Computer

Complementary Methods: Shadowing, Site Analysis

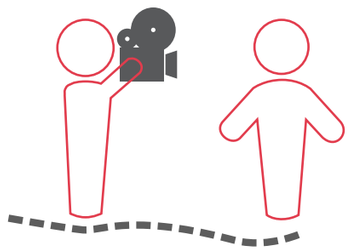
Procedure

1 **Select an activity or journey**

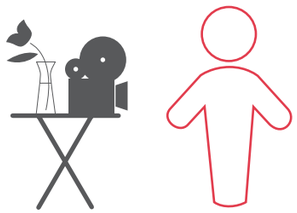
that the user carry out related to the design/problem opportunity.

2 **Capture the user's behaviour through their journey**

by following the users as he/she walks through the experience.



by setting up a camera on-scene to document repeated activities.



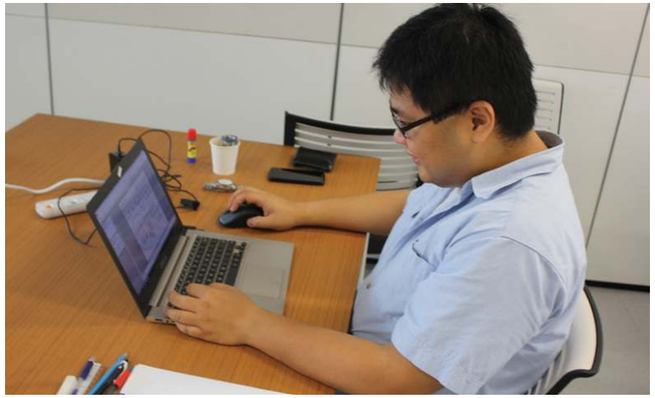
3 **Record and transcribe**

the patterns in user behaviour and interaction.

4 **Analyse and extract**

any insights regarding user needs that are uncovered during the study.

Expected Footages



User using a product, observing usage patterns and expressions.

Users navigating a space, observe line-of-sight, wayfinding cues.

Useful Tip

As the observer or videographer, try to set up the recording devices or position without disturbing the user during the observation. Write down questions (if any) and ask after the session.

Have more than one observers to captures different camera angles, such as the first person view of the users or from a third person view. You may find pieces of information that is valuable or unusual.

Method

Site Analysis

CARD 5 Empathy

Design Thinking | Contextual Observation

Site Analysis explores the relationship between the selected space and the surrounding environment or infrastructure. Documentation assists analysis on site.

Why[2]: Site Analysis enables designers, engineers, and professionals to deeply understand the spatial context of use of the Products, Services and Complex Systems (PSS), uncovering latent needs and insights.

Materials: Accessibility to Site

Complementary methods: Benchmarking

Acronyms: PSS - Product, Service, or System
SI - Soil Investigation

Procedure

1 Select

The site and specific process or features of the site to analyse.

2 Reviewing existing data of the site

to understand the site's physical, mental, and social landscape (e.g. floorplans, functional zones, security etc.).

3 Develop a Template

and collect data on identified factors (e.g. stakeholder, activity, zones, etc.)

Stakeholder	Activity	Location

Fill up data collection template as you walk through the site

4 Select and construct model

that best communicates the results of the site analysis.

Relevant models

Architectural model

IDEF0

System Model

Floor Plan

Heat Map

Possible analysis data to collect[2]

- Location and neighbourhood context
- Legal information
- Natural physical features
- Man-made features
- Traffic or human circulation patterns
- Utilities
- Sensory
- Social and cultural information

Outcomes

- Internal structure
- User flows
- System structures
- System flow and checkpoints

Useful Tip

Take photos and videos to describe the observations and make use of objects to denote the scale in the photos or sketches.

Worked Example

The example shows two different methods used in site analysis. The method chosen depends on the context and the information requested. Thus, the selection of the methods should be systematic.2 The list of data required, their priority and length of investigation should be drawn up before embarking on the site analysis.

Site analysis can be done using tools such as drones or static cameras for canopy view of site. Videos and images can be transmitted real-time to assess site conditions. Recordings can be also used for calculation and data visualisation (e.g. traffic and pedestrian flow along certain roads).

Soil investigation (SI) is done to obtain the geotechnical properties for design and because of the heterogenous nature of soil, every site is treated uniquely. Information obtained from SI will be used throughout the various phases of the project and not only in the design phase.

Method

Semantic Inquiry

CARD 9 Empathy

Design Engineering | Core User Engagement

Semantic inquiry lists out a set of questions that requires responses on a rating scale, capturing the desired 'feel' of the product, service, or system.

Why: The method is geared towards discovering the desired emotion, experience, appearance, feel, layout, and usefulness of a design.

Materials: Semantic Inquiry Template, Online survey platforms

Complementary method: Affinity Analysis

Acronym: PM - Prime Minister

Scan or click here for a digital copy of the template

1 2 3 4 5

Procedure

1 Generate descriptive words

related to the desired product, service, or system.

Feminine
Fast Sleek
Delicate
Elegant Light
Specific

2 Form pairs of adjectives

that are opposites and rate them on a scale of 1 to 5

Opposite extremes		
Feminine	○ ○ ○ ○ ○	Masculine
Dark	○ ○ ○ ○ ○	Light
Formal	○ ○ ○ ○ ○	Informal
Modern	○ ○ ○ ○ ○	Classic
Reserved	○ ○ ○ ○ ○	Expressive

3 Gather images

that capture these qualities.

4 User feedback

let users rank their impressions of the desired product, service, or system in terms of the descriptive words.

Useful Tip

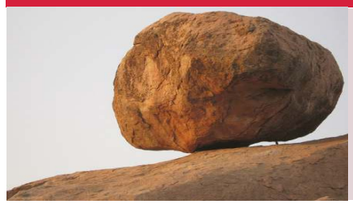
The Thesaurus or WordVis (http://wordvis.com/) can help you to generate the descriptive words.

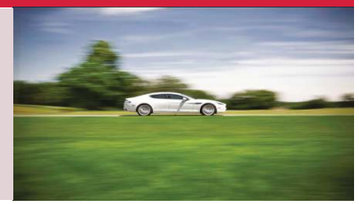
Worked Example 1

Ideation

Select the point between the two images that you feel best fits the target product/system in terms of mood/vibe.

Static ○ ○ ○ ○ ○ Dynamic





Calm ○ ○ ○ ○ ○ Exciting

Survey questions using Semantic Inquiry

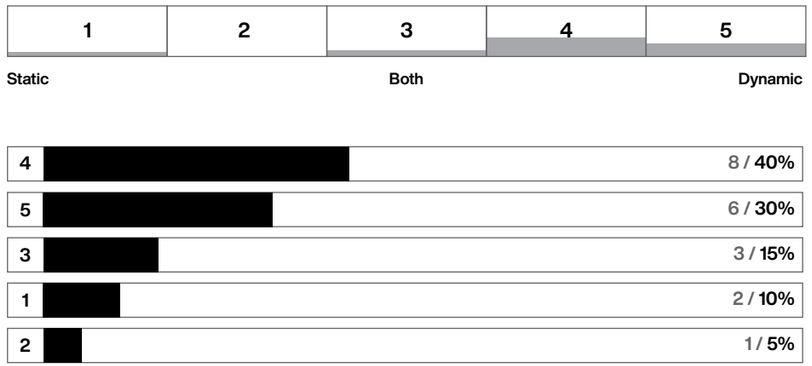


Image exploring user feedback results

Worked Example 2

Of Founders' memorial phase II

In his parliamentary statement on 13 April 2015, PM announced that he had asked Mr Lee Tzu Yang to chair a committee to gather views from the public and conceptualize a Founders' Memorial to educate future generations on the values and principles of the founding generation of leaders, and to take the project further if the idea finds resonance among Singaporeans.

More than 13, 000 visitors contributed their views on the possible design features and visitor experiences through Semantic Inquiry:

On a scale of 1 to 5, should the memorial:	1	2	3	4	5	Total
Be a Gallery (5), Park (1) or both?	27%	19%	39%	8%	7%	100%
Be Forward-Looking (5), Historical (1) or both?	16%	18%	47%	11%	9%	100%
Be Recreational (5), Commemorative (1) or both?	12%	20%	44%	14%	10%	100%
Cater for Large-Scale Programmes & Events (5), Individual & Reflective Spaces (1) or both?	13%	18%	38%	16%	15%	100%
Have Outdoor (5), Indoor spaces (1) or both?	11%	15%	50%	15%	9%	100%
Have Personal (5), Formal (1) or both?	10%	13%	41%	23%	13%	100%

The results showed that Singaporeans expressed support that the memorial should meet the following requirements in the chosen design:

1. Not only honour the past, but inspire the future
2. Be in a park setting, amidst greenery
3. Be located near water, reflecting Singapore's story
4. Be sited in an open space, with possibilities for future growth
5. Be accessible for all Singaporeans to visit with family and friends
6. Stand the test of time and be relevant for current and fture generations
7. Incorporate an indoor gallery for education and programmes to be conducted

Worked Example 3

Of Founders' memorial phase III

Attendees received a form like the one shown at every design booth

If attendees felt the design met a requirement, they had to shade that circle completely

Founders' Memorial Public Engagement | May 25 - 26

To respond, shade the box or circle completely with a dark pen

Design Booth

☐ A ☐ B ☐ C ☐ D ☐ E

Age

☐ 18 and below
☐ 19 - 35
☐ 36 - 59
☐ 60 and above

Ethnicity

☐ Chinese ☐ Malay ☐ Indian ☐ Other

Is not only able to honour the past, but also inspire the future

◯

Makes good use of the park setting, amidst greenery

◯

Makes good use of the site built near water, reflecting the Singapore story

◯

Makes good use of the site's open space, offering possibilities for future growth

◯

Would be accessible for all Singaporeans to visit with family and friends

◯

Would be able to stand the test of time and be relevant for current and future generations

◯

Has the capability to incorporate an indoor gallery for education, and the flexibility to run different programmes

◯

You never really understand a person until you consider things from [their] point of view - until you climb into [their] skin and walk around in it

Atticus Finch

Author of To Kill a Mockingbird

Method

Shadowing

Design Thinking | User Observation

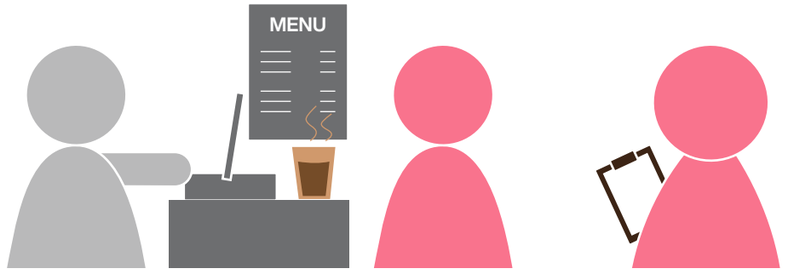
CARD 10 Empathy

Shadowing is a qualitative research technique where researchers act as observers of participants' natural behaviour with minimal interruption.

Why: Shadowing technique enables researchers to get as close to a first-hand or first-person perspective as possible to what users experience by direct observation. It also allows researchers to spot any discrepencies from the expected behaviour.

Materials: Camera

Complementary methods: Site Analysis, Multi-sensory Analysis



Procedure

1 **Brief the participants**

complete your preparation by building trust with the participants, encouraging them to think aloud, demonstrating if necessary.

2 **Preserve the natural state of the venue**

and allow for natural movement of participants at all times.

3 **Shadow your participants**

Take notes of observations or questions to clarify later.

4 **Seek clarifications**

After shadowing, hold a reflective exercise to clarify your observations and questions with participants. Dig deeper into the rationale behind their actions.

Template Structure

Where Location: **When** Date: Time: **Who** Name: Age: Gender: **Why** **Key Findings**	**Likes**	**Dislikes**	**Habits**
	Activities	**Objects**	**Space**

Worked Example

Shadowing a wheelchair user riding a taxi

Where Location: Taxi Stand **When** Date: 19-01-09 Time: 10 AM **Who** Name: Mike Tan Age: 40 Gender: Male **Why** Mike is an extreme user with disability **Key Findings** For wheelchair bound users, entering/exiting a vehicle unaided is demoralising and almost impossible	**Likes** Speaking to the taxi drivers and hearing about the stories of their lives.	**Dislikes** Visibly uncomfortable with having to bother drivers to help him get in and out of vehicle. He feels like he is inconveniencing them.	**Habits** Double and triple checks his belongings before exiting the vehicle.
	Activities Asks the taxi driver for recommendations of eating places along the route they are driving.	**Objects** Small sling bag he carries in the font for easier access.	**Space** The gap from the curb to the seat of the vehicle makes it hard for Mike to transfer himself without help.

Method

Multi-sensory Analysis

CARD 11 Empathy

Design Thinking | Contextual Observation

Multi-sensory analysis engages a user's sensory experience to understand the user's human experience, memories and emotional attachment to a product, service and system (PSS).

Why: Being rich in our sensory information gathering would be useful to discover latent needs, especially when designing for users who have one of their senses impaired.

Complementary methods: Site Analysis, Shadowing

Acronym: PSS - Product, Service, or System

Procedure

1 Record

user perception (qualitative) of various senses towards a PSS in a set time period.

2 Describe

Perception of various senses towards a PSS, through first hand experience. Best performed on site. Supported by Videography or Photography.

Key Components To Capture

Emotional
Reaction, both positive and negative

Visual
What visual stimulus, note colour and light

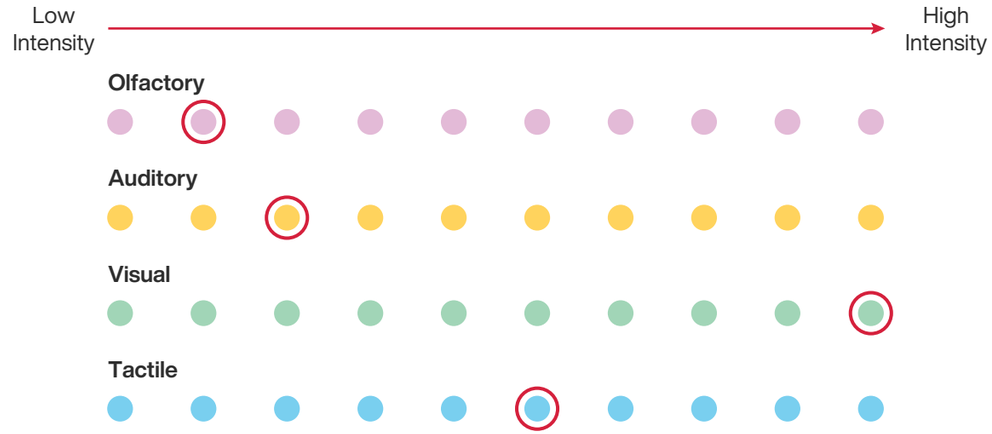
Auditory
What sounds indicate when heard

Olfactory
What smells users react to and why

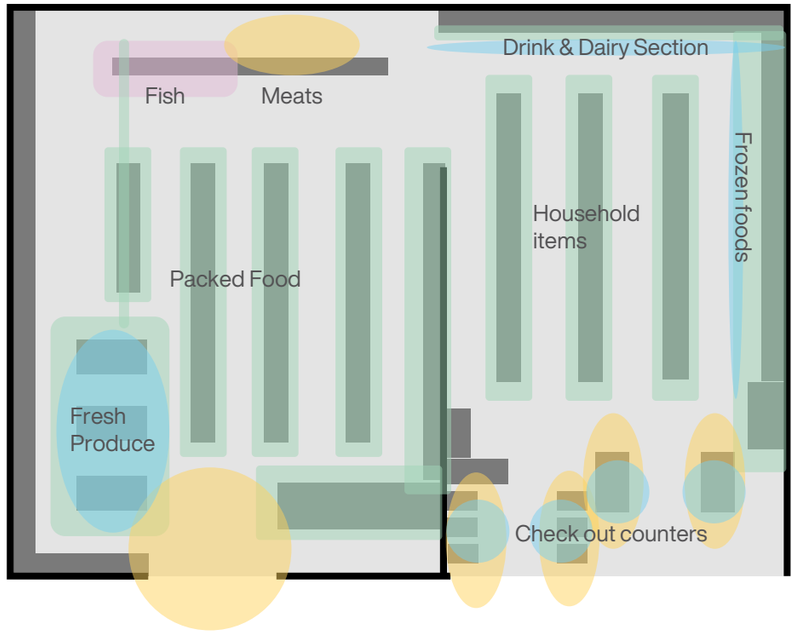
Tactile
What is felt by hand or skin

Worked Example

Multi-sensory Analysis of a Supermarket



Template structure of capturing key components in context.



Multi-sensory map of a supermarket

Method

Participatory Radar Map

Design Thinking | Core User Engagement

This map guides stakeholders in listing and prioritising their considerations, framed by select topics.

Why: Participatory Radar Map uncover what stakeholders are thinking. It challenges your assumptions and yields results that inform the design.

Time: 15 - 20 minutes

Materials: Participatory Radar Map Template, Sticky Notes

Complementary methods: Affinity Analysis, Hierarchy of Purpose, User Interviews

Scan or click here for a digital copy of the template

Procedure

1 **Identify**
within the Opportunity Statement for consideration

2 **Create**
a template of the radar map.

3 **Identify subcategories**
of the topic and label as the segments in the maps

4 **Invite**
a group of stakeholders to be participants or work on it individually.

5 **Apply**
Have each person individually reflect on the question and sections of the radar using Sticky Notes, and then plot those items according to personal significance

6 **Seek**
any insights and ask to understand their rationales for the plot.

Best Practices

Listen closely
when the stakeholders are sharing their thoughts, you might find valuable information that challenges your views.

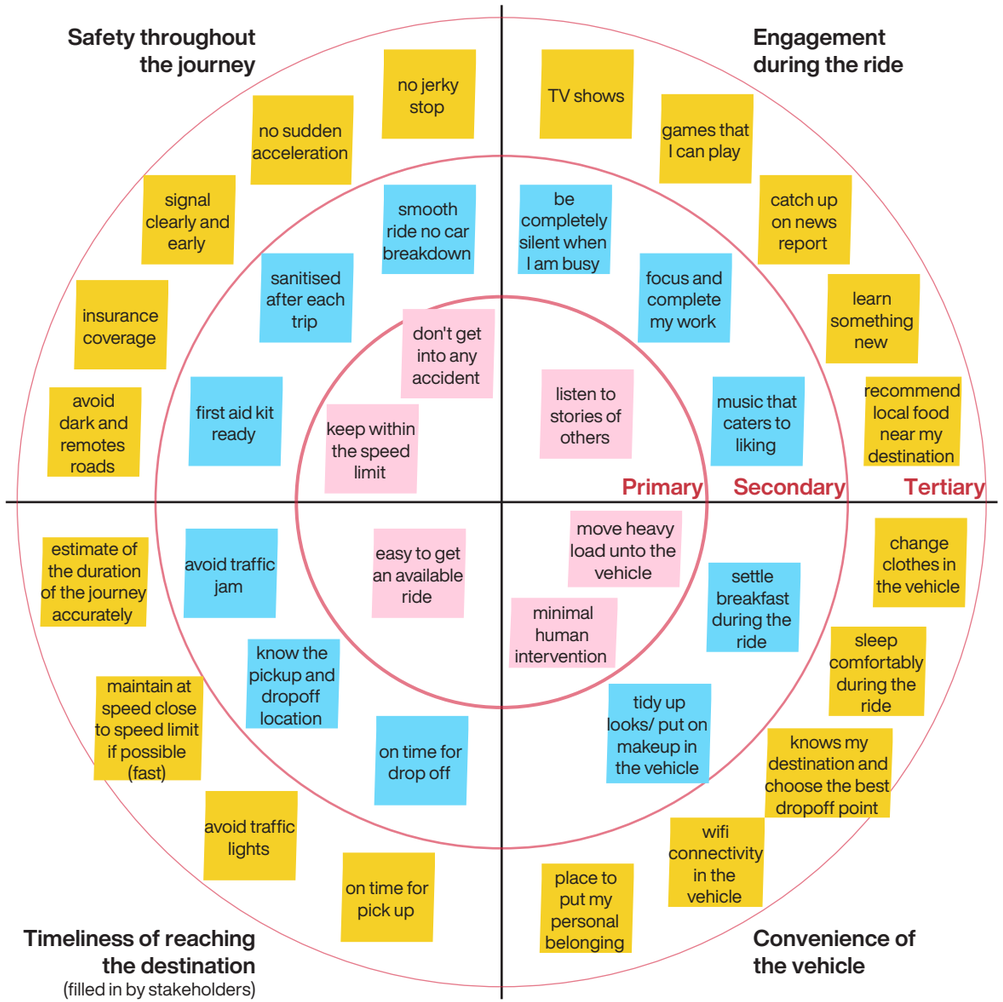
Leave some blanks
Leave 1-2 segments blank for the stakeholders to fill in themselves.

Divide a radar
into as many sections as you need. Most radars range between 2-8 sections.

Limit the number of items
that can fit into each section, (i.e., 1-2 for primary per section, 3-4 for secondary, and 4-6 for tertiary)

Worked Example

How might we design an autonomous vehicle for the future of Singapore?



Method

Cognitive Walkthrough

Design Thinking | Immersive User

A cognitive walkthrough provides usability evaluations of a product, service, or system (PSS) from the perspective of a user. Cognitive walkthroughs originated in cognitive science and human factors practice and are often used in user experience and user interface (UX/UI) design.

Why: When the tester vocalizes their decision making and reactions to the design, they help clarify where the design confuses or delights.

Time: 1 hour

Materials: Prototypes of various forms, such as wire frames, storyboards, role playing, mock ups, desktop walk through, etc.

Complementary methods: Wireframing, Physical Model, Wizard-of-Oz, Mockups (Paper Prototypes), Scaled Model, Isolated Subsystem Model, Immersive VR/AR, Additive Manufacturing (AM) Principle Design, Desktop Walkthrough

Acronyms: PSS - Product, Service, or System
UX - User Experience
UI - User Interface

Procedure

1 **Identify**

the type of experience you want to learn more from your users about.

2 **Choose**

your testers. You may learn something different from stakeholders, users, and experts.

3 **Prepare**

an experience or a prototype that testers can interact with.

4 **List**

tasks you will use to guide the tester through the experience. Often tasks are centered around specific interactions with the PSS.

5 **Probe**

the tester as they engage in tasks, encouraging them to vocalize their thinking process as they learn how to interact with the PSS.

6 **Practice**

with team members, both asking the tester probing questions, and taking notes of responses.

7 **Evaluate (Optional)**

after the walkthrough, ask the tester to evaluate the experience on a standardized usability or other scale.

8 **Analyze**

responses from multiple testers to identify PSS updates, modifications, improvements, advancements, spirals, and additional user needs surfaced by the walkthrough.

Best Practices

Actively listen

It is the tester's thinking process that is most important. Avoid leading questions to get the most genuine responses.

Engage

people with diverse experiences as testers. Broad perspectives of usability will best inform your decisions.

Centre

tasks around assumptions you want to test.

Adapt

to suit what information is most valuable. Tasks can be the primary or secondary structure for the walkthrough:

1. A primary task list guides each tester through the experience in the same way, which can be useful if you want to get feedback on a specific interaction flow
2. You may prefer to let the tester explore the experience to learn what grabs their attention, and use the task list to ensure you have covered all areas you are interested in.

Worked Example

App that helps students search for internships or jobs

Here are the objectives for the Cognitive Walkthrough session:

1. Identifying pain and gain points in the process of using the application
2. Discover usability issues in the current flow of application
3. Understand how users interact with the features

As the gestures for a phone application and laptop are different, be sure to explain this to the testers.

The testers will interact with the app prototype using a laptop. A set of tasks are prepared for the Cognitive Walkthrough. Tasks are single goals, accompanied by a few questions. Once they have completed a task, pause and ask them the questions.

Here are some guiding questions:

Task 1 - Apply internship or job

1. Is there any other info you would like to see on the job information page?
2. What are your thoughts about the recommended options?
3. How do you feel about the summary page of options?
4. What features would you like to add to this process?
5. What emotions do you feel or are invoked throughout the app interaction?

Method

Regulatory Context

Design Thinking | Contextual Observation

Legal and ethical parameters for opportunity spaces.

Why: No design is independent of its context. Legal and ethical considerations are generally intended to ensure user safety, minimize risks, and ultimately affect whether a PSS can enter a certain market.

Time: 1 week

Materials: Regulatory Context Template, Sticky Notes

Complementary methods: Risk Management Process and all methods under core and advanced prototyping methods

Acronym: PSS - Product, Service, or System

Scan or click here for a digital copy of the template

Procedure

1 Determine

what possible regulations or policies apply to your opportunity space. These might include ethical codes of conduct, local legislation, medical approval processes, or intellectual property concerns.

2 Gather information

from regulatory bodies and talk with experts to be sure you have the most up to date guidance.

3 Frame (Optional)

the state of the art in your opportunity area based on intellectual property filings (patents, copyright statements, and/or trademarks).

4 Plan

to collect and submit supporting data and evidence as needed to show your design concept meets relevant regulations.

5 Submit

a study plan or data collection plan to appropriate organisations, as needed to show your design concept meets relevant regulations.

Best Practices & Tips

Localise

Regulations differ by location throughout the world, and differ by industry.

Plan ahead

use regulations to inform prototyping and testing plans.

Risk awareness

Be cognizant of potential risks and benefits that may directly or indirectly affect users of your PSS. Can you minimize risks?

Look online

Many patent directories are online. (https://ipportal.wipo.int/, https://www.uspto.gov/patents/search)

Define

Interpret and reframe needs and map them into activities, functions and representations

MINSET

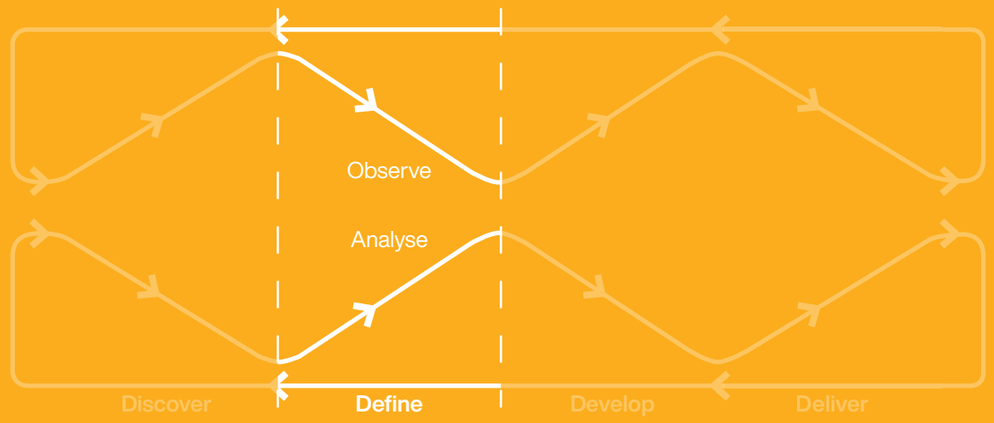
Mindfulness

Observe

- Who are the primary users?
- What activities do the users engage in?
- What are the users' journeys and emotions?
- What systems functions are needed?

Analyse

- How do we make sense of these findings?
- What are the key insights and foresights?
- How might the product, service, or system (PSS) fare in different situations?
- What are driving social needs and technical specifications?



Method

Affinity Analysis

Design Thinking | Data-driven Insights

CARD 1 Mindfulness

Affinity Analysis organises a large number of needs, ideas, or other design information into their natural categories and relationships. This method focuses on data analytics and clustering/categorising to derive design insights.

Why: Affinity Analysis is used for organizing, clustering and sense-making a large set of data (e.g. user needs, ideas).

Material: Sticky Notes

Complementary methods: User Interviews, Empathic Lead User, Persona, Scenarios

Acronym: PSS - Product, Service, or System

Procedure

1 **List**
needs interpreted from the Discover phase with your team.

2 **Write**
each need on a single card or Post-it.

3 **Present**
cards on the wall.

4 **Observe interactions with the product, service, or system (PSS)**
cards on the wall based on similar meaning.

Best Practices

Collect needs holistically
Conduct this method with a cross-functional team, including stakeholders.

Cluster needs intuitively
Do not agonise over perfectly clustering the needs as themes will emerge organically.

Label your clusters
Define and name themes based on content of ideas.

Discussion helps
Read needs aloud to the team while placing card on the wall, one at a time.

Worked Example 1

How might we design a holistic station for the future that provides future readiness in the design?

Cluster 1 **Data**		Cluster 2 **Convenience**		Cluster 3 **Staffing**	
Surveillance Cameras > Good Coverage > Analogue type switch to digital	Misalignment when train stops at station	Need to consider ease of modifications in case of increased ridership	Integrate with cordless ticketing initiative	Low ridership impact on station quality	Operations/ maintenance almost 'invisible' in station
Lots of open space – what could this be for?	Periodical review of ridership and data	Adequacy of ticketing machine and contingency	Space for commuters to gather/queue	Insufficient staff and not timely assistance	
		Obstructions to passengers' flow	Interactive panel as helpdesk		

Category/Theme | Site Analysis | Other Needs/Insights

Worked Example 2

This example of Affinity Analysis organises a large number of needs, ideas, or other design information collected from stakeholder feedback regarding a web-based data visualisation prototype into categories.

Affinity Analysis is used as a means to organise or achieve 'sense-making' from a large set of needs, ideas or design concepts.

How might we design a collaborative web platform around sharing, visualising, and comparing data for the future of young professionals and potential organisations for employment?

Privacy	Opt in to share profile information	Allow entry of user-selected information	Allow entry of user-selected information (e.g. certification)	Allow hyperlinks to Linkedin, personal website	
Personalisation	Allow entry of user-selected information (e.g. websites, ongoing projects, demographics, faculty, research areas)				
Function	Working functionality	Works the way it's expected to	Provide tutorial for site use/ function	Clearly present path of steps from end-to-end to develop profile and utilise	
Interpretation of Chart	Provide chart interpretation	Consistently represent chart (colours) within site	Personalise chart display	Explain competency chart	Intuitive data display
	Always show chart legend				

Information Integrity, Metrics	Allow feedback/ audit request	Continuously validate profile information	Comprehensive questionnaire applicable to all users	Display ideal/ realistic examples of levels; better descriptions	Keep information current with single update
	Show overview of organisation	Opt in to share profile information	Maintaining security of user data/ information	Give equal detail level to all data categories	Clearly identify source of data
	External certification to validate data	Objectively evaluate metrics	Transparently show source of competency data	Organising information in a way that is visually appealing	Provide more information at user's discretion
	Describing information so it is understandable	Clearly indicate how data is normalised	Allow users to protect identity by showing only aggregate data	Show running total of entered data to allow entry verification	Common language to build shared understanding
Personalised Search	Data Personalised filtering among matches	Filter by industry domain	Search/filter by competency	Filter results by data category	Distinguish required versus preferred levels
	Indicate priority of data categories				

Worked Example 2 (cont'd)

How might we design a collaborative web platform around sharing, visualising, and comparing data for the future of young professionals and potential organisations for employment?

Information Display	Always show header labels in questionnaire	Provide a definition and link to main site	Show tangible progress toward chart throughout questionnaire/ see it building	Clearly display information and ensure formatting compatibility	Show information in small portions
	Easily show additional information (tooltip, video)	Feature a more digestible definition view; hover feature for one at a time	Show additional detail on hover		
History, Trends, and Goals	Show version history	Create goal profile	Inform advising and goal setting	Indicate update history	View aggregate data to inform benchmarking
	Provide insight to data comparison	Illustrate broad trends	Show individual profile trends over time	Show change in individual data over time	Communicate digest of aggregate data/ trends
	Show aggregate trends over time for benchmarking				

Networking	Contact option to learn more	Show contact information to learn more	Connect to programs or profiles	Build active relationships between industry and universities	Facilitate contact for more information
	Feature additional information				
Collaborative Profile Creation	Having the option to fill out profile information offline	Ability to edit and save questionnaire	Allow multiple profiles under same login	Allow edit access to multiple users	Easily update profile information/ keep current
Accessibility	Display white text in a less harsh colour	Feature role and competencies, rather than years of experience	Generalise form to all practitioners	Easily select buttons	
Housekeeping	Corrected Typos				

Method

Activity Diagram

Design Thinking | Data-driven Insights

CARD 2 Mindfulness

Activity Diagram is a block diagram of sequential and parallel activities that capture user interactions with the Products, Services, or Systems (PSS). This is a very powerful technique to describe the detailed process of users with lots of design insights, not the functions or system being designed.

Why: Activity Diagram brings clarity in understanding the user activity flow. It can be used to discover opportunities for automation, removing unnecessary steps users take, introducing innovative user interactions and experiences, identifying effective channels for user interactions and experiences, combining activities, and identifying potential failure modes.

Materials: Sticky Notes, Wall/Board

Complementary methods: User Interviews, Personas, Scenarios, User Journey Map

Acronyms: Doc.- Document
PSS - Product, Service, or System

Procedure

1 **Observe or speculate the activities and user interactions with a PSS**

Do this across the full value chain, i.e. from the moment the PSS 'enters', and then 'exits', the user's journey.

2 **Record each step individually**

with one step per activity block. Use physical or digital sticky notes if you wish.

3 **Connect the activity blocks**
with directed arrows, fit all the blocks into one diagram.

4 **Repeat the observation process with real users**

to validate that the activity diagram is complete.

Useful Tip

This method provides the capability to breakdown user experiences, to capture work and play flows, to identify opportunities for simplification and automation, and to extract key insights for innovation. Activity diagrams may be easily combined with User Journey Maps.

Best Practices

Think user-centred

Activities should start with verbs (action words). Arrows represent order or causality of activities. Nodes (boxes) represent user activities.

Activities may be performed sequentially or in parallel

Clearly distinguish parallel (independent) and sequential (dependent) activities. Designers/ Engineers could ask, 'Could [Activity B] be done without doing [Activity A]?'.

Involve everyone

First work individually on naming activities, then refine them as group.

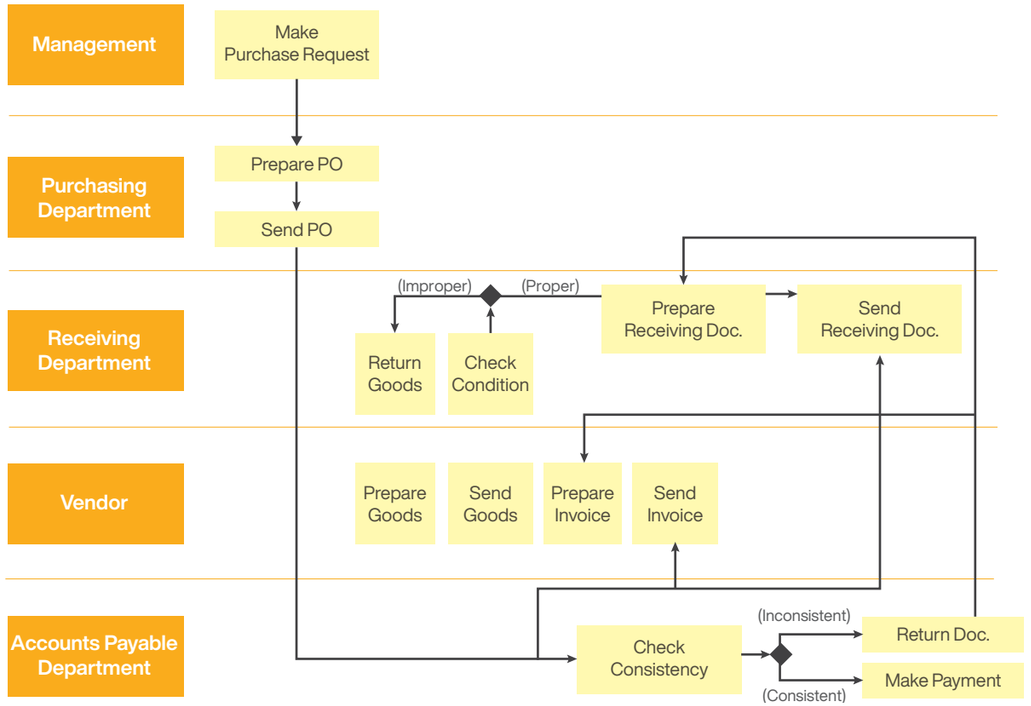
Define the system boundary of the PSS

Begin by recording the first and last step of the interaction and proceed with the steps in between.

Worked Example 1

Ford's Purchasing Process (1980s)

An activity diagram of Ford's purchasing process in the 1980s is drawn here. The Account Payable Department's 'Check Consistency' activity was identified to be a bottleneck in their purchasing process.

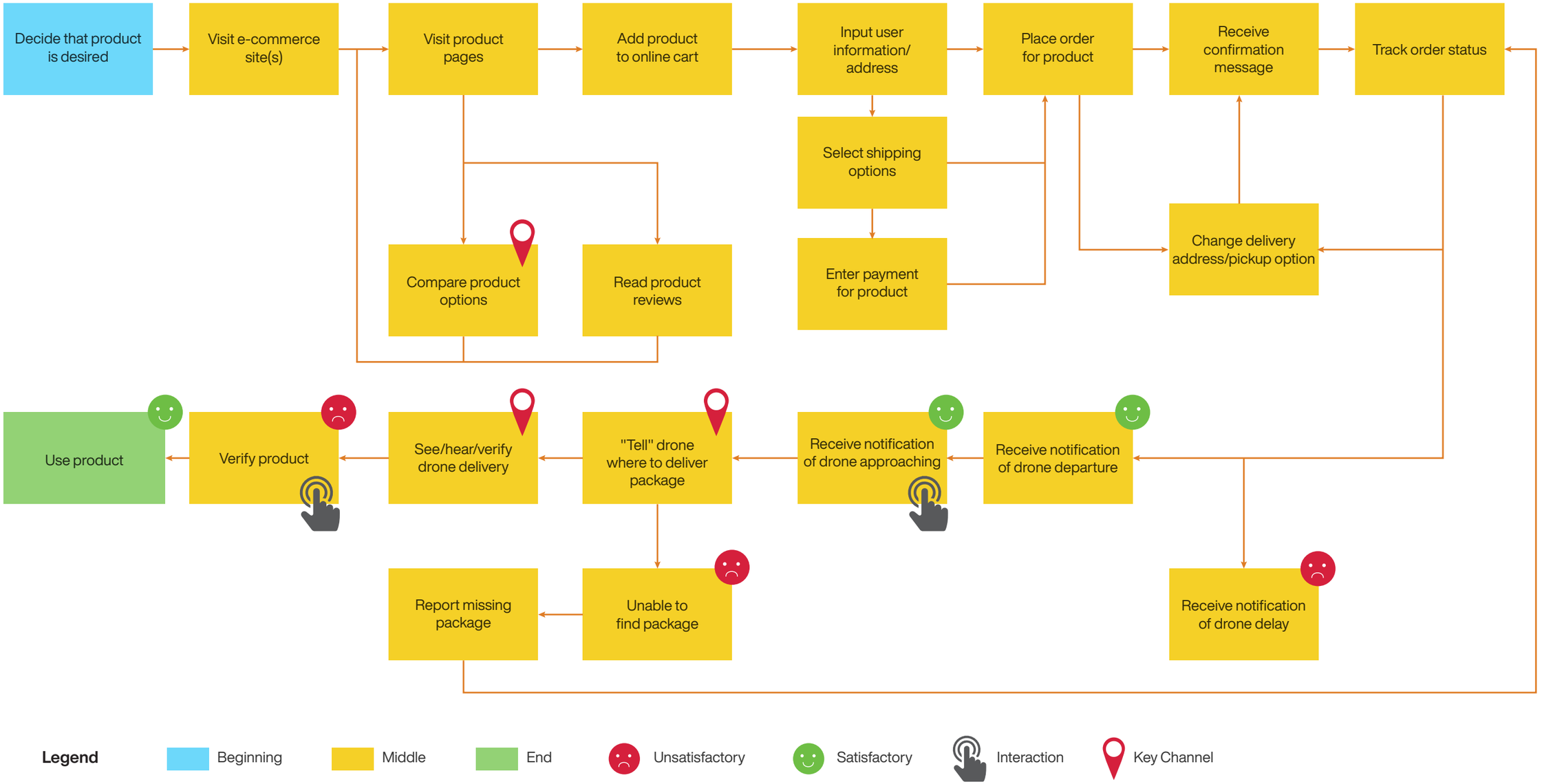


Worked Example 2

Online shopping with drone delivery - activity diagrams from the user's perspective.

Useful Tip

If any of the activities seem too vague, try to expand on the activities and break down into smaller steps.



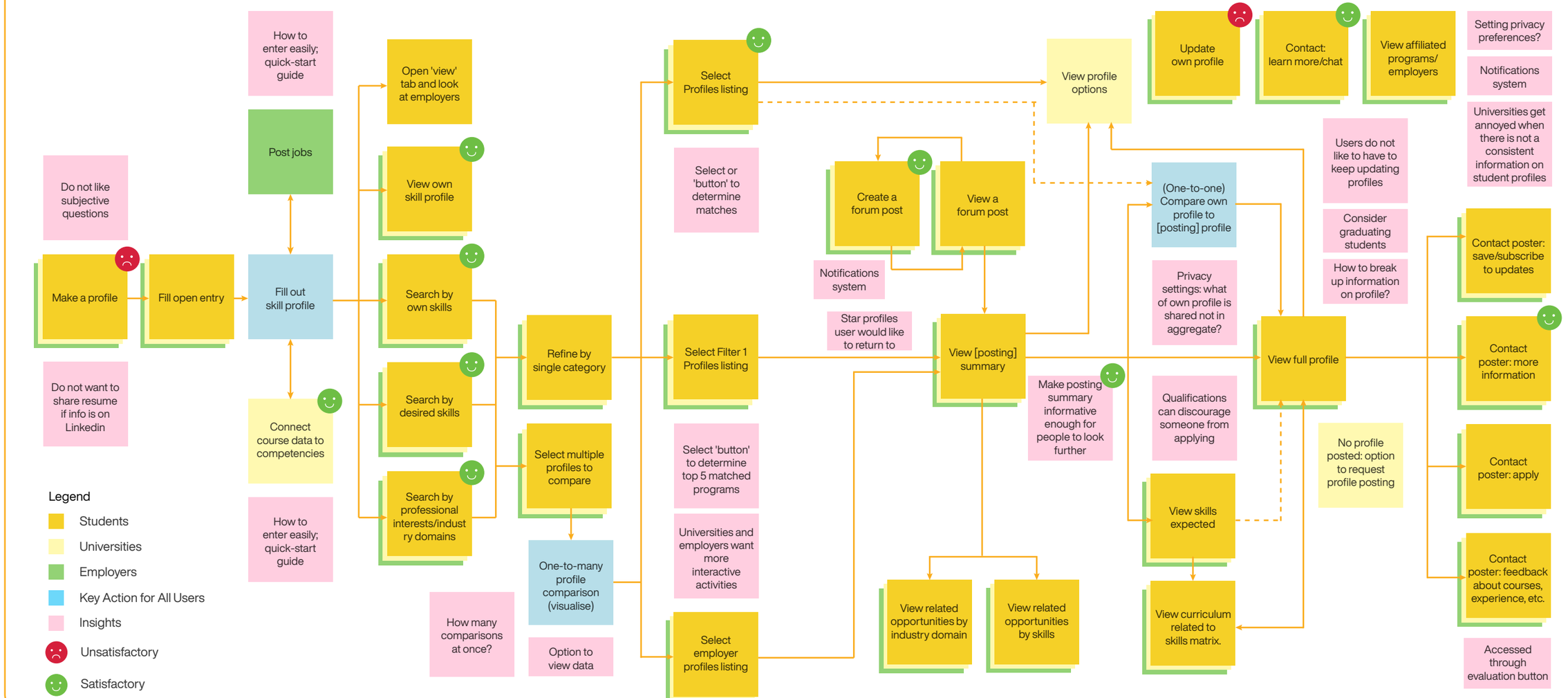
Worked Example 3

Activity Diagram brings clarity in understanding the user activity flow. It can be used to discover opportunities for automation, removing unnecessary steps users take, introducing innovative user interactions and experiences, identifying effective channels for user interactions and experiences, combining activities, and identifying potential failure modes.

In this example, the user experience of creating and editing profiles around skills and learning experiences is explored.

User Journey Map helps teams visualise and story-tell users' journeys for deeper empathy, enabling more integrated sense-making of needs and identification of specific opportunity areas for innovation. It also creates a shared reference frame around the user experience across stakeholders.

How might we design a collaborative web platform around sharing, visualising, and comparing data for the future of young professionals and potential organisations for employment?



Method

Systems Function Model

CARD 3 Mindfulness

Systems Thinking | Unraveling the System

Systems Function Model serves as a collection of summarised, high-level requirements and allows designers, engineers, and professionals to explore behaviours of the PSS.

Why: By thinking through behaviours, designers, engineers, and professionals naturally identify functions and insights about the PSS. Systems Function Models provide a breakdown of the system into modules, subsystems and functions. Insights, modules and key functions may be identified to generate opportunities.

Complementary methods: User Interviews, User Journey Map, Benchmarking, Affinity Analysis, System Architecture

Acronyms: AV - Autonomous Vehicle
Comms - Communication
GPS - Global Positioning System
HMW - How Might We
PSS - Product, Service, or System
UAS - Unmanned Aerial System
UAV - Unmanned Aerial Vehicle

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Procedure

1 Compile user needs

gathered from user research, such as user journey map, scenarios, interviews and questionnaires..

2 Define system boundary

of the PSS that designers want to investigate to find innovative opportunities.

3 Derive functions from user needs

and write them down in a list. Ensure that the functions serve the user's needs.

4 Organise functional interactions (Optional)

and connect the functions together using flows. These flows can be represented by arrows and can be classified based on how they cause functions to interact (e.g. energy, material, signal)

Framework

Apply Extreme-User Experience Framework

read more about the framework on page 39

a. Derive systems function that corresponds to the critical points for improvements identified using Extreme-User experience with User Journey Map.

b. List them as function-flow pairs that represent the design transformations required to ease user interaction. For example, capture user attention, provide feedback.

c. Extract sub-function that contribute to the identified systems function.

d. Use the sub-function to guide ideation.

Useful Tip
Functions are the operations performed by the PSS and not by the user

Best Practices

Keep functions abstract

Functions start with verbs and should not be associated with entities within the system.

Build your vocabulary[1]

Develop an extensive vocabulary of functions related to the opportunity helps in generating well-defined systems function model.

Understand the system's scope

The degree of specification depends on the type of design and customer needs. Using a more general flow description produces a generic function structure and a wider range of concept variants. However, if customer needs dictate concreteness in flows, then an increasingly specific level is more valuable.

Worked Example 1

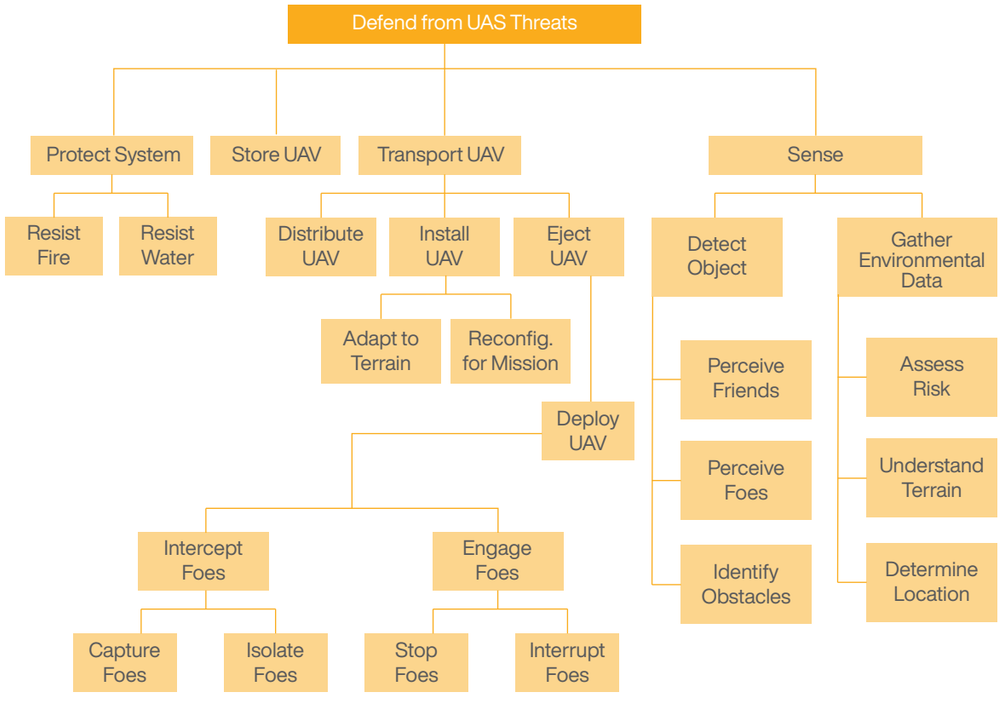
A list of system functions based on a remote-controlled Unmanned Aerial Vehicle (UAV) system used to defend against UAS threats.

How might we defend against Unmanned Aerial System (UAS) threat of Key Installation?

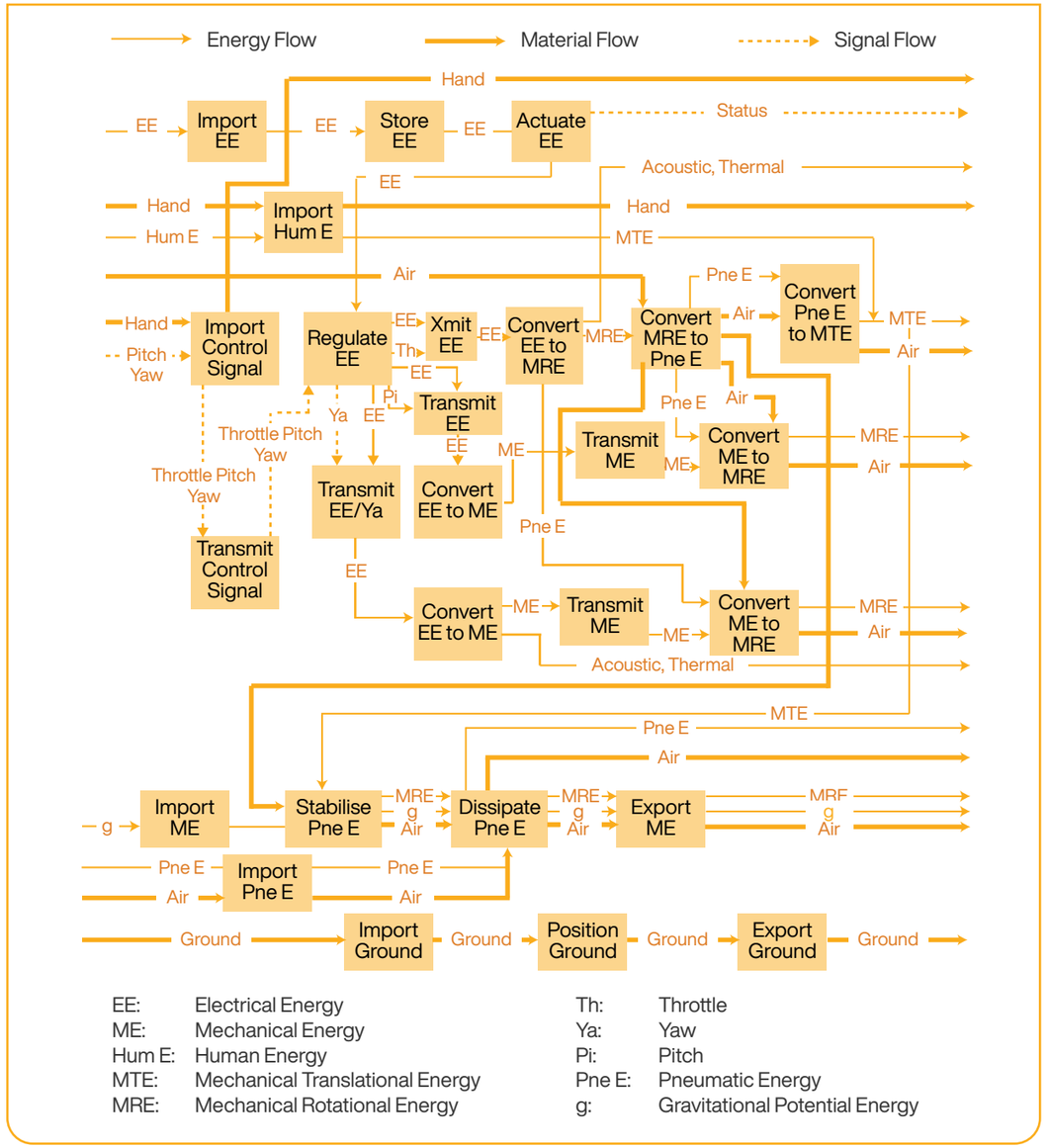
- Protect system from fire and water damage rapidly
- Store UAV in easily deployable space
- Transport multiple UAVs to area of interest easily
- Intercept foes without any collateral damage to key installation
- Stop foes from doing harm
- Detect dangerous object clearly
- Detect friendly units clearly
- Detect and avoid obstacles accurately
- Gather information such as GPS location accurately
- Understand terrain completely
- Assess risk of UAS Threat swiftly and accurately
- Alert user even when they are not paying attention to the system
- Provide intuitive manoeuvre during a high stress situation

Worked Example 1 (cont'd)

The system can be analysed in greater detail by creating a function tree from the list of functions, organising them hierarchically and breaking them down into sub-functions. A function tree starts with an overall function of the system, and branches out into primary, secondary and teritiary sub-functions, with increasing specificity. Function trees enable better understanding of the relationships between sub-functions.



Taking a step further, the list of functions could be organised into a Systems Function Model, which connects functions to one another via flows. These flows can be classified into energy flow (e.g. kinetic, electrical, hydraulic, magnetic energy), material flow (e.g. body parts, gas, liquid, solids), or signal flows (e.g. status, control). In the example given, these types of flows are represented using standard arrows, bold arrows, and dotted arrows, respectively.



Worked Example 2

A Systems function models may be in the form of lists of functions, a function tree, a function structure showing flows of energy, materials, and signals-information, or a blueprint of functions.

When stating functions, a suggested structure of the function statements for an opportunity/system is to start with an active **VERB**, followed by what the verb is acting on – **NOUN + ELABORATION**, and ending in an **ADJECTIVE or ADVERB**, providing a sense of what is intended to be achieved and how it might be measured. The examples shown on this page utilise this suggested structure, providing designers with the ability to define and clarify the opportunity statement, derive insights and foresights from functions, and use the functions in subsequent phases such as in Develop through ideation.

Suggested Structure of Systems Function

VERB + NOUN + ELABORATION + ADVERBS / ADJECTIVES

NOUN + ELABORATION: what we are concerned about

ADVERBS / ADJECTIVES: descriptive word

- Quickly, promptly, immediately, constantly, preemptively, preventively, continually, periodically
- Efficiently, proficiently, resourcefully, capably, skillfully
- Thoroughly, carefully, painstakingly, judiciously, meticulously, comprehensively
- Effectively, completely, absolutely, extensively, broadly, expansively, usefully, usably
- Excitedly, enthusiastically, joyfully, cheerily, jubilantly
- Compellingly, captivatingly, grippingly, enthrallingly, engrossingly
- Orderly, systematically, logically, tidily
- Obviously, clearly, visually, visibly, audibly, tactilely, perceptibly, evidently, olfactory, fragrantly
- Accurately, precisely, truthfully, justly, equitably
- Intuitively, instinctively, automatically, spontaneously, implicitly
- Safely, securely, carefully
- Comfortably, contentedly, easily
- Fully, copiously, abundantly, effusively
- Meaningfully, expressively, eloquently, evocatively
- Ethically, morally, justly
- Accessibly, conveniently, suitably
- Valuably, gainfully, economically, profitably, beneficially
- Strategically, purposefully, advantageously
- Desirably, pleasantly, pleasingly, satisfyingly
- Credibly, believably, convincingly, reliably, realistically

B Systems functions are useful and span all types and disciplines of design, and across all PSS. To show the variety and user-centred focus of systems function, an example is shown here for 'HMW design an amazing childcare experience?'

How might we design an amazing childcare experience?

The system must be able to:
- Calm baby when upset quickly
- Feed baby when hungry promptly
- Warm milk when needed quickly/pre-emptively
- Prepare food before scheduled meals accurately
- Monitor baby when unattended constantly
- Notice anomalies when upset quickly
- Alert caretaker to danger immediately
- Calm and assure parents who are anxious/worried thoroughly

C Systems functions may have a technical and pragmatic focus, and they may include intangible and emotional characteristics. Identifying and stating emotional functions for our design opportunities and co-creation with users enables us to connect with people, be user centered, and engage our mindset of empathy with depth and passion. An example list of functions, following the suggested structure in A., is shown here, for the opportunity statement of 'HMW increase brand awareness for our organisation, with users at the center?'

Intangible/Emotional functions

How might we increase brand awareness for our organisation, with users at the centre?

The system must be able to:
- Impress viewers when encountering content immediately
- Intrigue potential users to sign up quickly
- Compel potential users to share about the brand excitedly
- Disseminate information when needed effectively
- Monitor baby when unattended constantly
- Notice anomalies when upset quickly
- Alert caretaker to danger immediately
- Calm and assure parents who are anxious/worried thoroughly

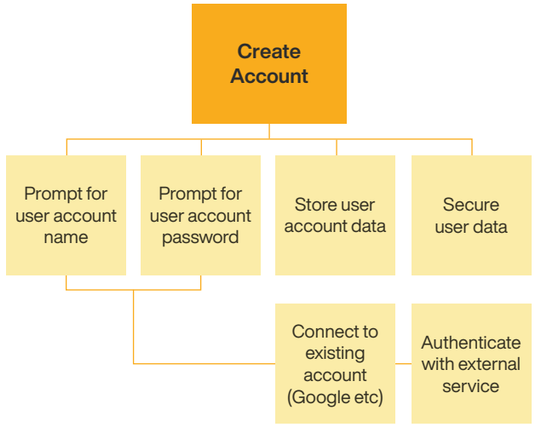
D As an additional example of systems functions utilising the suggested structure from A. and integrating both technical and emotional functions, we consider the opportunity statement of 'HMW effectively assist participants-users with wayfinding for physical and digital spaces?' This example continues the demonstration and illustration of the variety and span of PSS that may be reframed and expressed in terms of a systems function model.

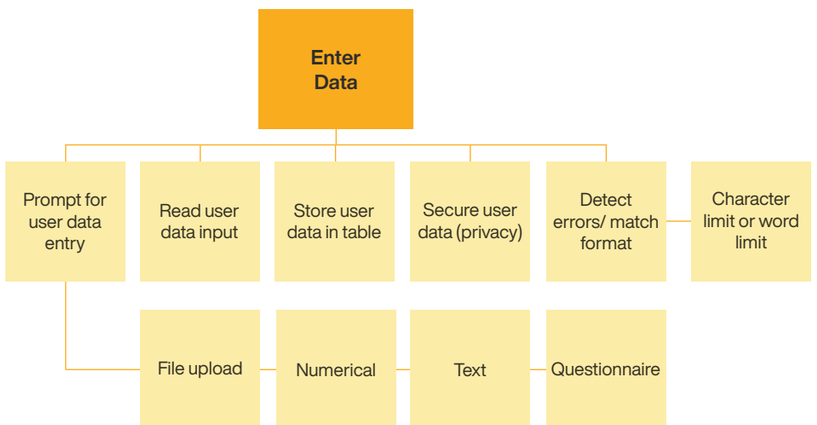
The system must be able to:
- Calm baby when upset quickly
- Feed baby when hungry promptly
- Warm milk when needed quickly/pre-emptively
- Prepare food before scheduled meals accurately
- Monitor baby when unattended constantly
- Notice anomalies when upset quickly
- Alert caretaker to danger immediately
- Calm and assure parents who are anxious/worried thoroughly

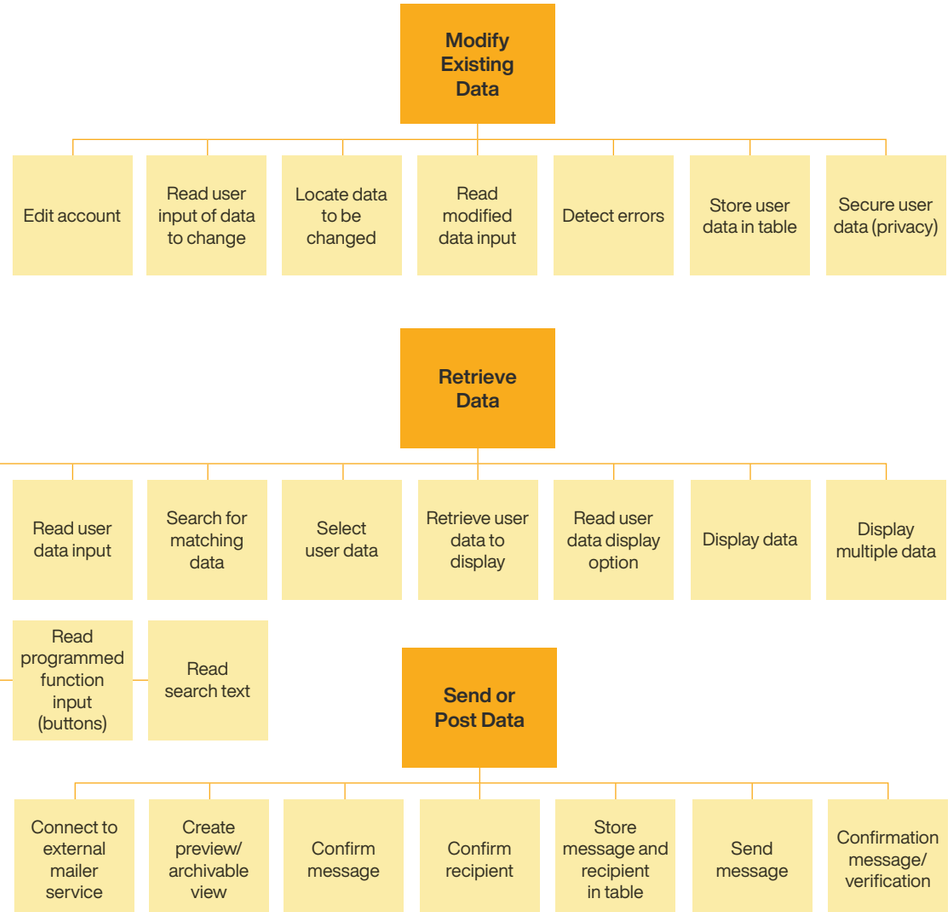
Worked Example 3

The systems function tree articulates the core basic functions required of a design solution to the design opportunity. The function tree is helpful to identify similar sets of subfunctions, indicating common modules, or parts of the design that can be used in multiple places.

How might we design a collaborative web platform around sharing, visualising, and comparing data for the future of young professionals and potential organisations for employment?







Worked Example 4

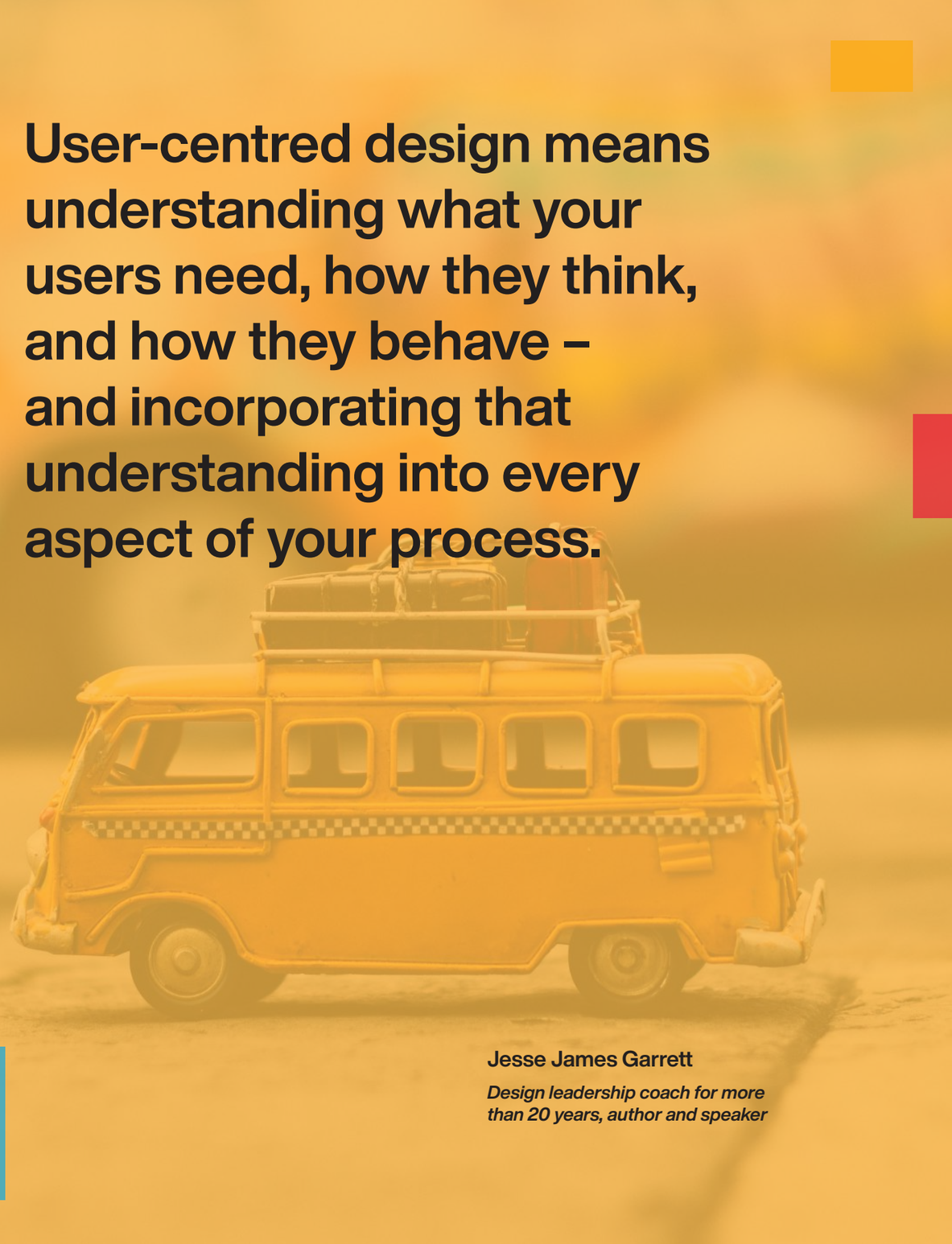
Autonomous Vehicle (Taxi)

Order Taxi	Access the AV	Entertainment
Receive & process order quickly	Upload customer customised AV inputs quickly	Display customer customised AV inputs
Capture preferences fully	Monitor customer health vitals constantly	Display, relevant local information (news, weather)
Predict orders and requirements accurately	Validate pickup point accurately	Sense and learn customer preference for media, news, local information discretely
Convert requirements to commands	Open passenger door automaticially (without using hands)	Suggest customer profile-based entertainment appropriately (kid, tourist, local, business professional)
Feed comms commands to virtual assistant	Feedback non-visually when the passenger door is opened responsively	Interact with customer engagingly
	Provides shelter when the customer boards the taxi helpfully	
	Directs the taxi to immobile customer intuitively (wheelchair user, parents with baby stroller, etc)	

Legend

- Function
- Sub-function
- Extreme-User Experience Framework

User-centred design means understanding what your users need, how they think, and how they behave – and incorporating that understanding into every aspect of your process.



Jesse James Garrett

Design leadership coach for more than 20 years, author and speaker

Method

How Might We

CARD 9 Mindfulness

Design Thinking | Scoping Opportunity

A How Might We (HMW) statement is a reframing technique that concisely states the scoped and reframed opportunity based on key needs and insights uncovered from research and other design innovation methods.

Why: How Might We allows the design team to think critically about the problem/ opportunity and to decide if they should pivot or sharpen the scope, so that they are clear about the stakeholder, the solution and the purpose of the solution.

Complementary methods: All methods in Develop phase

Acronym: HMW - How Might We

Procedure

1 Identify key needs and insights

uncovered and synthesized from research.

2 Draft the HMW statement

HMW statements come in several structures. Here is a basic one:

How might we → do something for someone → in order to → achieve a goal ?

Try to create more than 1 HMW statement to capture multiple stakeholder perspectives and/or measures of success.

3 Scope the opportunity of the HMW

by broadening or narrowing it as appropriate, such that it allows an exploration of multiple solutions. This will take practice.

Framework

Apply Extreme-User Experience Framework

read more about the framework on page 39

Consider the learnings from extreme scenarios, draft a HMW statement.

How might we [extreme-user experience inspired system function] to [what we want to achieve]?

Useful Tip

A good How Might We statement should

- Invite multiple solutions
- Address a real problem
- Leave the team feeling inspired to work on it

Worked Example

How might we	→	do something for someone	in order to	achieve a goal ?
How Might We	→	empower health workers in their day-to-day operations	in order to	improve the standard of care services ?
How Might We	→	demonstrate the usefulness of technology to the elderly	in order to	increase the overall technology adoption rate ?
How Might We	→	create an office space for executives	in order to	to make them look forward to coming to work ?
How Might We	→	alert user even when they are not paying attention to the system	in order to	inform users of any critical changes or unnoticed errors? ?

Extreme-User Experience Framework

Improving Toilet Conditions

How Might We enable public transport commuters to easily report poorly serviced station toilets in order to improve toilet conditions and reduce complaints?

Prudent Spending With Cashless Payment

How Might We equip young students to do cashless payments while developing skills in prudent spending?

Traveller Experience And Security Screening

How Might We improve and streamline the traveller experience while improving the level and speed of security screening?

Method

5 Whys

Design Thinking | Probing Root Causes

CARD 7 Mindfulness

5 Whys is a questioning technique used when engaging with users after a response is given.

Why: 5 Whys is a method to dig deeper and uncover needs that is not obvious or unobservable to get essential answers to a complex issue such as psychology or emotional needs.

Complementary methods: User Interviews, How Might We

Procedure

1 **Start with a broad question**

2 **Go deeper with First 'Why'**

Remember not to ask horizontal questions (How, What etc.)

3 **Write down answers**

and pay attention to transition to a deeper level of understanding of a problem.

4 **Be mindful**

to reach a core fourth or fifth 'Why?'

Worked Example

HMW design enjoyable and valuable AV rides for families?

Insight: Mother of 2 prefers taking double decker bus with her kids.

Q1 **WHY**... do you prefer taking double decker buses?

Oh! My kids really enjoy them.

Q2 **WHY**... do your kids enjoy them?

They really love the upper deck.

Q3 **WHY**... do they love the upper deck?

They love the view!

Q4 **WHY**... does this bring you enjoyment?

It's nice that my kids are engaged and entertained.

Q5 **WHY**... do you enjoy your kids being engaged and entertained?

They're happy, and gosh, I finally get to take a break and relax from watching them all the time.

Method

Service/UX Blueprinting

Systems Thinking | Unraveling the System

CARD 11 Mindfulness

Service/UX Blueprinting is a diagram that visualises the relationships between people, products and processes in a specific user journey[3] or scenario. It is an extension of an activity diagram and journey map, complementing the frontstage with the backstage.

Why: Service/UX Blueprinting brings clarity with a big picture view of the products, services, and systems (PSS) and helps align teams and facilitate knowledge sharing as well as support ideation and prototyping.

Materials: Sticky Notes, Wall/Board, Service/UX Blueprinting Template

Complementary methods: User Journey Map, Activity Diagram, Personas, Scenarios, Storyboarding

Acronyms: AV - Autonomous Vehicle
FOH - Front of House
PA - Public Announcement
PID - Passenger Information Display
PSS - Product, Service, or System
UX - User Experience

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Procedure

1 **Lay out the space**
and different stages in the PSS in the UX/ Service Blueprint

2 **Fill in the user/customer journey and frontstage actions**
fill in the 'Sketch and Build Plan' section. Sketch key components of the prototype, labelling the intention of the component, and materials required.

3 **Fill in the Backstage Actions, Support Processes**
which may include system functions

4 **Add the evidences**
and any relevant additional elements

5 **Find insights**
from the Service/UX Blueprinting

Useful Tip
Mapping a service/UX blueprint requires information from various different sources. It is necessary to make sure the interactions are truthful from every source to detect gaps in the service.

Key Elements of a Service/UX Blueprint[3]

Evidence	Props (physical or digital evidence) that support the customer/user
User actions	Steps the customer/user takes
Frontstage actions	Steps that occur directly in view of the customer (both human-to-human and human-to-computer)
Backstage actions	Steps and activities that occur behind the scenes to support onstage happenings
Support processes	Internal steps, and interactions that support the employees in delivering the service

Worked Example 1

To investigate the transfer experience at previously built interchange train stations, the organisation's team created a service blueprint from the initial train to the transferred train. Each customer action is analysed in detail, listing evidences, frontstage actions, backstage action and support processes into one section.

How might we design future ready stations, considering the integration of a future interchange?

Steps	Initial Train	Platform of Initial Train		Transfer Walkway		Train Platform		Transferred Train
Evidence	Announcement	Signage, temporary guide rail	Escalator/ stairs/ lift, visual cues	Travellators	Signage	Escalator/ stairs/lift, signage	Announcement	
User actions	Select door	Look and follow visual cues	Determine Direction	Take travellator or walk	Tap out and tap in for unpaid link	Check signage	PID next train Select Door	Enter train
Line of interaction								
Frontstage actions	Next station and interchange announcement			Ushers at critical points		Signage on replacement (ceiling escalator FOH)	Ushers at peak hour	
Line of visibility								
Backstage actions & Support processes	Passenger flow monitoring and reaction	Ushers at peak hour	Change of escalator direction when necessary					
	PA systems, PID systems, escalators, lighting							

Worked Example 2

This is a Service/UX Blueprinting for taking a taxi ride as a proxy as a potential for creating an AV system.

	Pre-journey				During journey					Post journey	
Steps											
Evidence	Mobile phone – booking confirmation		Pick-up point	Taxi license plate number	Taxi interior					Drop-off point surroundings	Mobile phone – feedback survey
User actions Passenger	Books vehicle	Tracks driver location	Waits at pick-up point	Boards taxi	Settles down in taxi	Talks to driver	Enjoys music	Tracks journey		Exits taxi	Leaves feedback
Line of interaction											
Frontstage actions Driver		Drives to pick-up point		Stops at pick-up point		Talks to passenger		Refers to map to help with wayfinding	Responds to next ride request	Stops at drop-off point	
Line of visibility											
Backstage actions Driver	Accepts ride booking										Review feedback
Line of internal interaction											
Support processes Company	Matches passenger and driver	Tracks driver location real time	Provide wayfinding and location information				Provide music streaming	Tracks travel journey progress real time	Matches next passenger and rider	Process payment	Collect feedback
Risks			Late arrivals	Ride cancellations		Harm from strangers encountered in ride sharing	Traffic jam	Car accident	Car sickness, vomitting		
Policies/ regulations			Feedback affecting passenger & driver track record			Passenger and driver identify and track record	ERP, COE	Traffic rules (e.g. speeding limits)			
Insights			Errors and difficulty in going to the exact pick-up point spot			What car interior makes social interactions conducive?	Enhancing entertainment options		Allow option to stop ride to deal with car sickness?	Leaving belongings behind in the taxi	

Method

Benchmarking

CARD 12 Mindfulness

Systems Thinking | Contextual Understanding

Benchmarking identifies and compares similar situations and/or solutions with one's company and/or solution.

Why: Benchmarking could help with understanding the competitor landscape and the company's competitive advantages. It could also improve performance by identifying and applying best demonstrated practices.

Materials: Library, Online resources

Complementary method: Systems Function Model

Acronyms: JR - Japan Railways
NYC - New York City
PSS - Product, Service, or System
TSIA - Technology Services Industry Association
USA - United State of America
UX - User Experience

Procedure

1 Form a List of Design Issues

A list of design issues must be developed for efficient exploration path

2 Form a List of Competitive or Related PSS

List all competitors and their different PSS models, and also other related PSS in their portfolio

3 Conduct a Information Search

- Gather as much information about the listed competitive PSS as possible
- Information could be related to functions or market segment

4 Benchmark by Domain/Market/ Systems Function/ Affordances

List all competitors and their different PSS models, and also other related PSS in their portfolio

5 Establish Best-in-Class Competitors by Domain/Market/ Systems Function/ Affordances

Call out the highest performing PSS across these dimensions

6 Plot Industry Trends for (Re-) DesignTask

- Categorise the PSS solutions by the socioeconomic status of the users and by percentage of the market
- Diffusion of innovation can be plotted as a timeline behaviour of Impact vs Time

Useful Tip

Benchmarking compares different companies in the same industry and uses a set of criteria to assess the similarities and differences, just like a ruler measuring different lengths.

Worked Example 1

The set of criteria chosen should be relevant to the area of opportunity for innovation. In this example, an external/competitive benchmarking was done with other rail systems around the world.

			
Criteria	Train System	JR Train System in Japan	NYC Subway System in USA
	Service Schedule	Ends around 11 PM - 1 AM	24/7 service
	Fare System	Ticket barrier	Swipe at entry only
	Operating Speed	120 km/h [1]	28 km/h [2,3]

Worked Example 2

E-commerce sites

Websites A-D are identified and benchmarked with one another according to the features as listed in the top row in the table below.

Website	Promotional Email Frequency	Loyalty Programmes	Average Order Value	International Shipping	Customer satisfaction
A	1 / year	No	$90	Yes	★★
B	3 / year	Yes	$130	Yes	★★★★
C	6 / year	No	$30	No	★★★
D	12 / year	Yes	$70	No	★★

Useful Tip

Benchmarking can also be done with other related industries, and should be done continuously to stay relevant.

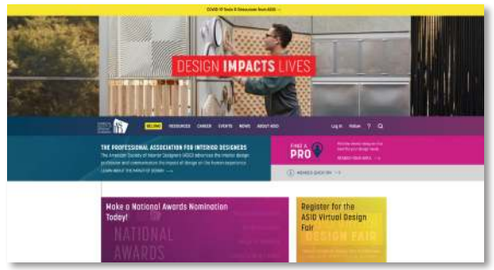
Worked Example 3

The set of criteria chosen for benchmarking should be relevant to the area of opportunity for innovation. In this example, benchmarking was done over a set of professional society websites according to user experience factors. This benchmarking helps identify design choices that contribute to positive user experience on the web, setting a standard by which future designs can be evaluated.

Other forms of benchmarking could complement the study. For instance, internal benchmarking could be used to study the innovations done by the organisation itself.

Resolving a tie between designs that receive the same benchmarking evaluation can be done through discussion of what details differ, and this could inform an evolution of the benchmarking criteria.

How might we design a collaborative web platform around sharing, visualising and comparing data for the future of young professionals and potential organisations for employment?



Website #1
American Society of Interior Designers
https://www.asid.org/

Website #2
Information Systems Security Administration
https://www.issa.org/

Website #3 Tie with #4
Technology Services Industry Association
https://www.tsia.com/

Usefulness	Communications and featured reports are easy to find. Language is effective and inviting: 'Belong' as well as clear presentation of opportunities to belon g and receive guidance for professional development.	Key Information all located in main title bar, making this site's purpose instantly clear.	Has a clear purpose, and lets the user know this by immediately asking 'How can TSIA help you?' below their mission statement on the home page.
Usability	Rollover boards give depth to information and allows for compact presentation.	Simple and straightforward design means this site is very easy to use.	The site is very easy to use and navigate; the user can clearly see all navigation options.
Desirability	Use of colour makes the site experience joyful. Pictures of people emphasise who the community is.	Eye-catching graphics and motion are a positive, but no pictures of human faces makes this group feel impersonal.	A calm blue and orange colour palette gives a business feel and uses the layout of the very popularised tiles on certain areas of the website; human faces provide a personal touch.
Navigation	Information clearly labeled and compact; social media connections clear. Information is up to date.	Navigation very easy. Information clearly labeled and compact; social media connections clear.	Navigation is clear; social media is active and links to connect are easy to find.
Accessibility	High contrast between background and font colours and large images help make this site accessible.	Medium contrast but large images help make this site accessible.	High contrast, however frequent use of dropboxes may cause more confusion.
Credibility	Emphasis on engagement by leadership with entire society; professional values are clear and consistent with presentation.	Very professional feel. Look and feel give a good sense of the organisation's values and how this group approaches the information security field, as well as clear ways to connect with others.	Appears a credible and established organisation.

Legend

Good points

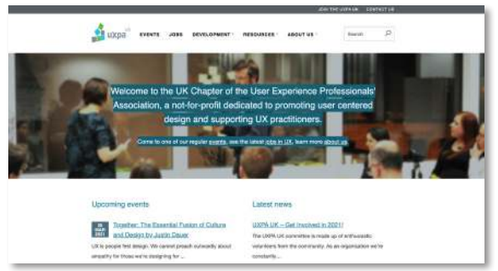
Bad points

Worked Example 3 (cont'd)

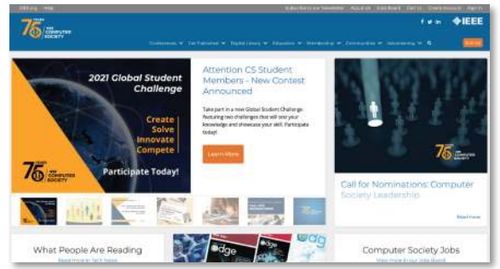
How might we design a collaborative web platform around sharing, visualising and comparing data for the future of young professionals and potential organisations for employment?

Website #4 Tie with #3
Healthcare Information and Management Systems Society
https://www.himss.org/

Website #5
Association for Computing Machinery
https://www.acm.org/



Website #6
User Experience Professionals' Association
https://uxpa-uk.org/



Website #7
IEEE Computer Society
https://www.computer.org/

Usefulness	Very clear and straightforward initiatives and solutions listed.	Effective presentation of the breadth of membership goals, how to learn more, and how to be involved in various initiatives.	Content is minimal but sufficient to introduce visitors to this community.	Very good resource for the latest conversations on technology.
Usability	Clear delineation of content with images to illustrate makes site easy to read and topics of interest are clearly labelled making it easy to focus on your interest areas.	Good job presenting information and data in an accessible way, particularly in digital library	Very simple layout and colours make experience very functional.	Many different opportunities and links to get more information.
Desirability	Shade of blue is very calming and the images of people provide a personal touch.	Information-heavy which makes sense for field, but would be more inviting to see more faces of who the society is. Good use of colour; simple but not distracting.	Look and feel is lackluster and feels cold.	The colour scheme is neutral and a little bland; colours could be richer. Look and feel does not match the theme of technology updates, and lacks a personal touch.
Navigation	Easy to navigate through; not a lot of information being thrown out at once on home page.	Navigation is very easy and intuitive.	Very easy to navigate site	A lot of information on the page can make it challenging to find what you're looking for. Several of the dropdown headers are overlapping topics, e.g. Publications and Digital Library.
Accessibility	Some pages are saturated with text which can be difficult to read; some font may be small.	Lots of information is presented well, with images to separate text. More can be done in some areas to break up the large amount of information and make it more digestible.	Large fonts and clear contrast between text and images make this site accessible.	Information accessible through direct links, rather than drop-down menus makes it easier for individuals with performance constraints
Credibility	Global healthcare company that shows its history and coverage across the industry interests adds credibility.	Presents as an innovative leader in the field.	Visual design choices do not appear to connect well or show appreciation for the field of UX.	Well established society; however there is a lot of information on the page

Method

Hierarchy of Purpose

Design Thinking | Scoping Opportunity

CARD 6 Mindfulness

Hierarchy of Purpose is an approach to help in reframing and scoping a design opportunity statement by re-writing the opportunity statement in quantitative way. It is part of the reframing and insight development process in the Define phase.

Why: Hierarchy of Purpose is useful to develop insights and foresights, to discover various causes and effects in an opportunity and helps to quantify the metric of success.

Material: Hierarchy of Purpose Template

Complementary methods: User Interviews, User Journey Map, Benchmarking, Affinity Analysis, Activity Diagram, Service/UX Blueprinting, Systems Function Model (Insights and Foresights from above)

Acronyms: HMW - How Might We
UX - User Experience

Scan or click here for a digital copy of the template

Procedure

1 State the original design opportunity statement

2 List up to four General

opportunity statements which have broader scope than the original statement. To abstract up, ask 'why'.

3 List up to four Specific

opportunity statements which have narrower scope than the original statement. To scope down, ask 'how'. Write them in the following format:

How might we increase/decrease [Metric] by [Desired level]%?

4 Review the list

of new statements and select one or more with the appropriate level of complexity.

Important Note

A design opportunity/problem may:

- Implicitly cover multiple user needs
- Be addressed with many potential solutions
- Be phrased as 'How Might We [design problem statement]' to encourage active response

Useful Tip

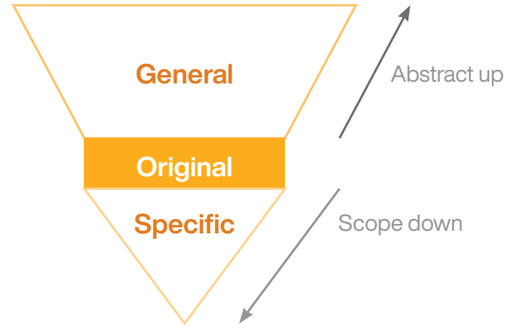
- Focus on goals, not solution
- Refrain from considering manpower, time, or monetary goals

Best Practices

Use the diagram on the right to help you to review the opportunity statement in Step 4

Ask questions such as:

'What will the original opportunity impact?' (Why?)



'How do we satisfy the original opportunity?' (How?)

The metrics you use can be % percentages, or embedded in the phrasing of your statement

Here are some examples:

HMW increase **employee statisfaction** to **more than 85%**?

HWM encourage jobseekers to **take up jobs that are not in demand by 50%**?

HMW **secure candidate profile authenticity to 100%**?

HMW create a great impression **in the first 10 seconds**?

HMW get users all the information they need within **3 clicks**?

HMW allow people to purchase goods from local artisans to be **as easy as walking into their local supermarket**?

Worked Example 1

General	HMW make road accidents a thing of the past?	HMW transition Singapore into a more knowledge-based economy?	HMW make Singapore car-lite?
	to prevent road accidents	to align with Singapore's more generally with Singapore's goals of Skills Future and raising the economic level of all Singaporeans	motivation from identified stakeholder needs of sustainable transportation and reduction of carbon footprint
	Why do we need to design an AV system?		
Original	HMW design an Autonomous Vehicle (AV) system for the future of Singapore?		
	How do we design an AV system?		
	insights directly from user needs and testing from interviews and focus groups	key user need categories and insights (affinity analysis); need categories and insights of enjoyable rides for users and professionally valuable rides	connect with extreme user personas and user needs; to connect with persons with disabilities, which in turn have unexpected and surprise benefits for all users
Specific	HMW retain a sense of emotional warmth in AVs even without a human presence? such that riders don't miss human drivers?	HMW make long AV rides more enjoyable and valuable, such that user satisfaction is > 99%	HMW allow users of any physical ability to be able to board the AV from any location?

Abstract up (Why?)

Scope down (How?)

Worked Example 2

General	How might we improve the efficiency of all the operations conducted in MRT stations?
Original	How might we enable ease of maintenance and reduce operational cost to lower overall project life cycle cost?
Specific	How might we design an inclusive station for maintenance and operation staff that increase/decrease the mean time to repair equipment by 50%? How might we increase/decrease facility/system downtime so as to reduce impact of travelling time for commuters by at least 50%? How might we increase/decrease energy consumption by 30% while increasing/decreasing comfort of commuters/staff by 50%?

Worked Example 3

General	How might we increase the canteen owners' satisfaction? How might we increase the customer base for the canteen?
Original	How might we increase the profit of canteen owners?
Specific	How might we increase/decrease canteen overhead by 40%? How might we increase/decrease cleaning staff by 50%? How might we increase/decrease trays left on tables by 80%? How might we place a return slot for trays at each exit (100% coverage)?

Method

Influence Diagram

Systems Thinking | Probing Root Causes

CARD 4 Mindfulness

Influence Diagram is a visual tool to represent the relationship between uncertain events (information), decisions, and outcomes.

Why: Influence Diagram shows how uncertain information propagates to impact design decisions and design outcomes. It is useful as a simple representation of whether uncertain variables are considered dependent, or independent. At early stages of design, influence diagrams are valuable to discover and represent factors that may impact design outcomes.

Materials: Sticky Notes

Complementary methods: User Journey Map, Personas, Scenarios, Activity Diagram

Procedure

1 **Identify the primary end outcomes(s)**

that are most important.

2 **Ideate on key design decisions and variables**

that may impact the decisions or outcomes.

3 **Connect variables, decisions, and outcomes**

with arrows to represent the flow of information: the result of a decision, or the value of a variable.

4 **Analyse the diagram**

to ensure that there should be no cycles; this implies information relevant to a decision depends on its outcome. Which variables are independent, and which are dependent?

5 **Quantify uncertainties**

if appropriate. Discuss whether the calculated range of outcomes is what is expected.

6 **Review and update**

as more is learned about what may impact the design, the diagram and uncertainties can be updated.

Key Components

People
Who is involved in the process?

Methods
What are the process steps?
How are decisions made?

Machines
What equipment is used?

Materials
What resources are required?

Measurements
What data is collected, and how will it be used?

Environment
What external factors impact the decisions or design outcomes?

Best Practices

Be consistent

There is not a unique influence diagram to describe a given situation. Therefore, a single diagram should be internally consistent, or representing a single view of a situation. If this is the case, the diagram is considered 'proper'.

Preparation

As soon as possible, the decision facilitator should develop a list of the uncertainties that will probably be important. Although this list will be revised during the analysis, it lays the groundwork for developing a deterministic model. The model will need to contain as explicit variables the major uncertainties identified and should be suitable for analysing the alternatives that have been developed.

Stop appropriately

When a level of detail is reached where intution and judgement can be used to make meaningful assessments, designers/engineers can stop adding to the diagram.

Complement with Decision Trees

Influence diagram contains basic information and is good for an overview. However, decision trees are more detailed and could get messier. Use influence diagram as a step to develop the decision tree and also to present to upper management.

Node Components

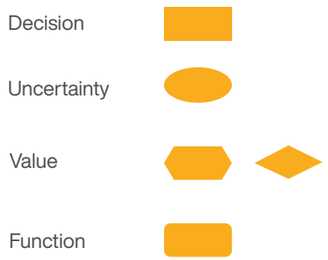
The meaning of each node component is determined by the shape. Node components1 consist of decision nodes, chance nodes, value nodes, and function nodes.

Decisions or 'decision nodes' are represented as squares or boxes. These are the actions carried out by the decision-maker.

Uncertain variables or conditions, 'chance nodes', are represented as circles or ovals.

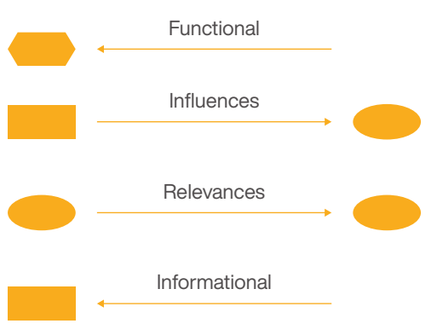
Final values or outcomes are represented as diamonds, hexagons, or octagons. There can only be a maximum of 1 value node, however the position of it depends on the outcome we are seeking.

Functions are represented as rounded rectangles.

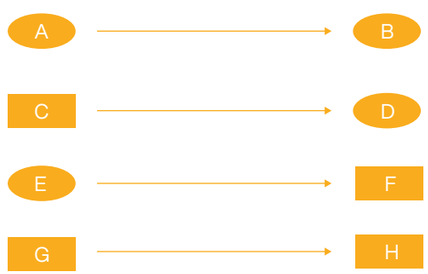


Nodes might be connected by arrows to show dependencies. The meaning of the arcs/arrows must be seen relative to the type of nodes they are connecting to. The lack of arcs/arrows, which implies lack of dependence, should also be noted in an influence diagram.

Arrows that go into outcomes or final value nodes are called 'functional'. Arrows that go from a decision to a chance node are called 'influences'. Arrows that go from a chance node to another chance node are called 'relevances'. Relevances does not imply causality. Arrows that go into decision nodes are called 'informational'.

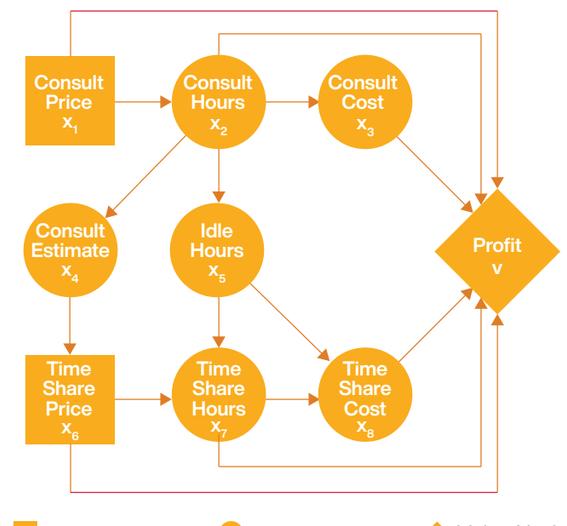


The probabilities associated with random variable B depends on the outcome of random variable A. The probability of random variable D depends on decision C. The decision maker knows the outcome of random variable E when decision F is made. The decision maker knows decision G when decision H is made.



Worked Example [6]

Influence diagram of a consultant having a computer that is not fully utilised, which has an opportunity to earn extra income. The extra income comes from time-sharing service as drawn in the lower part of the diagram. Dependencies of the value node, which is the profit in this case, is shown by the arrows into the value node. Independencies are also implied in the lack of arrows.



	Name	Type
1	Consult Price	Decision
2	Consult Hours	Chance
3	Consult Cost	Chance
4	Consult Estimate	Chance
5	Idle Hours	Chance
6	Time Share Price	Decision
7	Time Share Hours	Chance
8	Time Share Cost	Chance
v	Profit	Value

Useful Tip

Influence diagram can be expressed visually or mathematically when presenting to various stakeholders.

Method

House of Quality

Systems Thinking | Summary of Analysis

CARD 5 Mindfulness

House of Quality [2], sometimes called Quality Function Deployment translates user needs into a set of design requirements.

Why: House of Quality structures discussions about how design requirements contribute to satisfying user needs, how characteristics of the design positively or negatively interact, and benchmarks against market competition. Each area of the house is an opportunity for discussion and exploring different design functionality and embodiment alternatives.

Materials: House of Quality Template

Complementary methods: User Interviews, Benchmarking, Affinity Analysis, Personas

Scan or click here for a digital copy of the template

Procedure

1 Capture user needs

Developed in the define stage.

- 'What is to be done'
- 'What can the product, service, or system provide to the users'

2 Determine priority

of user needs relatively on scale of 1-5 or 1-10.

3 Translate user needs

Into measurable design requirements.

4 Determine relationship

of design requirements to user needs and the strength of the relationship.

5 Benchmark

Perform qualitative competitive benchmarking. Capture feelings of user.

6 Set targets

Set design requirement targets and select areas for improvement.

Best Practices

Prioritise users

Continuously seek user and stakeholder input as information is entered in the house of quality.

Be open

Treat results from the house of quality not as absolute decisions, but as a starting point for further ideation.

Function, not embodiment

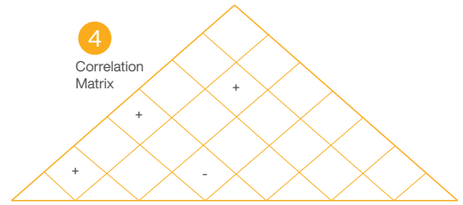
The house of quality is best used to consider the functional aspects of a design, rather than embodiment.

Worked Example

A New Transportation System

The attributes of design (left column) are reflected in the characteristic of design (middle table). In the first row, reducing energy usage and emission leads to an eco-friendly solution. Hence, we put crosses (x) to mark these relationships.

The roof of the house describes the interaction between each pair of functional characteristics. For example, increasing maintenance frequency decreases the average delay of the system (-), and increasing route coverage increases energy usage (+).



3 How: Functional requirements

1 What: User requirements	2 Importance rating	Energy usage	Route coverage	Average delay	Maintenance frequency	Space for bicycles	Stops close to housing and work	Average emissions	5 User targets and ratings i.e. Compare to exclusive automotive or bus travel
Eco-friendly		×						×	
Clean					×			×	
Provides access			×				×		
Punctual				×					
Reliability					×				
Multi-modal Friendly						×	×		

1 + 2 + 3 + 4 + 5

6 Targets: How much	kWh per passenger-kilometre	Percentage of area	Minutes	Hours per week	Number of dedicated bicycle storage	Average development density within	Annual GHG emissions

Method

Ishikawa (Fishbone) Diagram

CARD 8 Mindfulness

Systems Thinking | Probing Root Causes

Ishikawa Diagram, also called fishbone diagram, is a type of cause and effect diagram.2 It shows events that lead causally to a specific problem.

Why: Ishikawa Diagram is used to identify root causes of problems, provide insights to interventions that may help resolve problems, and identify variables to explore in testing for defect prevention.

Materials: Ishikawa (Fishbone) Template

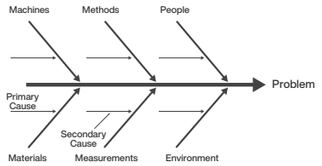
Complementary methods: User Interviews, Influence Diagram, Activity Diagram, Systems Function Model

Scan or click here for a digital copy of the template

Procedure

1 Identify Key Opportunity/Problem

and place it at the 'head' of the fishbone structure.



2 Identify parameters

of the system that fall under each of six key components:

People	Who is involved in the problem? What might human error look like?
Methods	What are process steps? What is required to execute the process?
Machines	What equipment is used? What makes the event happens?
Materials	What resources are required? What raw materials are used to produce the Products, Services and Complex Systems (PSS)?
Measurements	What data is collected from the event, and how will it used to evaluate the quality of the PSS?
Environment	What external factors impact the decisions or design outcomes?

3 Label primary causes

of the problem as horizontal arrows that lead into the associated component, and secondary causes branching again off of the primary causes.

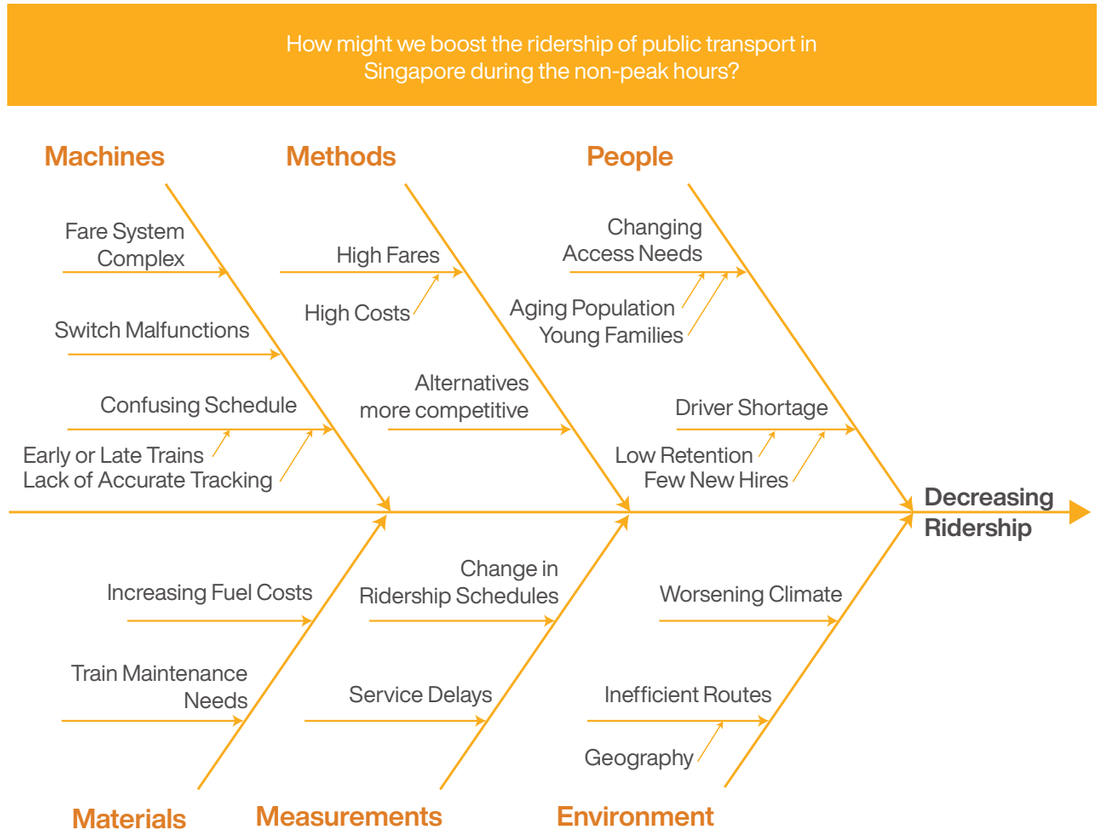
Useful Tip

This method can be combined with site analysis or shadowing to understand the 'environment' or 'people' branches better.

Worked Example

In this worked example, the problem of 'Decreasing Ridership' is identified. Many primary and secondary causes are then identified and labelled.

For instance, under the People component, a primary cause, 'Changing Access Needs' is identified and labelled. Secondary causes identified are 'Ageing Population' and 'Young Families'.



Method

Map the System

CARD 10 Mindfulness

Systems Thinking | Unraveling the System

Map the System visualises elements in a system and their interactions. Variants include stakeholder maps, value network maps, and ecosystem maps.

Why: Text It clarifies the relationships between different elements and highlights the values they exchange so that the design team can find leverage points to intervene and innovate in the system.

Materials: Kumu (optional)

Complementary methods: How Might We

Acronym: COVID-19 - Coronavirus Disease 2019

Procedure

1 Identify key elements in a system

central to the design opportunity statement.

2 Draft the How Might We (HMW) statement

Consider the basic structure of the system and map it out. Draw the basic shapes to represent the system, and plot the elements onto the map.

3 Illustrate relationships and interactions

Consider the influences one element has on other elements. Illustrate this with arrows and lines, labelling them with explanations.

4 Spot gaps and fill them in

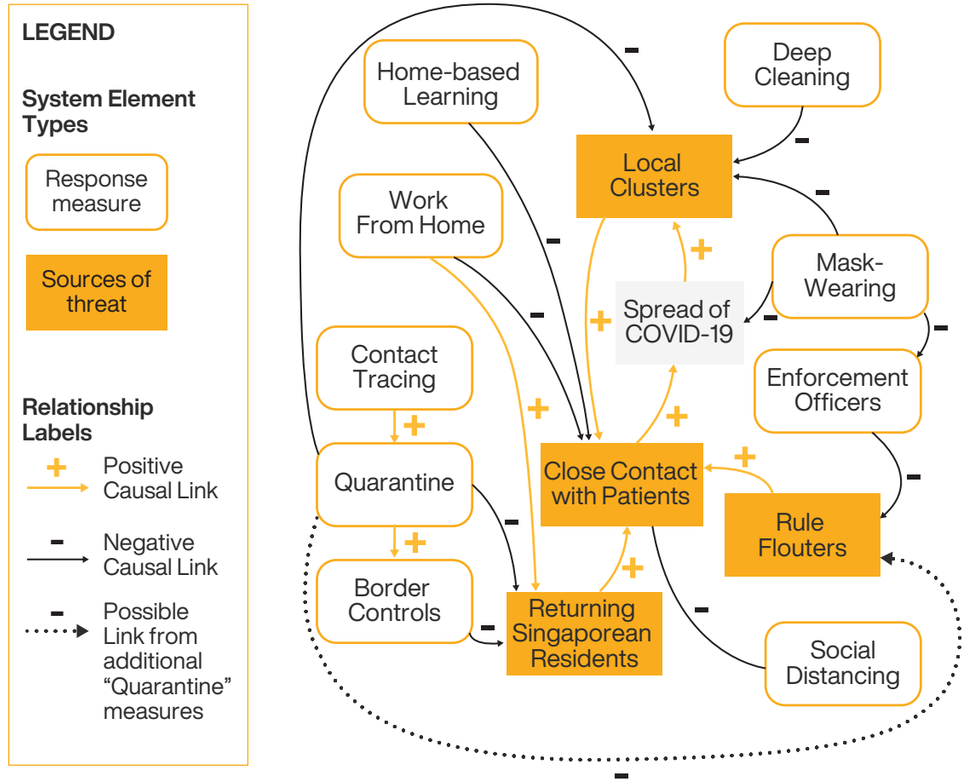
Take a step back to identify new or related areas of interconnection, and draw possible insights from these.

Did you know? A system is a set of related components that work together in a particular environment to perform whatever functions are required to achieve the system's objective. [5]

Worked Example

Singapore's Response System to COVID-19

This example illustrates a possible way the Singapore government's Disease Outbreak Response System could be mapped in the scenario of the COVID-19 Pandemic. The draft map clarifies potential sources of threat and current response measures. This draft map helps to uncover points where additional measures could be effective in stopping the spread of COVID-19.



OBSERVATION

There are fewer response measures to control the threat of 'Rule Flouters' than other threats.

AREA OF OPPORTUNITY

'Quarantine' could be applied to 'Rule Flouters' as a response measure. It can be done differently to highlight that even though 'Rule Flouters' are not actually infected with COVID-19, they pose a level of risk to society.

Our need will be the real creator

Plato

Philosopher during the Classical period who founded Platonist school of thought

Method

Framing/Reframing

Design Thinking | Scoping Opportunity

CARD 15 Mindfulness

Framing/Reframing provides alternative methods to reshape, restructure, disrupt the way we think about a question or problem.

Why: Framing/Reframing allows the design team to think critically about the problem/opportunity and to decide if they should pivot or sharpen the scope, so that they are clear about the stakeholder, the solution and the purpose of the solution.

Materials: Framing/Reframing Questioning Templates

Acronyms: PSS - Product, Service, or System
OS - Opportunity statement

Scan or click here for a digital copy of the template

Procedure

1 Explore User Stories

User stories are used to describe the motivations and needs of the users and their exploration of the PSS

2 Ask Socratic Questioning

Socratic questioning is helpful to probe for thoughts and determine validity of ideas. It can be used in design to interrogate and question the design opportunity, team and stakeholders, for pivoting perspectives.

3 Rewrite OS using Parnes' statement and restatement

Words that are picked can influence our perspective and chain of thoughts. The technique can be used to evolve problem statement to its most accurate representations by finding the real objective, true constraints through reshaping and restructuring the way we think about a problem using triggers

4 Consider list of "Top 10 innovation types and tactics"

The list, created by Doblin Innovation Consultants is a diagnostic tool to assess how we are approaching innovation internally, it can help analyse the competitive environment, and it can reveal gaps and potential opportunities for doing something different and upending the market.

10 Types of Innovation and Tactics

PROFIT MODEL Subscription	Create predictable cash flows by charging customers up front (a one time or recurring fee) to have access to the product/ service over time.
NETWORK Competition	Join forces with someone who would normally be your competitor to achieve a common goal.
CHANNEL Transparency	Let customers see into your operations and participate with your brand and offerings.
CUSTOMER ENGAGEMENT Experience Simplification	Reduce complexity and focus on delivering specific experiences exceptionally well.

Worked Example

Walt Disney

PROFIT MODEL Subscription	Personalized on-demand entertainment - Pivoted to provide streaming services based on a subscription model. Acquired BamTech well in advance to set this up a direct-to-customer streaming service.
NETWORK Merger's and Acquisition	Disney has a large portfolio of acquired companies: Disney, Pixar, Marvel, LucasFilm, ESPN, ABC, 21st Century Fox. This gives Disney+ content from not only its own originals but also the franchises under these titles.
PRODUCT SYSTEM Integrated Systems	Disney Imagineering - industry across industries. Disney does integration on a large and cutting-edge scale. It brings together the industries of architecture, design, industrial manufacturing, digital media, animation, animatronics, and 3D Modeling all together to create Disney imagineering that operates on an unfathomable scale and complexity to bring about end user experience.
EXPERIENCE Brand and Customer Engagement	Disney is a master at storytelling and creates a unique experience in their theme parks by putting the visitor through a story similar to the characters in a disney movie, with an unparalleled immersive experience. Their brand sells ‘magic’.

Methods

System Architecture

Systems Thinking | Unraveling the System

System Architecture is an approach to define how system elements will interact and relate to each other, without specifying either the detailed functionality or embodiment of the system.

Why: System Architecture is a foundation for design, including specifying upfront how system elements will interact in order to produce emergent behavior during use. This is especially valuable for complex systems in order to either manage or reduce complexity. It is also a tool for future verification and validation of the resulting design in the same abstract terms as the architecture.

Materials: Sticky Notes, Wall/Board

Complementary methods: User Journey Map, Scenarios, Activity Diagram, Storyboarding

Acronyms: QR - Quick Response
SUTD - Singapore University of Technology and Design

Procedure

1 Reframe problem

Do not assume that the initial statement of the problem is necessarily the best or even the right one. Continually seek the underlying purpose of the system.

2 Break down system into smaller elements

Choose elements so that they are as independent as possible (i.e. such that the elements exhibit low external complexity and high internal complexity). External complexity refers to inter-element interfaces, and internal complexity refers to intra-element interfaces.

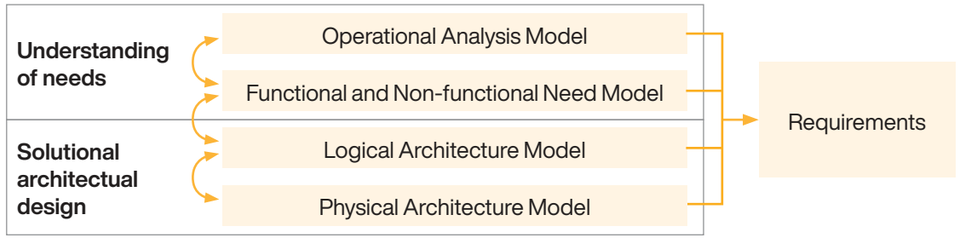
3 Connect

the activities in a single block diagram with directed arrows.

4 Repeat observation

with another user to validate the diagram, extract insights, foresights and latent needs.

Validating/justifying solution against operational need easing impact analysis



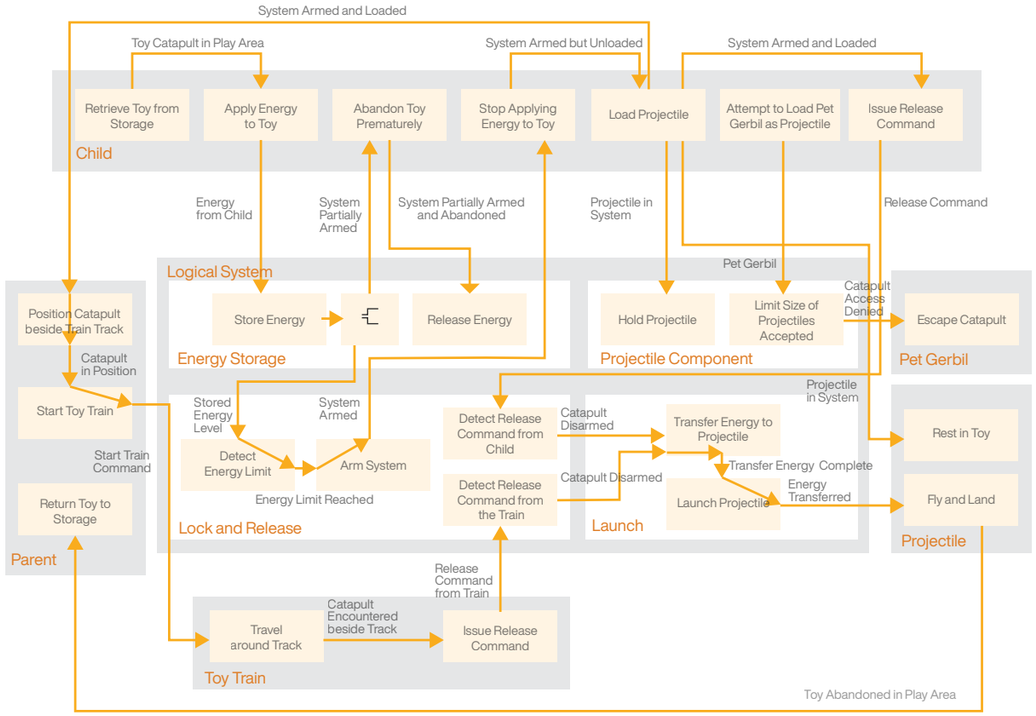
Overview of the components in laying out the system architecture[1]

Worked Example [8]

Due to the large amount of content, it is recommended that this step-by-step tutorial be done (scan the QR code provided to get to it). The tutorial was developed by Head of Pillar, Engineering Systems and Design, SUTD, Prof. Peter Jackson.

He uses an example of a system involving parent with his/her child and a toy catapult and illustrates how to use Capella, a software to systematically map out the complex system to fully understand the relationships in the system.

Step-by-step tutorial



Method

Participatory Valuation Game

Design Thinking | Advanced Insights

Participatory Valuation Game is an interactive game in which people use artificial money to rank and express their desire for certain features or functions.

Why: Participatory Valuation Game shows how people deliberate over the choices of features in the product, service, or system (PSS). It can uncover latent needs of users and allow the designers to prioritise certain functions in the solution.

Material: Valuation Cards Template

Complementary methods: Benchmarking, Systems Functions Model

Acronym: PSS - Product, Service, or System

Scan or click here for a digital copy of the template

Procedure

1 **Identify**
a PSS to focus on and generate a list of potential features

2 **Make**
multiple sets of cards for the features and include a price tag for each of them.

3 **Invite**
a group of stakeholders as participants.

4 **Give**
each participant a set of cards and a fixed amount of money. Money is usually to purchase between 1/3 to 1/2 of all the features.

5 **Ask**
them to purchase features with their budget and verbalise their thoughts as to why those features are the most important to them

Useful Tip

While the cost is arbitrary, it should connect in some way to how difficult it would be to implement.

Best Practices

Work in pairs
Make the participants work in pairs could help in the decision making process.

Leave a blank card
for the highest amount and the participants can fill it in with something they want thats not listed.

Put a price
Participants can also put a price on the features to align the value placed for each features.

Worked Example

Features for an autonomous vehicle

Participants are given $1200 to use. The features that are easier to implement are priced at $100 while the features that are most difficult to implement are priced at $500.

$1200 to use

$100	$100	$100	$100
Drive smoothly under normal circumstances	Open door upon arrival at destination	Alert and reroute to charging point below a certain battery level	Adjust aircon temperature and fan vents angles to the comfort of the passengers
$300	**$300**	**$300**	**$300**
Choose parking lot and park safely and with sufficient space to exit	Choose the most suitable route based on current traffic conditions	Connect and communicate with nearby vehicles beyond car lights and horn	Analyse and predict worn out parts or parts that need maintenance
$500	**$500**	**$500**	**$500**
Drive under low light or extreme environment conditions	Predict traffic conditions in the road in the next hour or two	Operate constantly without a need to visit charging station	Transform into an aerial vehicle when encountering traffic jam/ Bypass traffic jam

Method

Design Structure Matrix & Modularisation

Design Engineering | Advanced Insights

Dividing a system concept into individual components.

Why: Modules can be designed relatively independently once interfaces are defined, allowing parallelization. A common interface standard also enables flexible design where modules can be interchanged or swapped.

Materials: Spreadsheet

Complementary methods: System Architecture, Systems Function Model, Adjacency Diagram, Parallel Prototyping

Acronym: DSM - Design Structure Matrix

Procedure

1 **List**

primary components or functions of your design concept.

2 **Construct**

an adjacency matrix that has your list from Step 1 as both rows and columns. This is also known as a Design Structure Matrix or DSM.

3 **Enter**

a '1' in the matrix wherever there is a connection – mechanical, energy, material, or information – between components or functions.

4 **Rearrange**

rows and columns to create groups of cells in the matrix of more connected components or functions. Each grouping is a potential module, defined by a group of components or functions.

5 **Define**

interfaces between modules to parallelize further detailed design.

Best Practices & Tips

- Algorithms in programs like MATLAB can be used for the row and column rearrangement step
- A component or function that has connections to many other components or functions may be reserved as an 'integrative' element that connects to all other modules

Worked Example 1

A desk lamp

Key functions:

1. Output light
2. Switch power on/off
3. Adjust direction of light
4. House cabling

Design Structure Matrix

'1' in the matrix indicates a connection between the functions.

Function	1	2	3	4
1. Output light			1	
2. Switch power on/off				1
3. Adjust direction of light	1			
4. House cabling		1		

Modularisation

Columns and rows 2 and 3 are swapped.

Function	1	3	2	4
1. Output light		1		
3. Adjust direction of light	1			
2. Switch power on/off				1
4. House cabling			1	

Light module: output light and adjust direction of light

Power and housing module: switch power, house cabling

Worked Example 2

How might we optimize the design process for a recreational vehicle?

A recreational vehicle is a complex product with a large number of components and subsystems that have plenty of information dependency on each other which might result in a large amount of time spent in going through design iterations. In order to meet a faster turn-around time to introduce the product into the market, the Design Structure Matrix could be utilized to identify where components are interdependent on each other for information and consequently how all the components could be prioritized sequentially in increasing order of information dependency to reduce the amount of design iteration that the product design team needs to go through. This would lead to a reduction of time required to work out the design of the product.

Components Name		1	2	3	4	5	6	7	8	9	10	11	12	13	14
On-board Power Generator	1	1	1			1	1	1		1	1				1
Air-conditioning System	2		2	1	1					1	1		1		
Ventilation Fans	3			3	1		1			1	1		1		
No. of Personnel	4				4								1		
Exterior Camp Awning	5					5							1	1	
Interior Lighting	6						6								
Exterior Lighting	7				1			7					1		
Plumbing System	8				1				8	1			1	1	1
Kitchen Appliances	9				1				1	9			1	1	
Audio-Video Equipment	10						1				10		1	1	
Stowable Bed	11				1							11	1	1	1
Platform Size	12				1								12	1	1
On/Off-Road Transportation Mode	13													13	
Roof Expansion	14				1								1	1	14

DSM utilised to identify where components are interdependent on each other for information

In a commercial setting, time equates to money for many organizations. Product design teams often have their efficiency measured against the amount of time taken for them to take a product from conceptualisation up to the development of a minimum viable product (MVP) ready for market release. Hence processes such as the DSM is highly useful for teams to identify areas where components may be interdependent on each other for critical information and hence grouping such components to work on together in a design iteration would be much more efficient than to work on those items separately where parameters of one component may affect how the other may be designed or integrated together into the final product. The power of the DSM as an analytical tool helps to identify such interdependencies and also subsequently provide a recommended sequence of which components to work on first right up to the last.

Partitioned DSM		6	13	14	4	12	5	7	8	9	10	11	3	2	1
Interior Lighting	6	-													
On/Off-Road Transportation Mode	13		-												
Roof Expansion	14		1	-	1	1									
No. of Personnel	4				-	1									
Platform Size	12		1	1	1	-									
Exterior Camp Awning	5		1			1	-								
Exterior Lighting	7				1	1		-							
Plumbing System	8		1	1	1	1			-	1					
Kitchen Appliances	9				1	1			1	-					
Audio-Video Equipment	10	1				1					-				
Stowable Bed	11		1	1	1	1						-			
Ventilation Fans	3	1			1	1				1	1		-		
Air-conditioning System	2				1	1				1	1		1	-	
On-board Power Generator	1	1		1			1	1		1	1			1	-

DSM after partitioning/optimization. Yellow boxes shows where design iterations are expected

Method

Kansei Engineering

Design Engineering | Advanced Insights

Kansei Engineering is a survey-based technique to connect user perceptions to quantitative design decisions.

Why: Understanding how physical measurements and design characteristics impact a user's perception can provide a direction for focused ideation, or provide a way to select between concepts.

Time: 1-2 hours preparation, 1-2 weeks to collect responses, 1-2 hours analysis

Materials: Prototype images, Online survey platform, Spreadsheet

Complementary methods: Survey Design, Design Optimisation and all methods under core and advanced prototyping methods

Procedure

1 Select

1-2 perceptions that you want your design to embody. Perceptions relate to senses, so you might choose a reaction that relate to vision, hearing, touch, smell, or taste.

2 Choose

at least two different quantitative design characteristics that you want to explore. A characteristic might be a dimension, material, color, or shape. Each characteristic should have 2-4 different values, or levels, you want to test.

3 Prototype

a simple version of your design concept for each combination of levels.

4 Construct

a survey that asks users to evaluate each prototype on a scale for each perception. Use a five point scale that ranges from 'Very not [perception]' to 'Very [perception]'.

5 Analyze

and interpret responses by plotting each prototype on a chart with axes representing each perception. A trendline can be determined by examining how the perception increases, or decreases with each design characteristic.

Best Practices

Be specific

Choose precise words for the perceptions you wish to evaluate.

Notice heterogeneity

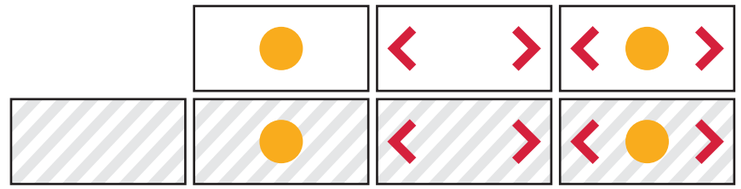
If you discover you have clearly different groups of responses in your data, that is an indication of multiple user groups with divergent preferences that you may want to explore further.

Worked Example

Safety and style of rear bicycle accessory

How might we enhance perceived safety and style of a rear bicycle accessory?

Sensory perceptions: **Safety** and **Style**
Characteristics: Bicycle light (yes/no), reflector (yes/no), and turn signal (yes/no)
Prototypes: one sketch for each combination of characteristic levels



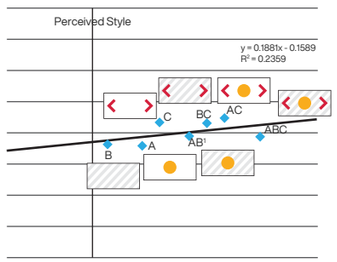
Sample survey question

How safe and stylish do you perceive this rear bicycle accessory to be?

Reflective surface and chevron turn signals

	Very not	Somewhat not	Neutral	Somewhat	Very
Safe	○	○	○	○	○
Stylish	○	○	○	○	○

Results



- Elements in combination are perceived as safer than a single element alone
- Chevron turn signals are perceived as most stylish of the three elements tested
- Concept with all three elements together has the highest perceived safety
- Note: trend is only valid for the concepts tested

Develop

Ideate and model concepts based on identified opportunities

MINSET

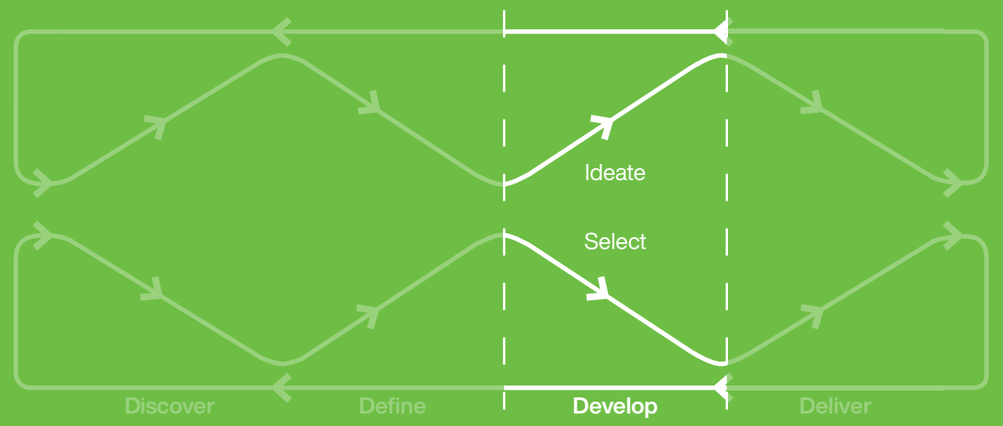
Joyfulness

Ideate

- How do we ideate?
- What are key methods we might use?
- How do we maximise quantity?
- What analogies may be used?
- How do we add depth and fidelity?

Select

- How do we down select ideas that ‘wow’?
- What are the 3 to 6 ideas to emerge from this sprint?
- How do we increase and embrace playfulness?
- How might ideas be combined to create improvements?



Method

Brainstorming

Design Thinking | Intuitive Ideation

Brainstorming is a common method of generating ideas.

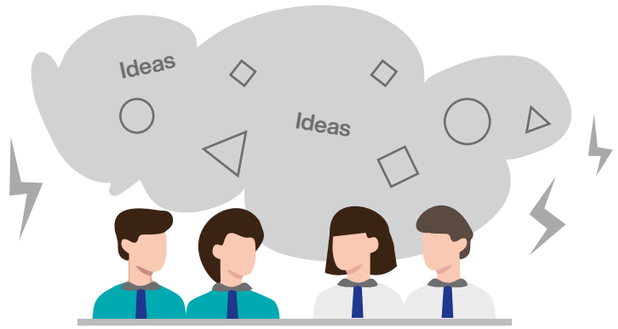
Why: Brainstorming is used when there is an opportunity and the team is ready to dive into ideation to solve a design problem.

Time: 0.5 - 1 hours

Material: Whiteboard

Complementary methods: User Interviews, Affinity Analysis, Activity Diagram, Hierarchy of Purpose, Systems Function Model

Acronym: GPS - Global Positioning System



Procedure

1 **Define**

the design opportunity. Be reminded of the design opportunity throughout the exercise. Use the keywords in the opportunity to brainstorm.

2 **Generate ideas individually**

This allows everyone to not have 'group think', where ideation is led by someone who is dominating the conversation.

3 **Share ideas with team**

Discuss and have conversations about each idea. Have one conversation at a time so that all ideas can be heard and built upon.

4 **Build on one another's ideas**

Think 'yes, and' rather than 'no, but'.

Best Practices

Defer judgment[1]

There is no bad ideas at this point. Ideas can be refined at a later stage of ideation.

Encourage wild ideas[1]

It is the wild ideas that often provide the breakthroughs. It is always easy to generate realistic rather than wild ideas.

Divide and conquer

The team can divide the design opportunity into various spaces. Be focused and disciplined so that the team can get a broad variety of ideas.

Involve everyone

First generate categories and solutions individually, then come together to synthesise your categories and solutions.

Worked Example

How might we locate or detect a lost golf ball?

- Bright coloured ball
- Sound horn in ball
- Exploding ball
- Golf lessons
- GPS system
- Scent-human
- Scent-dog
- Electronic grid with ball emitter
- Pressure sensitive ground
- String attached to ball
- Smoke trail
- Shorter golf course
- Spotters paced every 10m
- Coloured golf course
- Trajectory calculation system
- Robotic arm hits ball
- Mini camera in ball
- Light emitting ball
- Ball shoots flare
- Plexiglasside walls on golf course
- Speaker in ball; use microphone to call yourself

Method

DI Mindmapping

CARD 2 Joyfulness

Design Thinking | Intuitive Ideation

DI Mindmapping is an ideation method that is analogous to human memory. Ideas are organised in a hierarchical structure with individual ideas under categories which in turn map to a topic or design opportunity.

Why: DI Mindmapping serves as an effective visual documentation of brainstorming session and helps in down-selecting the favourite choices by conducting a voting session at the end of discussion.

Time: 0.5 - 1 hour

Materials: Whiteboard

Complementary methods: User Interviews, Affinity Analysis, Activity Diagram, Hierarchy of Purpose, Systems Function Model, Brainstorming

Acronyms:
AM - Additive Manufacturing
AV - Autonomous Vehicle
DI - Design Innovation
FDM - Fused Deposition Modeling
SLA - Stereolithography
SLS - Selective Laser Sintering
UX - User Experience

Procedure

1 State the design opportunity statement/HMW statement

in the centre of a large sheet of paper or whiteboard.

2 Generate ideas individually for 10-15 mins

Write each individual idea on a sticky note for easier categorisation and moving later. Aim for actionable ideas that are implementable, even if they are wild!

3 Consolidate ideas and cluster similar ones

Participants take turns to share their ideas and cluster similar ideas under common categories.

4 Identify the categories your ideas fall under

5 Utilise the categories to generate further ideas

Take the category as a start point to generate further related ideas you previously have not thought of.

Best Practices

Involve everyone

First generate categories and solutions individually, then come together to synthesise your categories and solutions.

Expand your mind map

A standard procedure is to start with categories and then creating solutions under subcategories. However, a new idea can open up a category which leads to more ideas.

Go for quantity

Target to generate at least 50 solutions to capture a diverse range of solutions as a team.

Discuss as a team

Not only does Mind Mapping allow organisation of ideas, it also facilitates ideation and discussion as a team. Discuss as a team with the mind map and build on it!

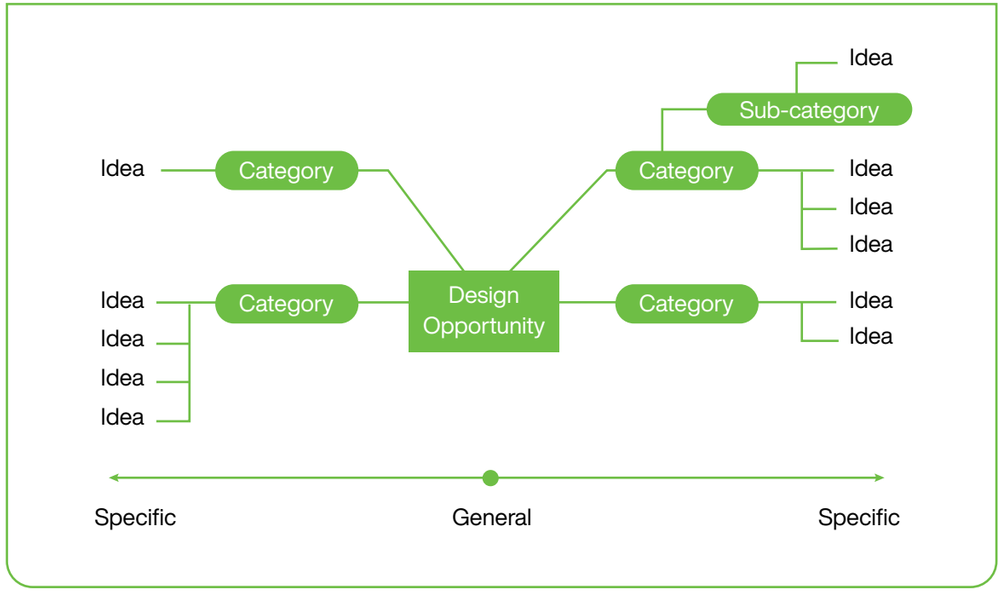
Have implementable ideas

Target to have solutions that are specific enough to be actionable. Solutions usually answer the 'How do we do it?' question.

Useful Tip

Ideas should be actionable.

Structure

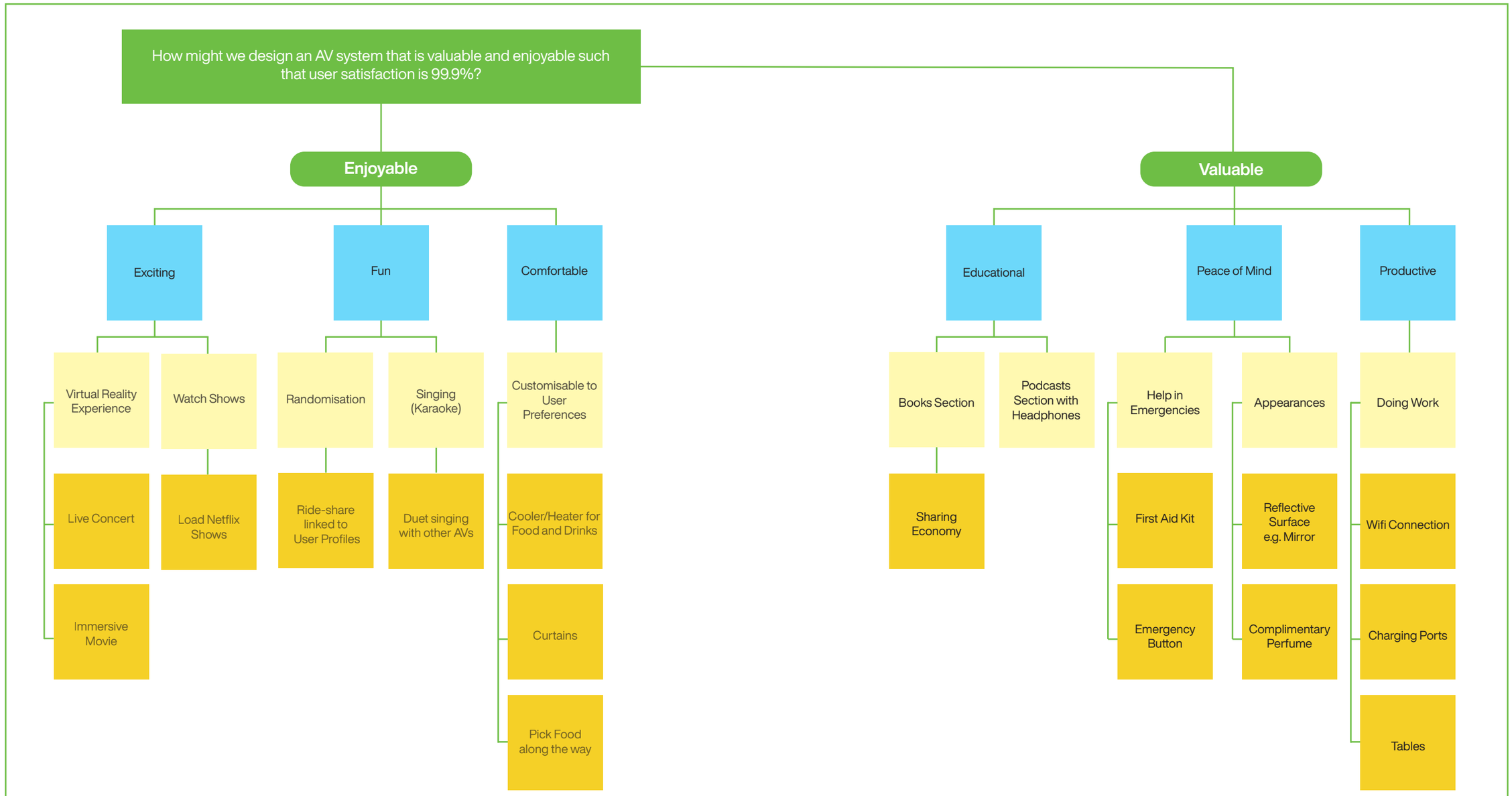


Worked Example 1

This is a portion of a mind map with the opportunity statement 'How might we design an autonomous vehicle (AV) system that is valuable and enjoyable such that user satisfaction is 99.9%?'.

Useful Tip

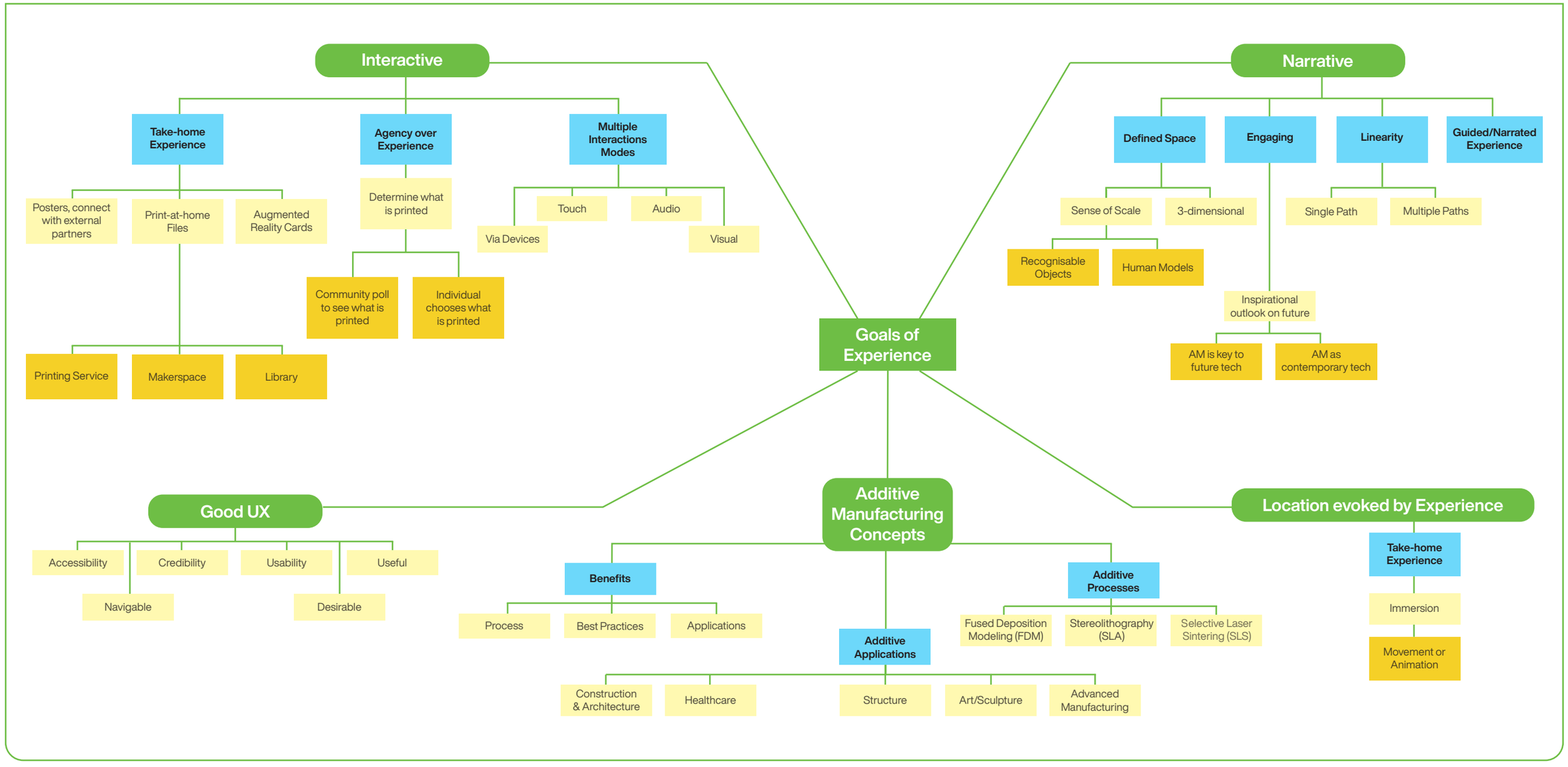
Don't forget about your personas when developing the mind map. Ideating with the users in mind is important for the solutions to be relevant.



Worked Example 2

This mind map was created for a project that focuses on developing a multi-sensory experience for users to learn more about additive manufacturing (AM) and how its application is enabling a better future.

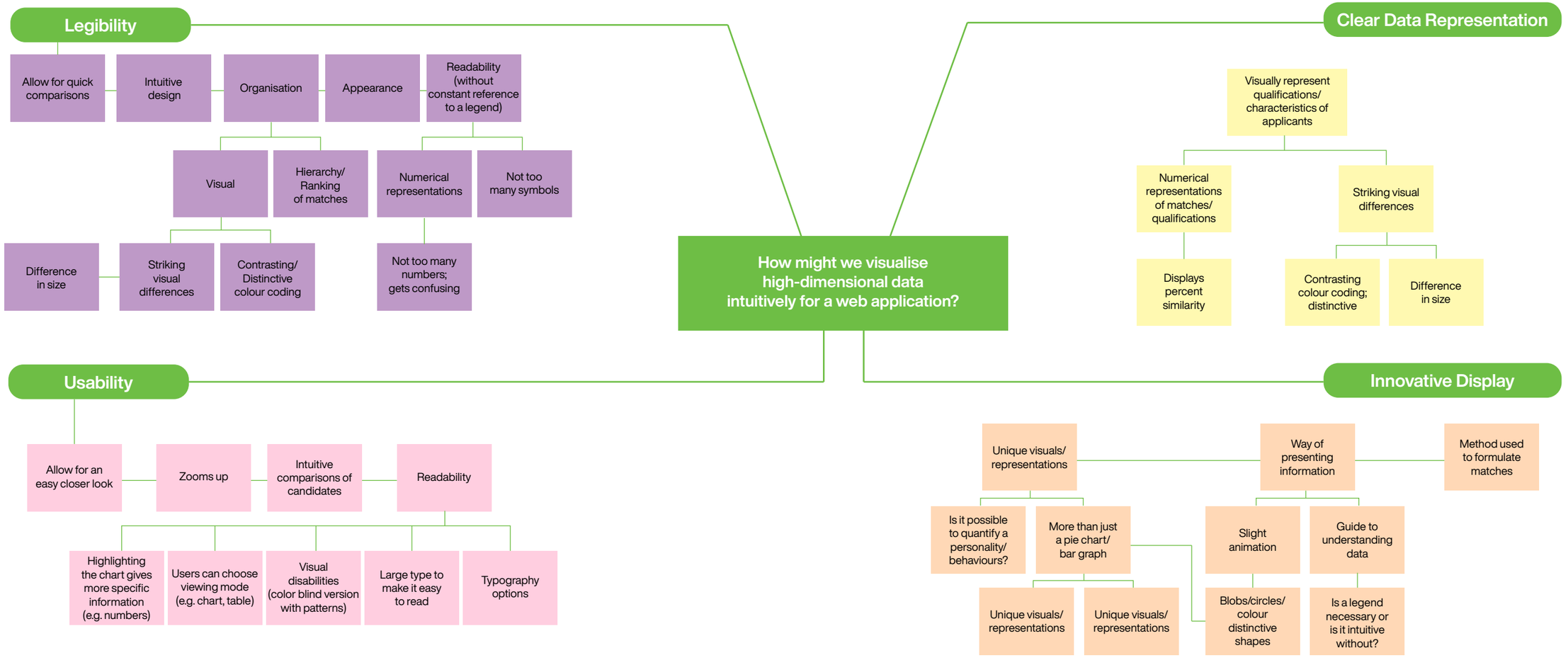
The ideas generated from this mindmap gave rise to the conception of a virtual and physical kiosk[1] that includes a series of display objects that provide a fun and tactile experience, demonstrations of topology optimisation, an augmented reality experience that brings the user to the surface of Mars, and a set of souvenir cards with a space-themed hologram.



Worked Example 3

This is a mind map completed by a team that focuses on the opportunity statement 'How might we visualise high-dimensional data intuitively for a web application?'

This was done in about an hour and the team generated 40+ ideas! They used Sticky Notes to write down ideas; each Post-it represents a single idea they had. The team members initially divided the opportunity space among themselves so that there was less overlapping of ideas, and more breadth and diversity of ideas. After several minutes of initial ideas, the team came together to ideate additional concepts collaboratively, building on each others' work.



Method

Design by Analogy

Design Thinking | Directed Ideation

CARD 3 Joyfulness

Design by Analogy is a method where inspiration for ideation is drawn from comparing a problem or opportunity to existing solutions or situations in other fields.[1]

Why: Design by Analogy helps designers, engineers, and professionals to generate creative ideas that are novel and useful with the help of prompts.

Materials: Design by Analogy Tools (see below)

Complementary methods: User Interviews, Affinity Analysis, Activity Diagram, Hierarchy of Purpose, Systems Function Model, Brainstorming, DI Mindmapping

Acronym: LED - Light Emitting Diode

Procedure

1 Identify characteristics, key words or prompts

that describe or may help to solve the problem or opportunity.

2 Observe similarities elsewhere

Look at other fields, like in nature, or other industries, drawing similarities in existing solutions or situations. Take note of similarities in function, appearance, process, etc.

3 Transfer and apply learnings

from existing solution(s) to the problem or opportunity.

Design by Analogy Tools

Use these tools to help ideate analogies, particularly in retrieving appropriate prompts:

Word Tree | www.wordvis.com

Provides a visual network of related words prompted by a single keyword of your choice, thus expanding the options available for exploration to work on your problem.[11]

AskNature[12] | www.asknature.org

A biomimetic database which inspires innovators with biological phenomena. Explore how nature may provide insight into solving your problem.

TRIZ[10] | www.triz40.com

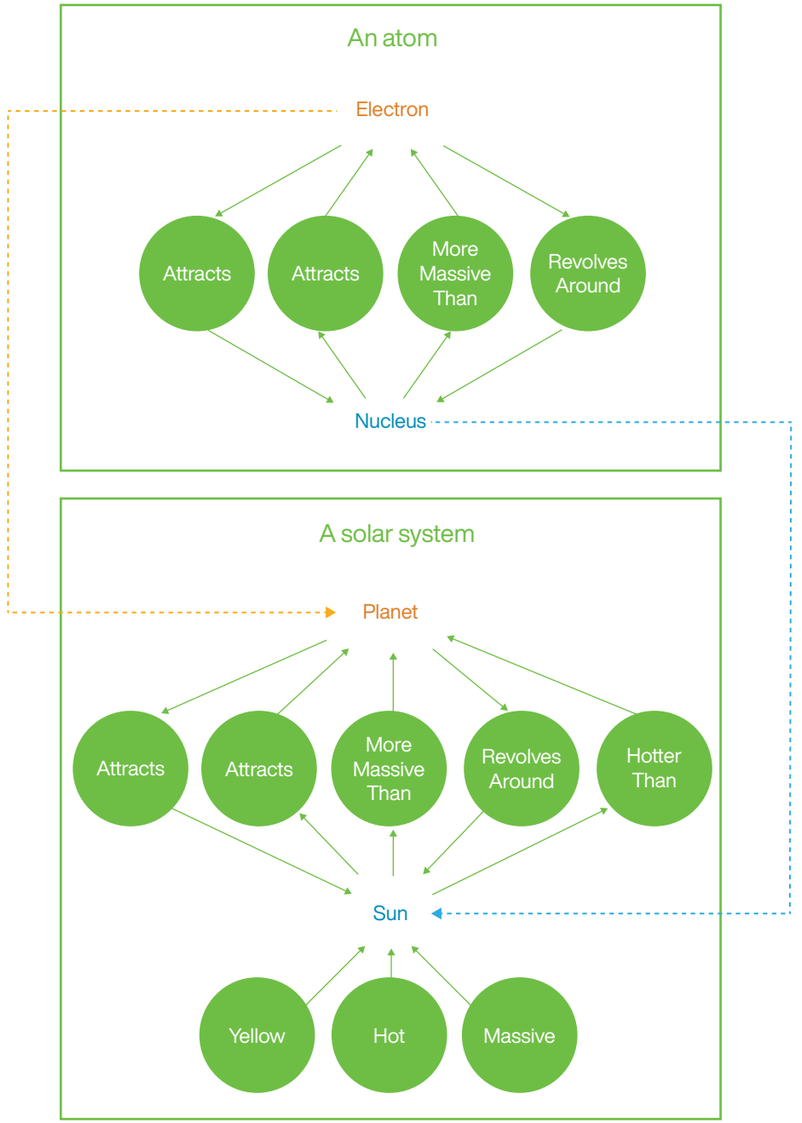
A systematic approach for understanding and solving problems based on principles of engineering and physics.

Analogous Inspiration [7,8]

Draws inspiration from tapping on memories of one's own experiences or from immersing oneself in other settings.

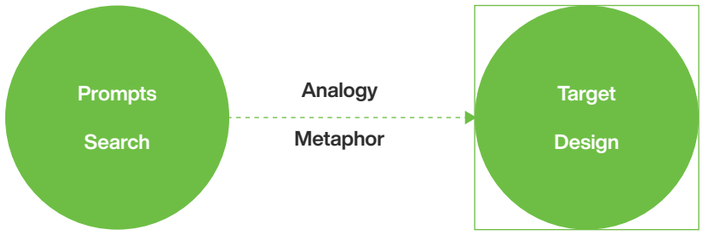
Illustrated Explanation[2]

An atom is analogous to a solar system because they have similar relationships.

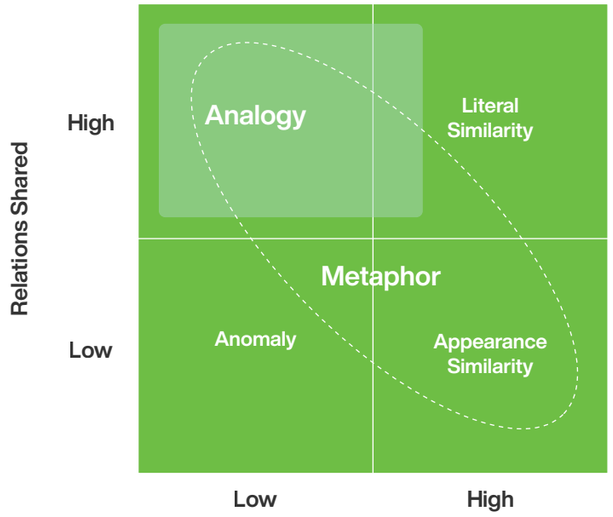


Concept of Design by Analogy[4,6]

The 3 diagrams aim to compare analogy and metaphor, understanding their similarity and differences.

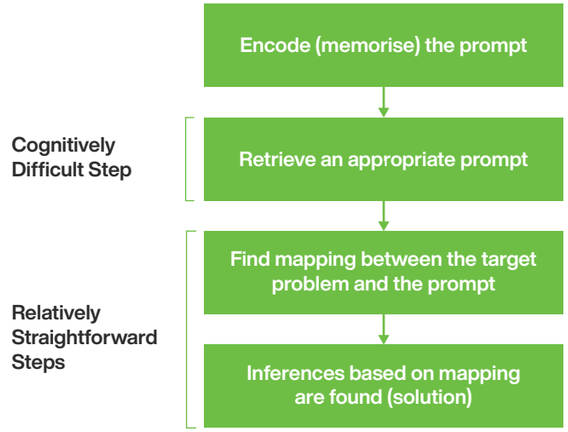


This diagram describes how the process of analogy and metaphor occurs. The designer usually searches for inspiration from a different domain (prompt) and applies it to the domain of interest (target). The prompt domain may not exactly map to the target domain (as seen in their incompatible shape), but proves to have some form of overlap.



The overlap, of relations and attributes, is shown in a graphical representation (on the right). The x-axis denotes the extent of the attributes shared by the prompt and target domain while the y-axis denotes the extent of relations shared by them.

Analogy, which takes the form of the rounded rectangle on the top left, is pictured as having high relational resemblance but low attribute resemblances between the prompt and target domain. Metaphor, which is represented by the area covered by the oval, shares some similarity to analogy but could also be inspirations that has high appearance similarity.



Understanding the difficulty of applying design by analogy

The diagram shows the general processes involved in applying Design by Analogy. It also highlights the retrieval of an appropriate prompt as the cognitively difficult step.

Worked Example

A Multi-functional shelves that are inspired by waffles can be unlocked and rotated to reveal the inner parts of the shelves. The inner parts can be used to store more secured documents.

B An information board inspired by tree rings can be used to chronologically record additions to the document and grow bigger progressively.

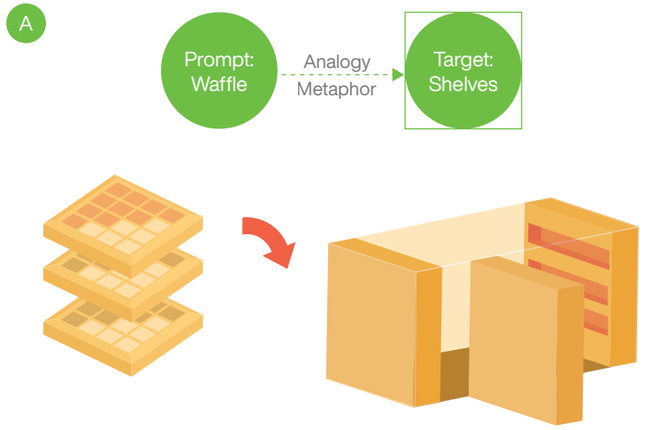
C Train platform inspired by Venus flytrap can be designed to lure people to less crowded area at the ends of the platform.

D LEDs inspired by lanterns can be used to lead people out of train tunnels during disruption. The LEDs gradually light up and provide assurance to the passenger in times of panic and chaos.

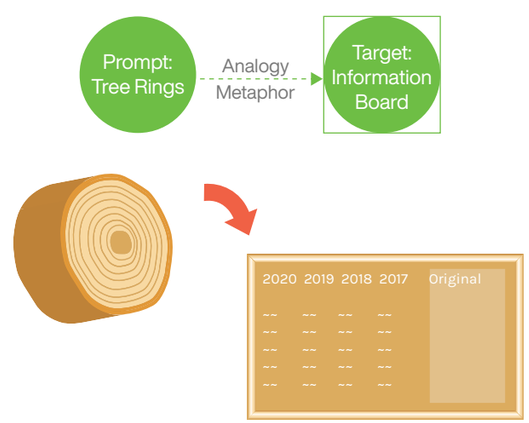
E A train nose could be reshaped, drawing inspiration from how Kingfishers dive at high speed into water without a splash, mimicking the streamline geometry of the kingfisher bill to drastically reduce sonic boom effect.15

How might we design a station that increases the productivity and efficiency of its processes while enhancing user satisfaction?

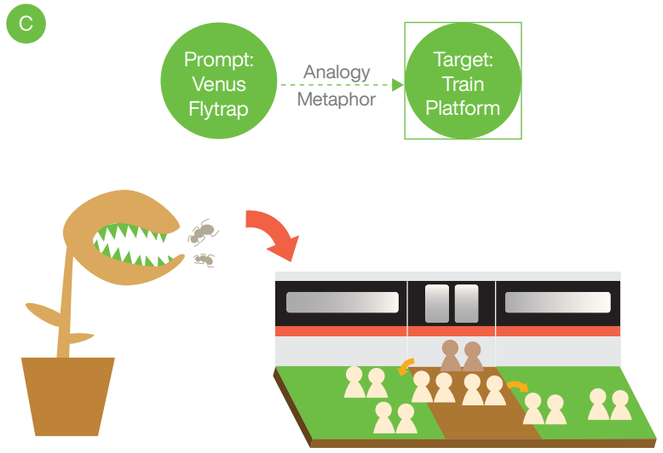
A



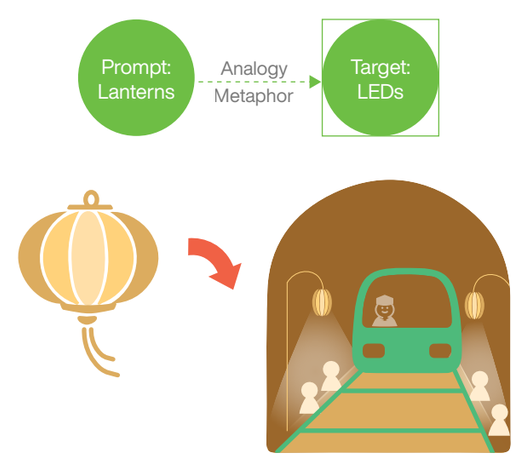
B



C

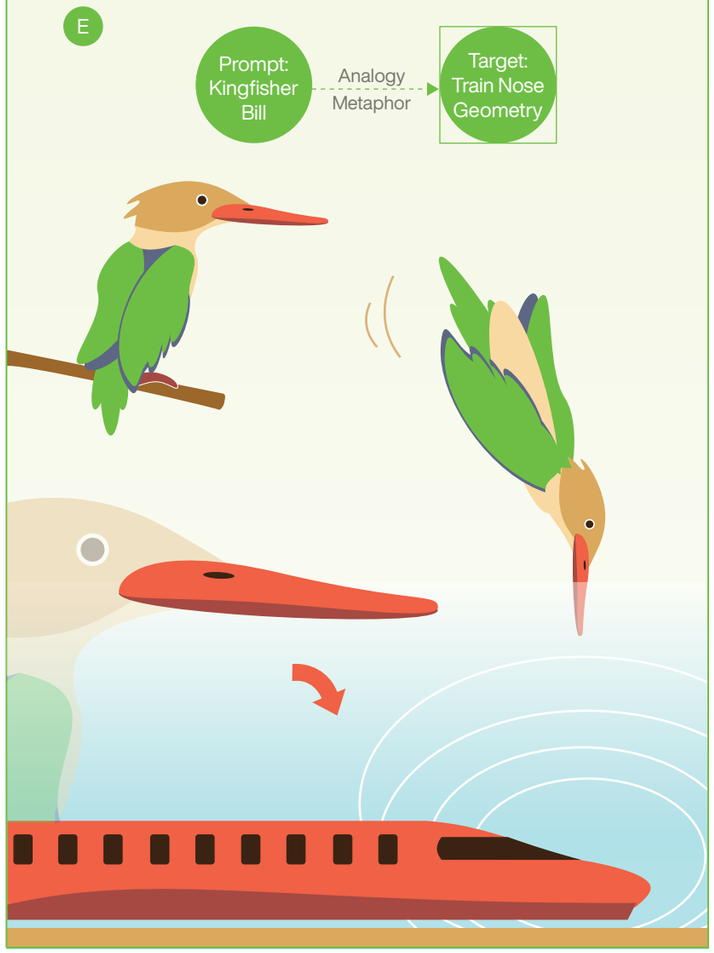


D



How might we rectify the problem of a loud sonic boom generated when trains travel through tunnels at high speeds?

E



Method

C-Sketch (6-3-5)

CARD 4 Joyfulness

Design Thinking | Intuitive Ideation

C-Sketch (6-3-5), or Collaborative Sketch, is a rapid way to generate and build upon the ideas that you and your team members have.

Why: C-Sketch is effective because it helps to provide different perspectives or insights into the solutions that are hidden from the sketcher. The design team can produce over 100 ideas with the help of this method!

Time: 1.5 hours

Materials: Coloured Markers, Timer

Complementary methods: User Interviews, Affinity Analysis, Activity Diagram, Hierarchy of Purpose, Systems Function Model, Brainstorming, DI Mindmapping, SCAMPER

It is called 6-3-5 because of 6 people, 3 ideas, 5 iterations

Procedure

1 Divide paper

into 3 sections.

2 Ideate individually, each using different coloured pens

where each design team member uses 15 minutes to sketch a total of 3 diverse ideas, 1 in each section. Label if necessary.

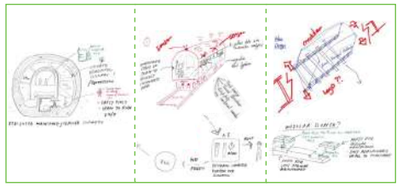
Members should stay silent till step 4.

3 Pass & improve on the ideas

or sketch by inserting an entirely new idea for 10 minutes. Repeat until the papers return to their owners.

4 Discuss & refine the ideas

with the feedback received. Additional guidelines include: no judgment or criticisms and to build on the variety of ideas generated by other teammates.



C-Sketch sheet
(digitalised on the facing page)

Best Practices

Be silent

Lack of communication between the team members may sprout very differing solutions due to their own perspective. Questions should be kept until the end of the entire sessions and be asked later.

Be free

If there is no more ideas that can be added to the paper, be daring to use the ideas as inspirations to create an entirely novel idea.

Be positive

Negative comments and malicious remarks make people discouraged and restrict them from voicing out their ideas in the future. The assessment of the idea's feasibility should also not be made during C-sketch.

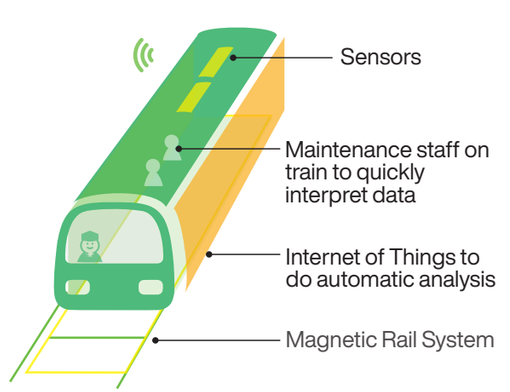
Co-create

Get users involved as participants in the 6-3-5 (C-sketch) method.

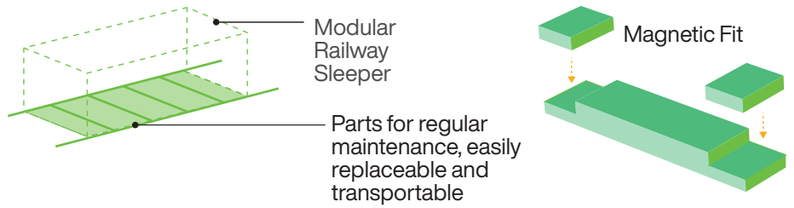
Worked Example

Changing the Tunnel Design

Maintenance-free Train



New Track Design to Ease Track Replacement



Method

Real-Win-Worth

CARD 12 Joyfulness

Design Thinking | Concept Selection

Real-Win-Worth is a strategy to manage risk and reward. It provides a way to rapidly assess the marketability of the Products, Services and Systems (PSS) by asking a series of questions.

Why: Real-Win-Worth is a systematic process to reveal faulty assumptions and possible risks which helps to prevent and/or fix problems of idea execution.

Time: 0.5 - 1 hour

Materials: 3 different Coloured Stickers

Complementary methods: Brainstorming, DI Mindmapping, C-Sketch (6-3-5), Design by Analogy, SCAMPER

Acronym: PSS - Product, Service, or System

Procedure

1 **Prepare**

a list of ideas or concepts that the design team has come up with, and work with assessors with relevant backgrounds to assess and progressively downselect them by asking the following questions.

2 **First, test for 'WIN'.**

Evaluate if ideas have a 'wow' factor that makes them desirable. Items that pass move on.

3 **Then, test for 'WORTH'.**

Question if ideas that have passed 'WIN', are potentially viable as a business, or simply make sense financially for the organisation to pursue.

4 **Lastly, test for 'REAL'**

For ideas that have passed 'WIN' and 'WORTH', question if they are feasible to produce. Does the technology for it exist? Items that pass all 3 criteria are top ideas that should be brought forward for prototyping.

5 **Discuss**

if any ideas can be improved to meet all three criteria.

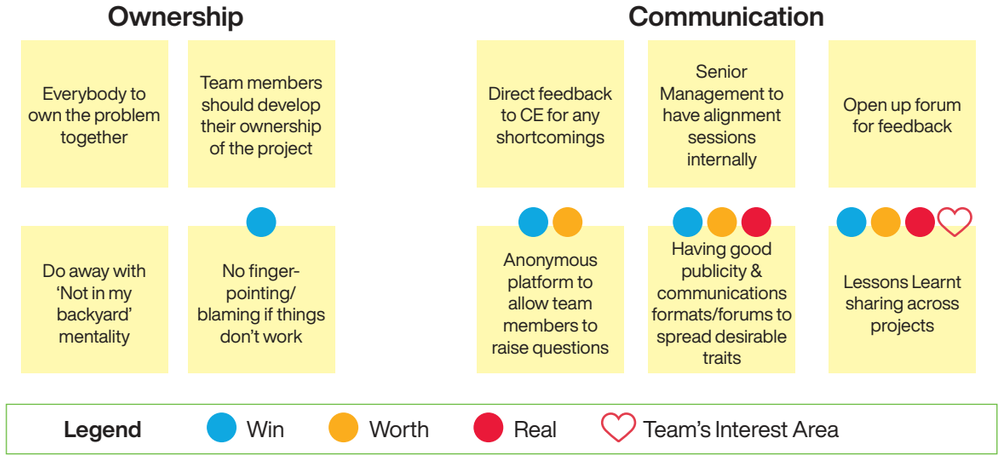
Guiding Sub-questions[1]

Real Is it real?	1. Is the market real?	▪ Is there a need or desire for the PSS? ▪ Is there buy-in from the stakeholders? ▪ Is the size of the potential market adequate? ▪ Will the customer buy/use the PSS?
	2. Is the PSS real?	▪ Is there a clear concept? ▪ Can the PSS be made? ▪ Is it technically feasible? ▪ Will the final PSS satisfy the market?
Win Can we win?	1. Can the PSS be competitive?	▪ Does it have a competitive advantage? ▪ Can the advantage be sustained? ▪ How will competitors respond?
	2. Can our company be competitive?	▪ Do we have superior resources? ▪ Do we have appropriate management? ▪ Can we understand and respond to the market?
Worth Is it worth doing?	1. Will the PSS be profitable at an acceptable risk?	▪ Are forecasted returns greater than costs? ▪ Are the risks acceptable?
	2. Does launching the PSS make strategic sense?	▪ Does the PSS fit our overall growth strategy? ▪ Will top management support it?

Worked Example 1

The team discussed their ideas as a team using Real-Win-Worth Questions. Stickers were placed on ideas that fulfilled the respective criteria, progressively downselecting the ideas. The team added one more criterion, 'Team's Interest Area', as part of the downselection.

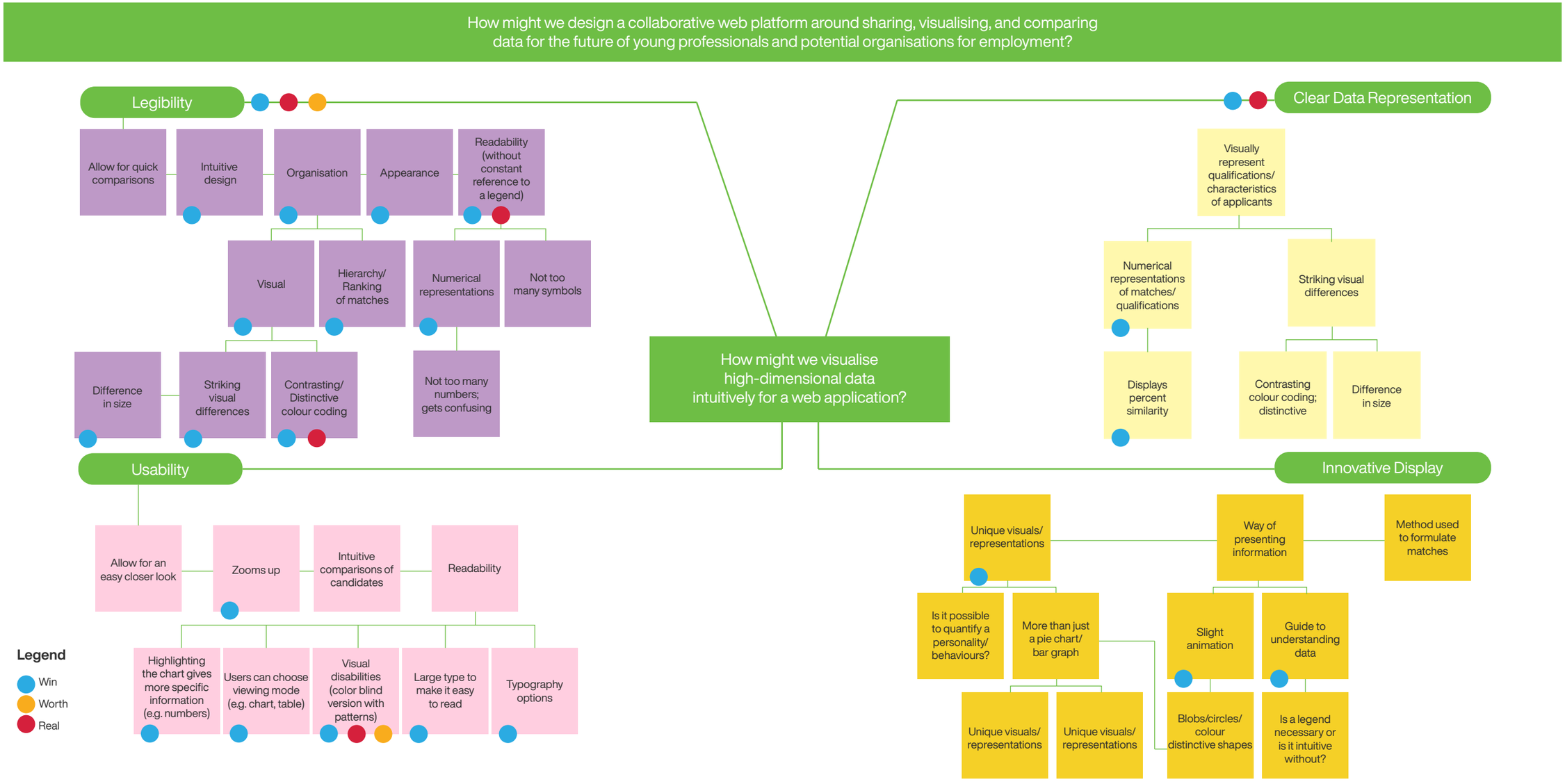
How might we align towards a clear vision for a project and break silos within disciplines?



Worked Example 2

The team discussed their ideas together and evaluated them using Real? Win? Worth It? questions. Stickers were placed on ideas that fulfilled the respective criteria, starting with "Win", followed by "Real", then "Worth", progressively downselecting the ideas.

After evaluating the ideas, the team felt that the categories "Legibility" and "Clear Data Representation" were highly important and rated them with "Win", "Real" and "Worth" stickers as well.



**You can't use up creativity.
The more you use,
the more you have.**

Maya Angelou

*Author, actress, screenwriter,
dancer, poet and civil rights activist*

Method

Co-Creation

CARD 12 Joyfulness

Design Thinking | Ideation Approaches

In co-creation or co-design, the person(s) who will eventually benefit from the design process is included as a member of the design team. They play an active role in the project development.

Why: In co-creation, the users' opinions are valued and their considerations and suggestions are being heard throughout the design process, which shorten the feedback and testing process.

Acronym: AFM - Atomic Force Microscope

Procedure

1 **Establish**

the most important challenges and pain points.

2 **Ideate**

Use ideation methods to solve these challenges.

3 **Iterate Collectively**

on the solution concepts generated.

KEY COMPONENTS

Quick Improvement Cycles

- Quick improvements of concepts
- Inclusion of multiple stakeholders
- Breaks traditional roles and fixation
- Extract user needs upfront

Problem-Solution Linkage

- Connect need finding to solutions directly
- Higher accuracy in need finding
- Keep the design team 'grounded'

Worked Example

Schedule from a co-creation event

Till 9.00 AM	Check-in & Breakfast
9.00 AM	Day 2 Kickoff
9.50 AM	Break into tracks
10.00 AM	Team Pitches
11.00 AM	Find Team Formation
12.00 PM	Lunch
1.00 PM - 6.00 PM	Hacking
6.00 PM	Dinner
7.30 PM	Pulse Checks
7.30 PM	End of Day 2

Schedule a hackathon to understand how each stakeholder is affected by a problem

Co-creating Prototypes

The design team working along stakeholders for the next generation atomic force microscope (AFM), a collaboration between LEGO and Tsinghua University

Method

Rip & Rap

Design Thinking | Permutational Ideation

CARD 6 Joyfulness

Rip & Rap allows research and design teams to 'cut' a variety of images sourced across different media (e.g. magazines, internet, photographs) and 'paste' them into a collage.

Why: This method is great for expressing creativity in other than words and helps the design team describe their ideas quickly using existing images.

Complementary methods: Morph Matrix, Mashup

Acronym: AV - Autonomous Vehicle

Procedure

1 State design opportunity statement/HMW statement

and break into teams of 3 to work. Have ready a blank physical or digital canvas to build a collage of images.

2 Start collecting images

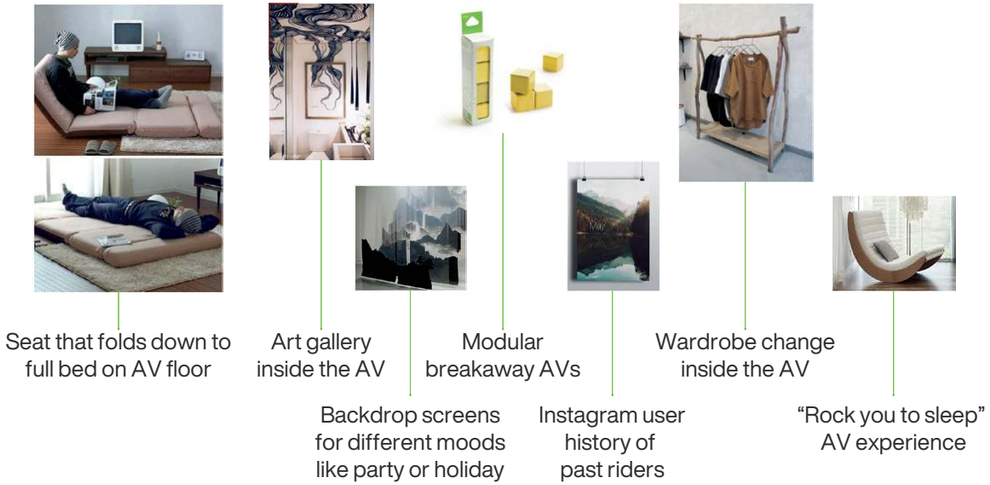
They may come from completely unrelated domains that can be linked to the design problem/ HMW statement.

3 Consolidate and present collage

Explain your collage to others and gather responses.

Worked Example

Ideas for additions to an autonomous vehicle



Example of a Rip & Rap moodboard with the interpretations of each picture in the context of improving an AV.

Method

Mashup

Design Thinking | Permutational Ideation

CARD 5 Joyfulness

Mash-Up is a collaborative method that combines one or more unrelated fields or domain of design.

Why: It generates odd or unexpected ideas by introducing elements from other unrelated domain into the opportunity statement to generate fresh ideas.

Materials: Whiteboard

Complementary methods: Rip & Rap, Morph Matrix

Procedure

1 **Pick one or more unrelated categories**
One of these should be loosely related to the design opportunity statement.

2 **Generate and list ideas**
Come up with as many ideas as possible related to each category.

3 **Combine ideas and consider how the mashup could be implemented**
Consider elements from both categories and combine them to produce new mashed-up ideas.

Best Practices

Be thorough in the combination of ideas and do not bring any prejudice beforehand.

Template Structure

Category 1	Category 2
1.	A.
2.	B.
3.	C.
4.	D.
5.	E.
6.	F.
7.	G.
8.	H.
9.	I.
10.	J.

Final list of mashup

Worked Example

An indoor entertainment/taxi service mashup

Indoor Entertainment (Unrelated to the Opportunity Statement)	Taxi Service (Related to the Opportunity Statement)
1. Massage Seats	A. Booking App
2. Minibar	B. Payment Options
3. Karaoke TV	C. Pick-Up Point
4. Cinema	D. Loyalty Program
5. Online Courses	E. Shared Ride
6. E-Library	F. Multiple Destinations
7. Cafeteria	G. Transporting Additional Pay
8. Climate Control	H. Charge Per Kilometre
9. Bed for Rest	I. Charge for Waiting Time
10. Washroom	J. Vehicle Identification

Final list of mashup

1A. Book a vehicle with massage seats
2D. Minibar inside a vehicle for loyal customers
4B. Pay for in-car cinema experience

Method

SCAMPER

CARD 7 Joyfulness

Systems Thinking | Permutational Ideation

SCAMPER is a tool to help to come up with creative ideas for improving existing solution. It is a mnemonic that stands for: Substitute, Combine, Adapt, Modify, Put to Other Use, Eliminate, Reverse.

Why: SCAMPER asks questions, challenges assumptions that exist and prompts designers to come up with creative ideas to difficult problems easily.

Materials: Whiteboard, Sticky Notes

Complementary methods: User Interviews, Affinity Analysis, Activity Diagram, Hierarchy of Purpose, Systems Function Model

Acronym: PSS - Product, Service, or System

SCAMPER questions

S — Substitute
What can be substituted?
Can the rules be changed?

C — Combine
What purpose can be combined?
Can resources/talents be combined to create new solution?

A — Adapt
What else is similar to this?
Who could we emulate?

M — Modify
What can be magnified, expand, or extended?
What changes can be made in the plans or process or marketing?

P — Put to Other Use
Can this be used elsewhere?
Who else can use it?

E — Eliminate
How can you simplify the Products, Services and Complex Systems (PSS)?
What features can be eliminated?

R — Reverse
What other arrangement is better?
What are the opposites or negatives of this?

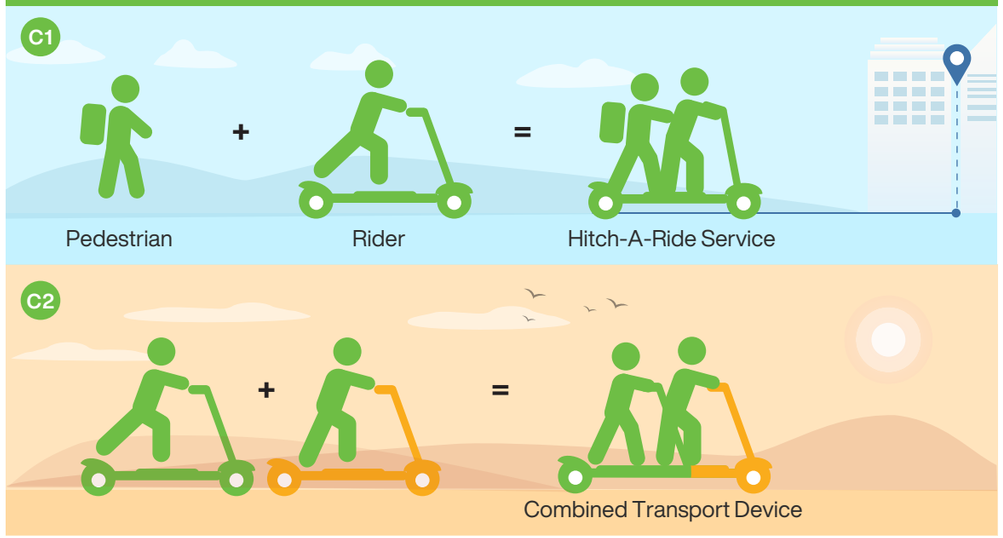
Procedure

1. **State the design opportunity statement/ HMW statement**
2. **Read and Apply**
   each SCAMPER question to the design problem/ HMW statement.
3. **Generate and Record**
   on the solution concepts generated.

Useful Tip
It's natural for some ideas generated with SCAMPER to be impractical. Don't worry about it - just generate as many ideas as you can!

Worked Example

How might we drastically reduce or protect people against accidents related to using last mile transportation devices while inspiring travellers?



Combine

C1 By combining the commuting experience of riders and pedestrians, we can start a hitch-a-ride service for both groups to reach their destination together.

C2 We can combine two or more last mile transportation devices together, either by from the back or attaching them side-by-side, which will create new commuter experience for families and friends.

Worked Example (cont'd)

Adapt

A1 Speed humps, which are used on the roads, can also be placed in pedestrian walkways to reduce the speed of last mile transportation devices.

A2 Obstacle avoidance algorithms used in manoeuvring autonomous vehicle/robots can be installed in last mile transportation devices to stop and avoid collision with pedestrians.

Put to Other Use

Equipment used in sports event can be used for protecting oneself when riding on last mile transportation devices.

P1 For example, a soccer ball used in a soccer match can be transformed into a helmet by deflating and connecting with a chin strap.

P2 Another example would be to use a shin guard as an elbow guard to protect against falling injuries when riding on a last mile transportation device.

Reverse

R1 To prevent riders from falling off their last mile transportation device and suffer injuries, an airbag could be positioned at the base near the ground which will activate and cushion the fall of the riders.

R2 Detection devices can be placed on pedestrians to alert them of incoming vehicles instead of relying on the riders to spot nearby pedestrians. This could also be a communication device to alert riders of incoming pedestrians.

Method

Morph Matrix

CARD 10 Joyfulness

Design Thinking | Permutational Ideation

Morph Matrix or Morphological Matrix breaks down a concept into different functional aspects or design parameters and creates permutation using different ideas for each aspect. It is very similar to mashup, but contains more atomic parts.

Why: It is a systematic way of going through different possibilities and finding new combinations of different aspects for a novel and impactful concept.

Materials: Whiteboard

Complementary methods: Systems Function Model

Procedure

1 **Identify key functions**
of what the ideal product, service, or system (PSS) must do or have.

2 **List functions**
or components in the first column of a matrix.

3 **List ideas**
in the subsequent columns for the respective function or component. Ideas can come from concept generation methods.

4 **Combine ideas**
that seek to satisfy the specifications of the product, service or system to create diverse concepts.

Framework

Apply Extreme-User Experience Framework

read more about the framework on page 39

Include the system-functions identified from applying extreme-user perspectives.

Systems Fuction + How Might We statements

used as inputs for

Morph Matrix

Outcome

Problem

- Clear problem decomposition
- Broad exploration of design space
- Compose new design module combinations

Useful Tip

Doing market research and trending technologies might help to inspire unconventional ways of providing the functions.

TEMPLATE STRUCTURE

Function	Idea 1	Idea 2
Function 1		
Function 2		
Function 3		

Worked EXAMPLE

Autonomous vehicle (taxi)

Function	Idea 1	Idea 2	Idea 3
Store and supply energy	Diesel	Gas	Electricity
Convert energy into motion	Wheels	Magnetic levitation	Track
Allow access	Conventional	Canopy	Sliding
Support customer comfortably	Sun shades	Automated doors	Reclined seats
Entertain customer	Music	Livestream video	Games
Passenger door opens automatically	Voice activation	Motion Sensor	Bluetooth signals from app to taxi
Non-visual feedback when door is opened	Music	Announcement	Phone vibration

New Concept 1

Extreme-User Experience Framework

Method

TRIZ

Design Thinking | Directed Ideation

CARD 8 Joyfulness

TRIZ, a Russian acronym for the Theory of Inventive Problem Solving (TIPS), is a collection of universal principles and physical effects for creativity and physical systems.

Why: TRIZ can assist in developing innovative, creative and novel solutions through design-by-analogy, the application of design principles, and the solving of complex problems with inherent contradictions and conflicts.

Materials: TRIZ reference table

Complementary methods: SCAMPER

Acronyms: CPR - Cardio-pulmonary Respiration
PSS - Product, Service, or System
USSR - Union of Soviet Socialist Republics

Scan or click here for a digital copy of the template

Procedure

1 Identify

design conflicts of the product, service, or system.

2 Select TRIZ feature

Decide which TRIZ feature (also known as Generalized Parameter) to preserve and which to improve (list at the next page).

3 Identify conflicts

Identify the TRIZ principles for breaking your conflict with the TRIZ matrix (from the list of design principles).

4 Ideate Solutions

using the suggested TRIZ principles.

Useful Tip

Conflicts and contradictions are avenues for innovation and creative tensions and we encourage you not to look for compromise between the two features. Look for solutions in which the influence of the main problem factor/feature is either totally eliminated or even reversed.

While the original method is meant for physical product design, it is possible to create a set of generalised design principles for digital or virtual products as well.

Fun Fact:

TRIZ was developed in the U.S.S.R. between 1946 and 1985, by engineer and scientist Genrich S. Altshuller and his colleagues.

Worked Example

Designing a cardoor

Before

The force required to close doors was found to be too high for users in order to create a complete seal around the door.

Conflicts:

Shape & force of intensity

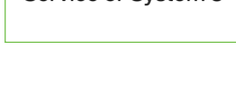
Rubber Door Seal before using TRIZ

After

The parameter change principle was used to make the door seal robust by changing its flexibility using a hollow cross section that still makes the door easy to open.

Parameters:

- Parameter Change
- Preliminary Action
- Thermal Expansion
- Composite Materials



Template Structure (Contradictions Matrix)

* The full matrix can be found online at www.triz40.com

Improving Features \ Worsening Features	Parameters of Product, Service, or System 1	Parameters of Product, Service, or System 2	Parameters of Product, Service, or System 3
Parameters of Product, Service or System 1	+	-	8,15
Parameters of Product, Service or System 2	-	+	-
Parameters of Product, Service or System 3	8,15	-	+

Triz 40 Inventive Principles

Segmentation	Partial/Excessive Actions	Flexible Shells and Thin Films
Taking Out	Another Dimension	Porous Materials
Local Quality	Mechanical Vibration	Colour Changes
Asymmetry	Periodic Action	Homogeneity
Merging	Continuity of Useful Action	Discarding and Recovering
Universality	Skipping	Parameter Changes
Russian Dolls, 'Nesting'	Blessing in Disguise	Phase Transitions
Anti-Weight	Feedback	Thermal Expansion
Preliminary Anti-Action	Intermediary	Strong Oxidants
Preliminary Action	Self-Service	Inert Atmosphere
Beforehand Cushioning	Copying	Composite Materials
Equipotentiality	Cheap Short-Lived Objects	
'The Other Way Round'	Mechanics Substitution	
Spheroidality – Curvature	Pneumatics and Hydraulics	

Worked Example 1

Examples of the Inventive Principle: Periodic Action

Instead of continuous action, use periodic or pulsating actions.

- Hitting something repeatedly with a hammer
- Replace a continuous siren with a pulsed sound.

If an action is already periodic, change the periodic magnitude or frequency.

- Use Frequency Modulation to convey information, instead of Morse code.
- Replace a continuous siren with sound that changes amplitude and frequency.

Use pauses between impulses to perform a different action.

- In cardio-pulmonary respiration (CPR) breathe after every 5 chest compressions.

Worked Example 2

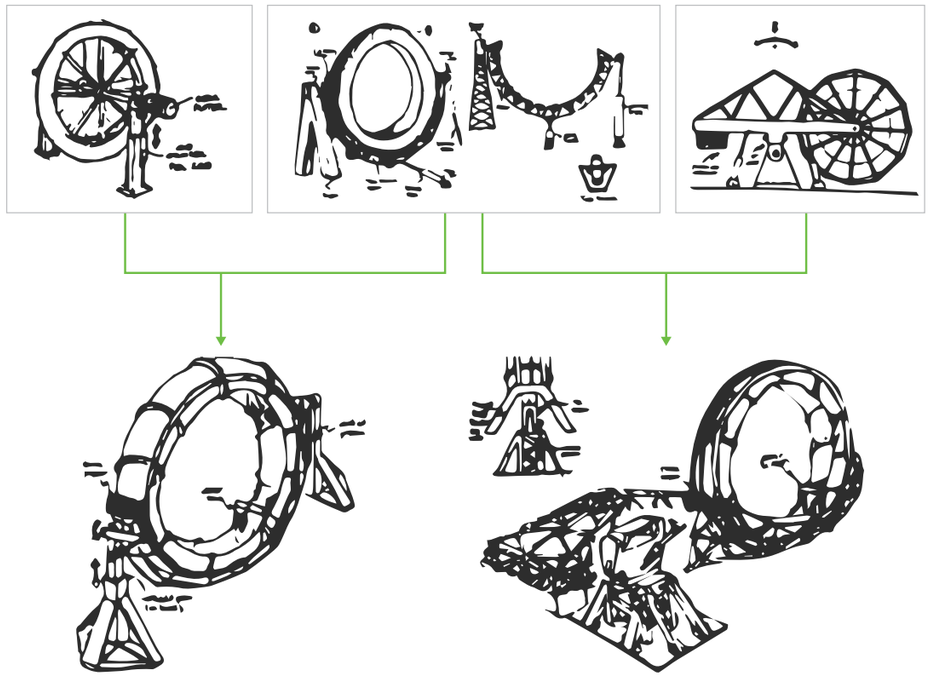
The Other Way Round (Inversion) Inventive Principle - Water slide ride as a perpetual motion machine

To overcome space and water supply limitations / conflicts, an idea for a new water slide amusement park ride is developed with the TRIZ inventive principle of The Other Way Round (Inversion). A rotary slide is created, with water held at the bottom of a rotating wheel. A person rides the rotating and oscillating wheel (donut) on an inner-tube, applying the inventive principles by inverting the motion of a typical water slide ride. In this case, the wheel rotates and oscillates, emulating the motions, velocities and effects of a cutting-edge water slide ride, and the rider stays at the bottom of the wheel, as opposed to the slide staying fixed and the rider moving downward.

Water slide are often thrilling and contains element of surprises. That can be done by adding sideway motions swinging the users to the left or right, and increasing or decreasing the velocity of the slide.

The sketches represent the mechanical and system consideration when integration all the elements into a single novel structure.

How might we develop a water slide with limited space and with virtually no water?



Method

Core-periphery Word Cloud

CARD 9 Joyfulness

Design Thinking | Directed Ideation

This method is used to generate a word cloud comprising of key words and idea functions derived from previously generated ideas and descriptions for further directed ideation.

Why: Core-periphery Word Cloud is a systematic ideation method to generate diverse ideas and can be easily automated to generate a list of ideas from the inputs. It also prioritise the functions that appeared in higher frequency.

Procedure

1 **Extract keywords**

from the descriptions of previously generated ideas. Keyword extraction tools can be applied if the data set is large.

2 **Rank words by their applicability to the design problem**

which can be estimated as the frequency of words in ideas, the connectivity of the words in their co-occurrence network, or other indicators.

3 **Generate a core-periphery word cloud**

where words with higher applicability are positioned more central in the cloud. Words in the core provide relevance, while words in the periphery provide more novelty.

4 **Browse and recombine words**

in the core and periphery.

5 **Elaborate and generate ideas**

based on the recombination of words to generate new design ideas that are both novel and relevant.

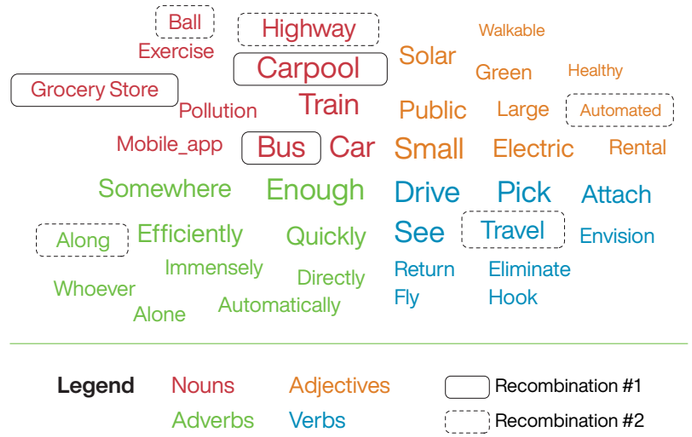
Template Structure

Prep work: Previously generated ideas

1. Keywords
2. Applicability ranking of words
3. Core-Periphery Word Cloud
4. Key-Word Recombination
5. New Ideas

Worked Example

Core-periphery word clouds generated from previous ideas on public transport



Generating new ideas from recombinations

No.	Key-word recombination	New Ideas
1	Bus, Carpool, Grocery store	Buses can be carpooled to a grocery store on weekends.
2	Small, Bag,Travel, Along, Highway	Small automated balls with occupants travel along highways.
...	...	...

Method

Parallel Sketching

CARD 11 Joyfulness

Design Thinking | Intuitive Ideation

Parallel sketching is used to combine and modify features from different sketches of the ideas. A table template would help to organise the combining process.

Why: Parallel sketching is a design ideation tool to accelerate the development of many variations on a design.

Complementary methods: Morph Matrix

Procedure

1 **Define**

the basic optical framework of your product, service, or system.

2 **Create Templates**

Create a number of empty templates using the framework from step 1.

3 **Sketch 5 variants**

Try to sketch at least 5 or more different ideas on the templates.

4 **Review Sketches**

and try to create new 'very different' ideas, sketch it on the template.

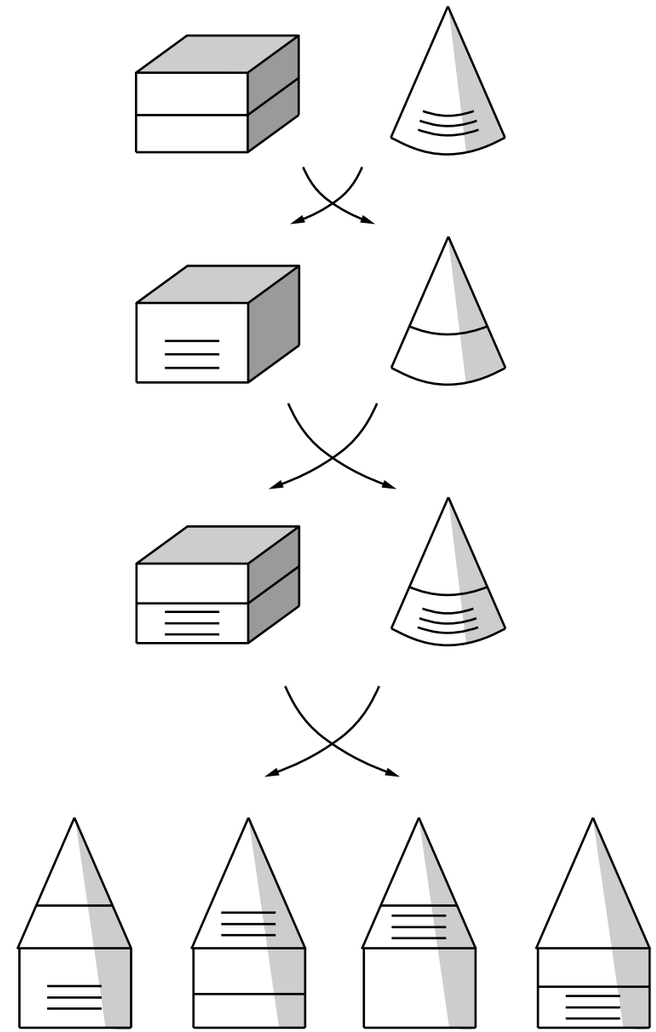
5 **Repeat**

Repeat all the steps until you have populated the matrix, repeat as needed.

From left to right: The bottom, top and front views of a ring (the product)

A printed out template from step 1 as a Matrix

Worked Example



Method

Product-Service-System Design (PSS)

Design Thinking | Ideation Approaches

CARD 13 Joyfulness

Product-service-system design emphasises the relationship between products and services in developing a sustainable competitive advantage.

Why: A holistic understanding of the solution as a system of product and the services developed for the users, ensures that the product and services developed are complementary and support each other.

Acronym: PSS - Product, Service, or System

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Procedure

1 **Customer Needs**
Identify customer needs.

2 **Material Needs**
Identify customers' material (product) needs.

3 **Service Needs**
Identify customer service needs.

4 **Production**
Identify means of producing products.

5 **Providing Service**
Identify means of producing products.

6 **Business Model**
Develop a business model.

7 **Customer Validation**
Validate with customers.

Objectives

- Structure interactions among stakeholders.
- Understand the deeper value that is being provided.
- Develop a sustainable 'ecosystem'.

Template Structure

Customer view	**Needs** What are the customers' needs? **Value** What does the customer perceive as valuable?
Design layers	**Deliverables** What is delivered to the customer? **Life-cycle activities** What are the overall life-cycle activities connecting resources? **Actors** Who are the actors, stakeholders, and business units involved in life-cycle activities? **Core products** What are the core products, services or systems? **Periphery** What is the backstage equipment, which is not directly visible to the customer, and what are the peripheral systems? **Contract** What are the conditions that have to be mentioned, fixed, or expressed by the contract? **Finance** What is the underlying cost structure and cash flow model? **Optional layers** What are the optional layers to emphasize specific characteristics and effect zone in a PSS?

Method

Paired Comparison Chart

CARD 15 Joyfulness

Systems Thinking | Concept Selection

Paired Comparison Chart compares ideas in pairs, relative to one another, without the need for identifying criteria.

Why: Paired Comparison Chart ranks ideas to quickly identify the top ideas to move forward with. This method is particularly useful when evaluation criteria is unclear, or subjective.

Materials: Excel Sheet and Paired Comparison Chart Template

Complementary methods: Prioritisation Matrix, Pugh Chart

Scan or click here for a digital copy of the template

Procedure

1 Draw a table

listing the ideas along the first row and the first column (refer to the template at the back).

2 Compare the ideas in pairs

Going column by column, run down the cells in each column, recording '1' if the idea of the column is evaluated as relatively better than the idea of that row, and '0' if it is relatively worse.

3 Sum up the score in each column

and record the score of the idea represented by each column in the appropriate cells below (refer to the example at the back).

4 Rank the ideas

according to their scores.

Useful Tip

Write down and document the reason why the '1's and '0's are given. This will be helpful to remember the thought process of the team and to also provide justifications.

Template Structure

In Comparison with variant	Variant A	B	C	D	E
A	-				
B		-			
C			-		
D				-	
E					-
Sum					
Rank					

Worked Example

The worked example above explains how prioritisation matrix works. In each box, you can ask: Is [top header variant] better than [leftmost column]? 'Better' is a subjective word and the team can discuss among themselves if there is any clarification needed and explanation. This can be done individually first then as a group, to prevent group thinking.

In Comparison with variant	Variant A	B	C	D	E
A	-	1	0	1	0
B	0	-	0	1	0
C	1	1	-	1	0
D	0	0	0	-	0
E	1	1	1	1	-
Sum	2	3	1	4	0
Rank	3	2	4	1	5

'-' because a concept variant is not compared to itself

'0' indicates that concept variant 1 is not better than 2.

'1' indicates that concept variant 1 is better than 3.

We can’t solve problems by using the same kind of thinking we used when we created them.

Albert Einstein

Theoretical physicist and one of the most influential physicists of all times.

Method

Prioritisation Matrix

Systems Thinking | Concept Selection

CARD 16 Joyfulness

Prioritisation Matrix arranges and visualises ideas or desired features in a 2x2 matrix based on two important criteria.

Why: Prioritisation Matrix allows designers and users to prioritise ideas for testing or implementation, based on their relative positions within the matrix.

Materials: Prioritisation Matrix Template

Complementary methods: User Interviews, Affinity Analysis, Brainstorming, DI Mindmapping, C-Sketch (6-3-5), Design by Analogy, SCAMPER, (Systems Requirements from System Architecture)

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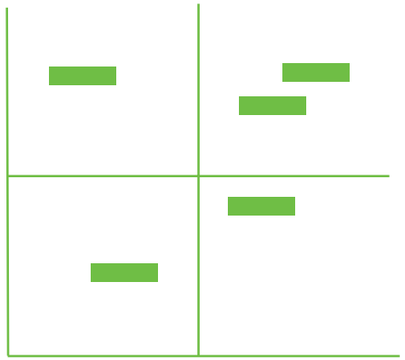


Procedure

1 **Pick two criteria**
central to the design problem.

2 **Draw horizontal and vertical axes (forming a 2x2 matrix)**
and assign the two chosen criteria to the two axes.

3 **Plot ideas on the matrix**
discussing and positioning them as a team, rating them based on the two chosen criteria and the scale.

4 **Discuss the plot**
selecting which ideas to pursue and synthesise.

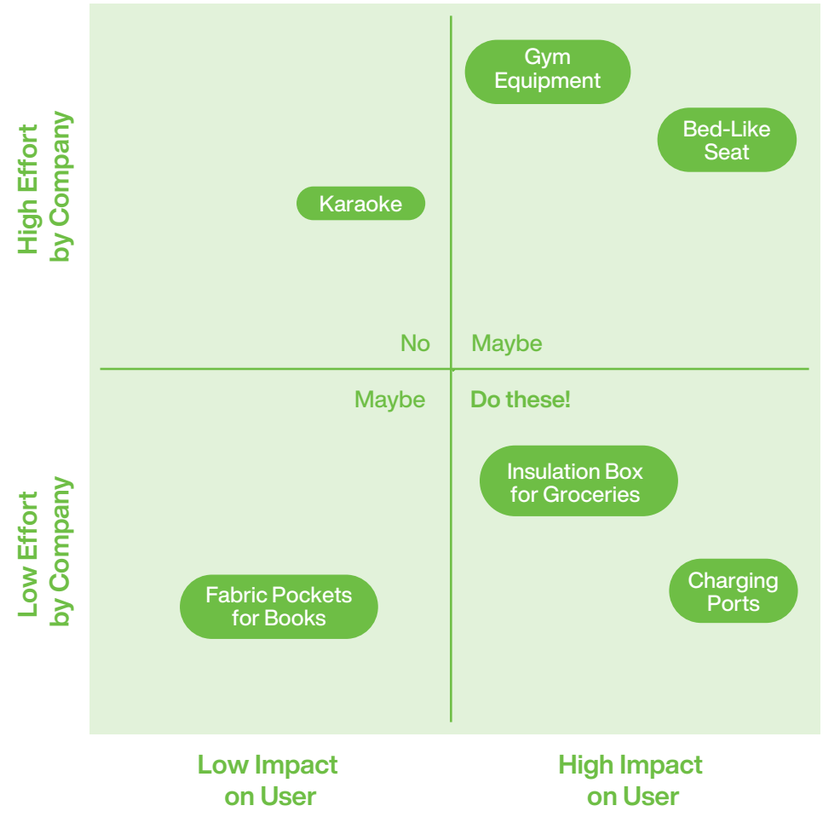
Typical Evaluation Criteria

- Effort
- Cost
- Urgency
- Feasibility
- Risk
- Impact
- Value
- Importance
- Potential
- Reward

Worked Example

Added convenience in vehicles

In this example, 'Impact' and 'Effort' were chosen as evaluation criteria. The ideas were evaluated based on those criteria.



Method

Pugh Chart

Design Engineering | Concept Selection

CARD 17 Joyfulness

Pugh Chart is a method to evaluate the overall value of ideas/ concept variants through a series of pairwise comparisons against a set of selection criteria. It also permits a degree of qualitative optimisation of the alternative concepts through the generation of hybrid concepts.

Why: Pugh Chart presents a clear and neat documentation of the selection process of the solution and identifies weakness in design that can be improved on. Pugh Chart's advantage over other decision-making tools is its ability to handle a large number of decision criteria.

Materials: Excel Sheet

Complementary methods: User Interviews, Affinity Analysis, Brainstorming, DI Mindmapping, C-Sketch (6-3-5), Design by Analogy, SCAMPER, (Systems Requirements from System Architecture)

Scan or click here for a digital copy of the template

Procedure

1 Generate

selection criteria for the concepts and assign weight to each criterion so that the sum of the weights add up to 100%.

2 Draw

a table with concept variants listed in the header row, and selection criteria listed in the leftmost column.

3 Set

a reference concept variant. All other concepts will be compared against this reference concept variant and its rating is 3 by default. Rating for other variants ranges from 0-5.

4 Compare

each variant to the reference variant, oneat a time and for each selection criterion. Record '4' or '5' if it fares better than the reference, '3' if it fares the same, and '1' or '2' if it fares worse.

5 Sum

the total evaluation for each design. The score for each selection criterion is the product of the weight and rating.

Useful Tip

Assign equal weights for each selection criterion for a simpler Pugh matrix. The weights can be ignored, and the ratings can be summed up to give the evaluation directly. Another possible modification to improve the matrix is to add qualitative evaluation to each rating, which may be more objective and encourage discussion and awareness of design decisions.

Template Structure 1

Selection Criteria	Weight (100%)	Concept Variants A	B	C	D	Ref.
						3
						3
						3
						3
						3
						3
						3
Total Score						
Rank						
Continue?						

Template Structure 2

Design Criteria	DATUM	Alternative Design Concepts: Design Concept 1	Design Concept 2	Design Concept 3
Design Criterion 1				
Design Criterion 2				
Design Criterion 3				
Design Criterion 4				
Design Criterion 5				
Total +				
Total –				
Total				

Worked Example

This Pugh Chart example shows several concept variants of an opportunity, 'How might we drastically reduce or protect people against accidents related to using last mile transportation devices while inspiring travellers?'

Details of each variant can be found in the SCAMPER Method. Variants rated low compared to others may not be pursued depending on the amount of resources available to the design team.

How might we drastically reduce or protect people against accidents related to using last mile transportation devices while inspiring travellers?

Selection Criteria	Weight (100%)	Concept Variants				
		Hitch-a-Ride	2-in-1	Speed Humps	Soccer Ball Helmet	Airbag (Ref.)
Protection against injuries	25	1	1	4	2	3
Mass of transportation devices	20	2	1	5	2	3
Convenience	10	5	2	1	4	3
Affordability	10	2	2	1	4	3
Eco-Friendly	10	5	3	2	2	3
Inclusiveness	10	5	5	3	4	3
Simplicity	15	1	2	5	2	3
Total Score		2.5	1.95	3.45	2.6	3
Rank		4	5	1	3	2
Continue?		No	No	Yes	Yes	Yes

Worked Example

Coffee grinder

Design Criteria	Alternative Design Concepts			
				
Cost	0	+	+	--
Store Grinder	0	++	+	0
Put in Beans	0	0	-	0
Cleanable	0	0	-	0
Total +	0	3	2	0
Total –	0	0	2	2
Total	0	3	0	-2

Method

SWOT Analysis

Business Model Innovation | Concept Selection

SWOT Analysis is a strategic planning and management tool consisting of four components: 'Strengths', 'Weaknesses', 'Opportunities' and 'Threats'. It could be used for strategic planning, in carving out a sustainable niche in the market.

Why: SWOT Analysis could help with strategic planning and carving out a niche in the market, leveraging on strengths and opportunities and being mindful of weaknesses and threats.[1,2]

Materials: SWOT Analysis Template

Complementary methods: Design by Analogy, SCAMPER (Refined Concept Sketches or Models)

Acronyms: SWOT - Strength, Weakness, Opportunity, Threat

Scan or click here for a digital copy of the template

S	W	O	T
Strengths	Weaknesses	Opportunities	Threats

Procedure

1 **Evaluate the internal factors**

with the 2 components, 'Strengths' and 'Weaknesses'.

2 **Evaluate the external factors**

with the 2 components, 'Opportunities' and 'Threats'.

3 **Create**

strategy plan, considering potential connections between the 4 components, and prioritising them.

Useful Tip

SWOT analysis can be used for the design of the business, for the design team as well as design ideas. Use it flexibly to evaluate the current status of the project.

Worked Example[5]

A special meat and fruit pie café sells hot pies and frozen take-home options, as well as an array of fresh salads and drinks. They are planning to open an outlet in Yubetchatown and want to develop a business model that will facilitate scalability and franchising. This is an example of how their SWOT analysis might look like.

	Strengths	Weaknesses
Internal	**Location** Our first location downtown will attract visitors and downtown shoppers. **Uniqueness** We stand out as a unique alternative to fast food and we offer high-quality food in a distinctive atmosphere. **Strong Management** We have assembled a team that embraces different disciplines with expertise in all areas of the business.	**Lack of Capital** All startup funds will come from loans and investors. **Lack of Reputation** We have not established ourselves as reputable meat pie provider yet.
	Opportunities	**Threats**
External	**Area Growth** Yubtchatown is growing by 8.5% annually. **Working Families with Children** This is a growing population, both in numbers and in their choice of convenient foods. Two income families have less time to prepare a meal.	**Competition** One competitor sells similar pies, and has loyal customers and relationship with businesses that regularly buy from them. **Being Unprepared for Opening Numbers** Initial poor service or product quality could discourage customers from returning.

Method

Adjacency Diagram

Systems Thinking | Directed Ideation

Adjacency Diagram is a table that shows what spaces should and should not be near to each other on plan.

Why: Adjacency Diagram helps translate a list of physical spaces and its requirements into a schematic design. It provides a broad overview of spatial relationships and builds upon word or verbal descriptions. It is often used together with bubble diagram which lay out spaces in a certain arrangement using the relationship.

Materials: Wall/Board

Complementary methods: Site Analysis, Benchmarking, Affinity Analysis, Systems Function Model

Procedure

1 Generate

a list of spaces that are to be included in the design.

2 Determine

adjacency of each space in relation to another (refer to Diagram A). Leave blanks for spaces that are not related to each other.

Shade the box green if the 2 spaces must be next to each other, it means that they have an important relationship.

Shade the box grey if the 2 spaces are good to be next to each other, it means that they have a desirable relationship.

3 Draw out

the spaces and represent each space as a bubble. Note that size of each bubble should be proportional to the size of the space allocated.

4 Draw out

the relationship between the spaces, using solid bar (green) to represent an important relationship and hollow bar (grey) to represent a desirable relationship (refer to Diagram B).

Useful Tip

Add more columns to the adjacency diagram to record other useful details, such as floor area and function of spaces.

Worked Example

Diagram A: Adjacency Diagram[12]

Diagram A is the worked example of the adjacency diagram (A) (B). The entity listed as rows is the name of each spaces (A - K are used instead as representation in this example), and the respective coloured box represents different relationships between spaces. Blank boxes might also provide information since it shows a lack of relationship.

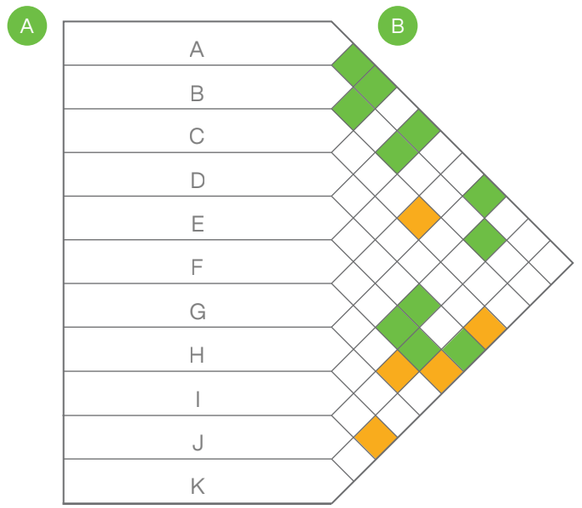
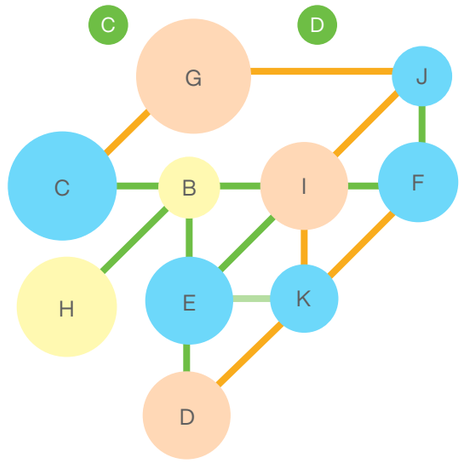


Diagram B: Bubble Diagram[3]

Diagram B is a worked example of the bubble diagram, which is an extension of the adjacency diagram. It translates a set of matrix into a visual representation of the spaces (C) (D). The bubble diagram is meant to be quick and iterative. Because it is usually hand-drawn, the diagram can be rearranged. While drawing the bubble diagram, take into consideration the function of each space and functions are carried out over multiple spaces.



Method

Design Optimisation

Design Engineering | Directed Ideation

Design Optimisation uses a mathematical objective function, encapsulating what gives your design value to users, as a guide to find the design concepts that deliver the most value.

Why: Optimisation algorithms are efficient ways to search a large design space, allowing for iterative testing computationally before prototyping a select number of promising alternatives found from optimisation. Optimisation can also reveal areas of the design space that are not intuitively obvious to explore.

Materials: Software for solving optimisation problems (e.g., Excel, MATLAB)

Complementary methods: Hierarchy of Purpose, Kansei Engineering, Real-Win-Worth, Paired Comparison Chart, Prioritisation Matrix, Pugh Chart, SWOT Analysis and all methods under core and advanced prototyping methods

Procedure

1 **Represent**

your design concept with a set of variables that describe the concept. Examples of design variables are lengths or dimensions, material properties, or quantities of components.

2 **Define**

an objective function that connects the mathematical representation of your design to desired outcomes, such as weight, cost, desirability, usability, or performance.

3 **Bound**

your design space using constraints, for example to ensure lengths are non-negative, or that material properties are realistic. Constraints should be a function of design variables.

4 **Select**

an optimisation algorithm to search the design space defined by your design variables and constraints, and guided by your objective function.

5 **Repeat**

your optimisation using different initial designs as starting points.

6 **Explore**

optimal solutions that are on a constraint. Would your solution improve if you could exceed the constraint? What does that mean practically?

Best Practices & Tips

Well-posed and well-bounded

Sanity check: your objective function and constraints should bound a set of solutions that make physical sense

Visualize your design space

if you can. How many variables do you have? How do you expect your objective function to vary across those variables?

Some optimisation algorithms are computationally expensive

To shorten the time to complete, explore alternative algorithms or use a surrogate model.

Multiple objectives

Designs will often have tradeoffs between multiple objectives, and a best design is one that you decide meets all objectives satisfactorily.

Optimisation Algorithms

Algorithms are computational routines used to efficiently search a design space for optimal solutions. Algorithms search over the design space of potential variable values, evaluating your objective function at selected points to determine where to search next for a maximum or minimum objective value.

Algorithms you can find in common software like Microsoft Excel include:

- **Simplex method** is a type of linear programming, and efficiently solves systems of linear equations such as a linear objective function with linear constraints.
- **Gradient based algorithms** such as gradient descent, Newton's method, or Generalized Reduced Gradient (GRG) are used for continuous, nonlinear objective functions.
- **Evolutionary algorithms** such as genetic algorithms, particle swarm, or simulated annealing evolve designs based on their performance according to the objective function. May be less computationally expensive than gradient based algorithms.

Worked Example

An example design goal, written as an optimisation problem: Maximize the amount of liquid a cylindrical can is able to hold (volume) while minimizing its weight, with a thickness not less than 0.01 centimeters.

The corresponding functions are:

Volume= $\pi(r - t)^2 h$ cm^3

Weight= $(2\pi rh + 2\pi r^2)t\rho$ grams

Legend
r = radius
h = height
t = thickness
ρ = material density

Written mathematically, the optimisation goal can be written as follows, with a and b as parameters that vary the relative importance of each part of the design goal (volume and weight) in the overall design:

Maximize: f(r,h,t) = a*V(r,h,t) – b*W(r,h,t) subject to constraints:

$2 \text{ cm} \leq r \leq 3 \text{ cm}$

$2 \text{ cm} \leq h \leq 15 \text{ cm}$

$0.01 \text{ cm} \leq t \leq 1 \text{ cm}$

$\rho = 2.7 \text{ grams/cm}^3$

By varying the relative importance of weight and volume goals, different solutions are obtained:

Design 1
a = 1
b = 0
Radius = 3 cm
Height = 15 cm
Thickness = 0.01 cm
Volume = 843 cm^3
Weight = 9.2 g

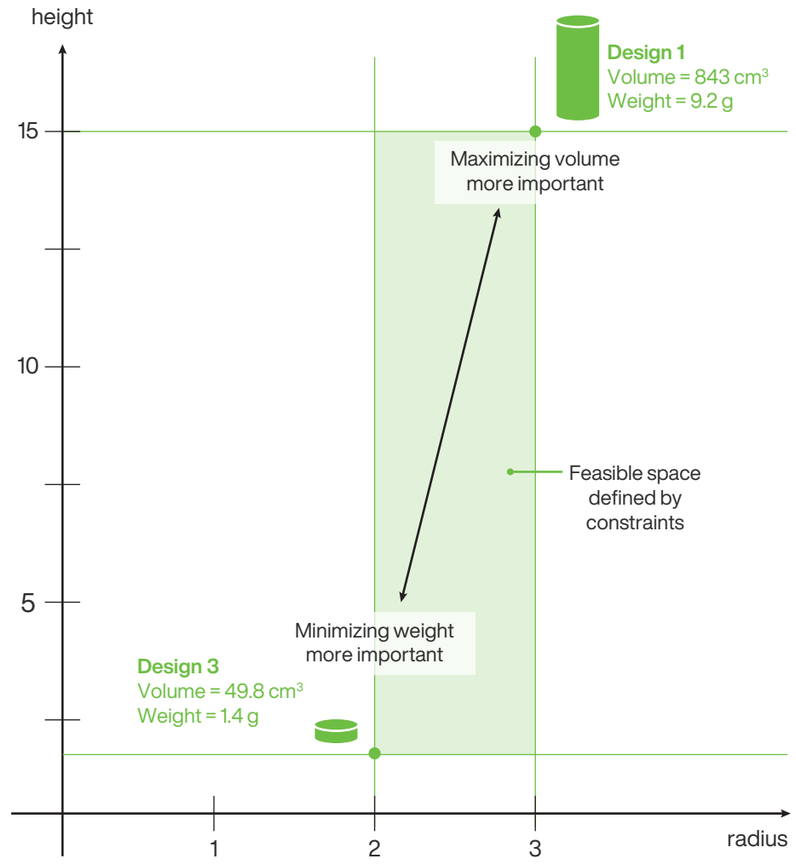
Design 2
a = 0.5
b = 0.5
Radius = 3 cm
Height = 15 cm
Thickness = 0.01 cm
Volume = 843 cm^3
Weight = 9.2 g

Design 3
a = 0
b = 1
Radius = 2 cm
Height = 2 cm
Thickness = 0.01 cm
Volume = 49.8 cm^3
Weight = 1.4 g

Results

Varying parameter values allows exploring the design space defined by the constraints, and there are two dominant solutions in this space. The results indicate that the volume is much more heavily weighted in the mathematical objective formulation, and additional concepts may emerge as alternatives if different relative weights are chosen.

Both extreme concepts are at the edge of what is defined as the possible range of variable values in the optimisation problem formulation, meaning that concepts with a larger volume and lower weight are likely possible if the constraints are changed.



Deliver

Iteratively prototype and test concepts and models with users

MINSET

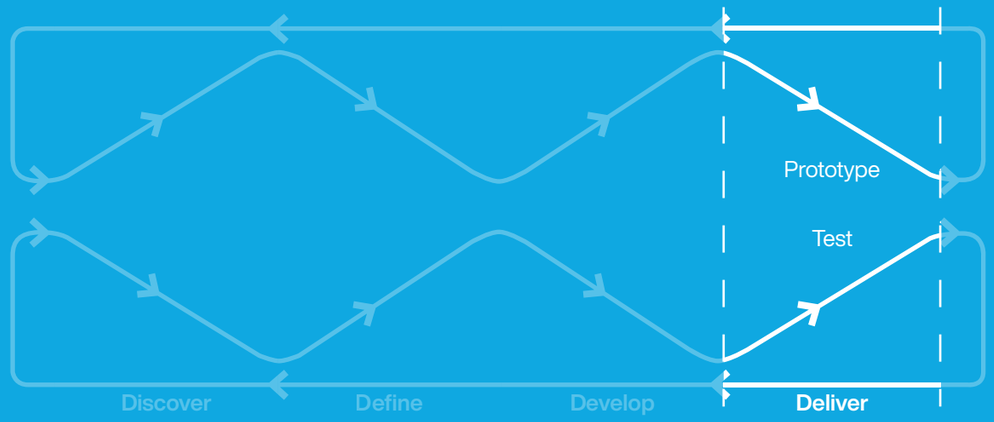
Non-attachment

Prototype

- What are different prototyping strategies?
- What prototyping principles should be used?
- How might we build the virtual or physical prototype?
- How might DIY concepts be applied?

Test

- What questions need to be answered by the prototype?
- How do we engage users?
- What is the minimum sample size?
- How might we mix and utilise both quantitative and qualitative results?



Method

Prototyping Canvas

Design Thinking | Planning

CARD

Non-attachment

Prototyping Canvas is a strategic prototyping template that guides users to answer critical assumptions or questions.

Why: Prototyping Canvas effectively guides designers through prototyping processes, facilitates a common prototyping language amongst team members. It encourages intentional prototyping practice, which should ultimately reduce resources and improve design outcomes.

Time: 45 mins

Materials: Prototyping Canvas Template

Complementary methods: Real-Win-Worth, Pugh Matrix, Prioritisation Matrix, Mockups, Physical Model, Role Play, Wireframing, Storyboarding

Acronyms: HMW - How Might We
UX - User Experience

Scan or click here for a digital copy of the template

Procedure

1 Prepare your opportunity statement/concepts

Be familiar with the prototyping mindsets, techniques, and approaches. Start with an opportunity and select a few top concepts or solutions.

2 Record and fill in the canvas

Let the critical assumptions and questions guide the prototype development. Fill in the template in any order until everything is done, leaving the 'Insights' box for after testing has been conducted.

3 Share as a team, and discuss

Talk about the various assumptions and questions you have all identified, and how you plan to build and test your prototypes.

4 Build, test, and reflect

Turn your sketches into prototype, and aim to test as soon as possible, ideally with users and stakeholders. Capture feedback from testing, both qualitative and quantitative and reflect on future directions.

Best Practices

Pair and Share

We recommend first work on the canvas individually or in pairs. Then, use the various Prototyping Canvas to have a larger conversation as a team.

Conversation Tool

Use the Prototyping Canvas as a conversation tool with your team, client, or other important stakeholders.

Mindsets

Make sure you embody the important mindsets for prototyping during this activity: have a bias towards action, practice non-attachment towards your concepts especially during testing, and build to think and using 'failures' as learning opportunities.

Quickest Path to Experience

Find the quickest path to experience: you want to prototype in the shortest amount of time with minimal cost and resources used to test your assumptions and/or answer your key questions.

Prototyping Principles

Use one or more prototyping principles to help you achieve building the simplest prototype possible to test your critical assumption or question.

Prototype with Purpose

Every prototype needs a purpose. A prototype should answer a question or validate/invalidate and assumption. Use your assumptions and questions to guide the development of the simplest prototype possible to validate these assumptions and/or answer these questions.

Useful Tip

The canvas can be used for planning both present and future prototypes. This can include what you will need or require to build/make the prototype regardless of when you do it i.e. what you have now and what you might need to go and get to get your prototype(s) built.

Worked Example 1

This is an example of the Prototyping Canvas for solving an opportunity/problem posed by the Robert Wood Johnson Foundation and solved by two design teams.

The team engaged in the human-centred design process to solve these opportunities/problems. This example is showing how one concept was parallel prototyped in 3 versions in order to understand how fun it would be for the children to use.

Useful Tip

Discuss the canvas as a team and use one canvas for each concept/solution.

Prototyping Canvas

1 Problem or Opportunity

How might we increase children's (age 3-5) social-emotional competencies?

2 Concept/Solution

Toy or game that teaches emotional intelligence to kids

Stakeholders
3

Client: Robert Wood Foundation
Users: Children ages 5-6 years in Colorado
Consumers: Parents of Children

Communication Strategy For Prototype
4

Use prototypes (3 in parallel) to elicit feedback from users (children) and consumers (parents) to further improve the concept

Assumptions & Questions
5

About the user and their needs
- Kids will find these toys/games fun to use.
- Toy is intuitive to use on own.
- Kids enjoy multi-modal interactions (movement, light, sound, touch).
- Kids are not always aware of emotions.

About the technical feasibility & functionality
- All components will fit in a compact toy.
- Integration of light, sound and feedback will be simple to achieve.
- Can 3D print toy casing within tolerance.

About the cost and business
- Parents will pay for the toy ~$30 USD.
- Early toys can be made in-house but later the manufacturing will be done off-site.

Critical Assumptions/ Questions
6

Assess above list: what is the most critical to the success of the project?

The toy needs to be fun and intuitive enough for kids to enjoy and use on their own. If we do not meet this need, the project will fail.

Insights Gained From Testing
11

What did you learn? Did you answer the critical assumption/ question?

Factors from all 3 concepts were liked. We plan to incorporate the most liked features together to make a multi-modal interaction toy that will bring back and test with users next week.

Resources To Build
7

Materials readily available or needed

Miscellaneous materials:
Electronics including Arduino and LEDs, Cardboard, Mirrors, Laminators, Colour Printers, Yoga Mat, Foam Core, Wood, Plastic

Time, Money, & People Allotted
- 1 week to build and test
- 5 team members
- < $200 for these prototypes
- Resources in design centre

Prototyping Approaches
8

- [x] Parallel Prototyping
- [x] Experience Prototyping
- [x] Remove Unessential Features
- [ ] Sub-system Isolation
- [ ] Role Playing
- [ ] Repurpose Existing Products
- [ ] Requirements Relaxation
- [ ] Sequential Prototyping
- [ ] Paper Prototyping
- [ ] Wizard-of-Oz
- [ ] Scaling
- [ ] Other: _____

Testing Plan
9

What are you testing?

Test 3 versions of toys: How fun and engaging are they?
Where are uses confused and uninterested?

What metrics are needed? Quantitative/ Qualitative assessment.

Quantitative:
- Time engaged
- Delight Scale
- Touch Points

Qualitative:
- Emotional Reaction
- Quotes - what is said
- Facial Expressions

Time, Place, People, & Materials required to test

Test with focus group of 5 families on Saturday at 9:00 AM.
Two team members needed. Bring 3 prototypes, notebook, stopwatch, camera, delight scale.

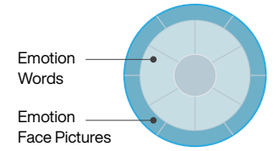
Sketch a Build Plan
10

Build the simplest prototype possible (least cost, time, and materials required) to test critical assumption and/or answer critical question.

Plan:

Parallel prototype 3 toys/games with low fidelity mediums/materials, relaxing many unessential features, to test the experience with users.

1. Feeling and Activity Spinning Wheel

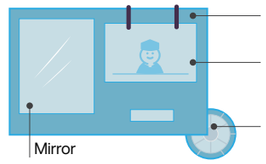


"Spin the wheel and try to align word with emotion"

3 spinning concentric circles

Materials:
Foam core, cardboard, print/laminate pictures

2. Feelings Self Reflection Multi-Modal Interactions



3. Feelings Embodiment Postures/Movement

"Yoga-inspired Game"

Yoga mat with pictures of animal describing certain emotional poses

"Happy Frog", "Silent Snail", "Angry Lion"

Worked Example 2

This is an example of a Prototyping Canvas used for an opportunity statement around data visualisation approaches. The opportunity here is: How might we design a collaborative web platform around sharing, visualising, and comparing data for the future of young professionals and potential organisations for employment?

The team engaged in deep discussion about each item in the canvas, particularly focused on assumptions to test how people understand and interpret multidimensional data. Prototyping followed parallel prototyping approach, resulting in a modular prototype that could be easily adapted and shown in different contexts to conduct several tests.

DIGITAL DESIGN
refer to page 2

Prototyping Canvas

1 Problem or Opportunity

HMW allow users to understand multidimensional dataset, individually and in relation to another dataset, at a glance?

2 Concept/Solution

Visualisations with striking visual differences and animations to provide quick and easy comparison

Stakeholders 3

- Individuals entering data
- Individuals searching for data
- Individuals using data to make decisions

Communication Strategy For Prototype 4

- Display visuals alone as part of a survey
- Display visuals integrated with functionality so users can interact with data

Assumptions & Questions 5

About the user and their needs

- Multiple view modes needed: qualitative and quantitative views
- Assume users are willing to enter full dataset
- Users prefer high contrast colours
- Users can interpret and comprehend multidimensional visualisations

About the technical feasibility & functionality

- Browser processing power capable of generating visuals
- Browser width < 600 pixels
- Viewable on a phone
- Security appropriate for information privacy
- Mobile responsiveness
- Data is verified

About the cost and business

- People are willing to take time to verify/validate others' data

Resources To Build 7

Materials readily available or needed

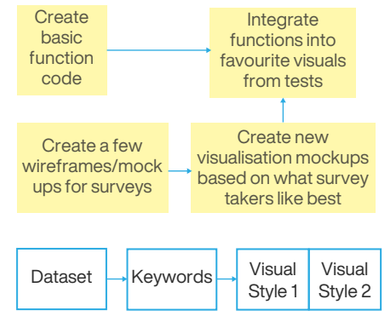
License for survey software; Adobe suite; CSS/Javascript

Time, Money, & People Allotted

- Emphasise existing resources to build prototypes
- 1 week development time
- Beta testers to refine mockups and survey forms

Sketch a Build Plan 10

Build the simplest prototype possible (least cost, time, and materials required) to test critical assumption and/or answer critical question.



Prototyping Approaches 8

- ☑ Parallel Prototyping
- ☐ Sub-system Isolation
- ☑ Requirements Relaxation
- ☐ Wizard-of-Oz
- ☐ Experience Prototyping
- ☐ Role Playing
- ☐ Sequential Prototyping
- ☐ Scaling
- ☐ Remove Unessential Features
- ☐ Repurpose Existing Products
- ☑ Paper Prototyping
- ☐ Other: _____

Critical Assumptions/ Questions 6

Assess above list: what is the most critical to the success of the project?

Critical assumption to test: Users can interpret and comprehend multidimensional visualisations. If false, users will not be able to perform core actions of searching for data or using data to make decisions, driving down the perceived value of the service.

Insights Gained From Testing 11

What did you learn? Did you answer the critical assumption/question?

Easiest visual style for identifying similarities and differences is not necessarily the easiest visual style for quick interpretation of a single chart. Helps narrow down visual styles, and suggests the best design may draw from a combination of features.

Gradation of colour to indicate change in values is useful, but may give the wrong impression that higher or lower values are better or worse.
Uncovered a new assumption we had not realised that different colours may have multiple unintended meanings

Testing Plan 9

What are you testing?	What are you testing?	What are you testing?
How each individual sees/comprehends data	How each individual is able to distinguish different data categories	Whether each individual can easily derive and use pertinent information from the visualisations
What metrics are needed? Quantitative/ Qualitative assessment.	**What metrics are needed? Quantitative/ Qualitative assessment.**	**What metrics are needed? Quantitative/ Qualitative assessment.**
• Ease of understanding Success: 4 or higher on 5 point scale for ease of understanding	• Time to complete comparisons Success: Response in under one minute	• Likert scale evaluation of usability Success: 4 or higher on 5 point scale
• Likert scale evaluation - UX factors Success: 4 or higher on 5 point scale	• Accuracy of comparison Success: correct evaluation of mock datasets	• Likert scale evaluation of usefulness Success: 4 or higher on 5 point scale
Time, Place, People, & Materials required to test	**Time, Place, People, & Materials required to test**	**Time, Place, People, & Materials required to test**
• Test several visualisations in an online survey • Survey takers	• Test several visualisations in an online survey • Survey takers	• Test several visualisations in an online survey • Survey takers

Method

Storyboarding

Design Thinking | Presentation

CARD 4
Non-attachment

Storyboarding is a tool to communicate your idea or scenario of use. A multimedia storyboard can include elements of video, sketch, text, audio, photos, and even physical prototypes to illustrate the story, be it linear or non-linear storyline.

Why: Storyboarding can serve many purposes. When used in the Discover phase, it can allow you to better understand current situations. In the Define Phase, it can allow you to hone in on key aspects of your design to iterate on. When used in the Deliver phase, it can allow you to quickly and effectively communicate your ideas and concepts.

Materials: Video/Audio Recording Devices and Multimedia Storyboarding Template

Complementary methods: User Journey Map, Personas, Scenarios, Service/UX Blueprinting, Prototyping Canvas, Wireframing, Mockups, Physical Model, Role Play

Acronyms: HMW - How Might We
UX - User Experience

Scan or click here for a digital copy of the template

Procedure

1 **Identify target user**
What are your user's key characteristics?

2 **Identify the story's key focus**
What are 3 most important details to convey?

3 **Identify the story's context**
Where and when does this story take place?

4 **Identify key actors**
Who are involved in the story? They could be inanimate objects.

5 **Choose the flow of events**
What is the sequence/order of events? Discuss it with your team and start drawing.

6 **Pitch and gather feedback**
Depending on your target audience, you will either seek to convince/persuade through your pitch (eg. to clients), or to simply gather feedback from users to fuel further design iterations.

Frequently Asked Questions

When should you use playacting instead of a storyboard?

A question you can ask yourself is: Are there a lot of human interaction touchpoints in this story? If so, perhaps it may make more sense to playact it out.

What would warrant the drawing/ recording of an event on a frame?

Each change in touchpoints/scenes/actions of the user ought to be its own frame.

How high-fidelity should your storyboard be?

This will depend on the target audience you intend to pitch it to. Should your target audience be clients that you are seeking to convince/ persuade with your storyboard, then by all means polish it up and make it sleek and presentable! For instance, you may choose to swap out the hand drawn images with photographs instead.

Alternatively, you may be pitching your storyboard instead to users in hopes of gathering their feedback. In this second case, time is of the essence, so prototype out the simplest version you can that still enables you to carry your intended message and experience across.

Template Structure

Scenario: Key Focus of Story

Start:	Next Scene:	Next Scene:
	Change in Touchpoint:	Short Description:
Next Scene:	Next Scene:	End: Resolution

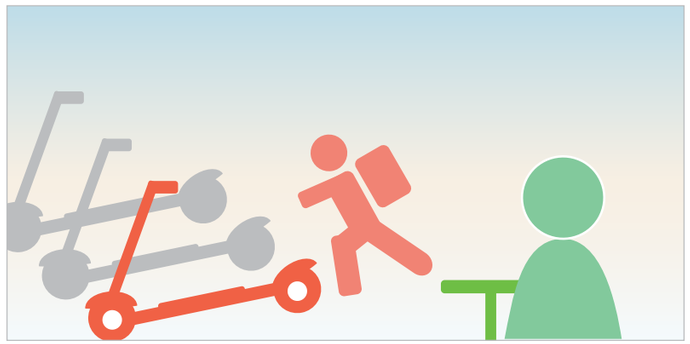
Worked Example

Re-illustrated sketch of a DI team member's Storyboarding sheet

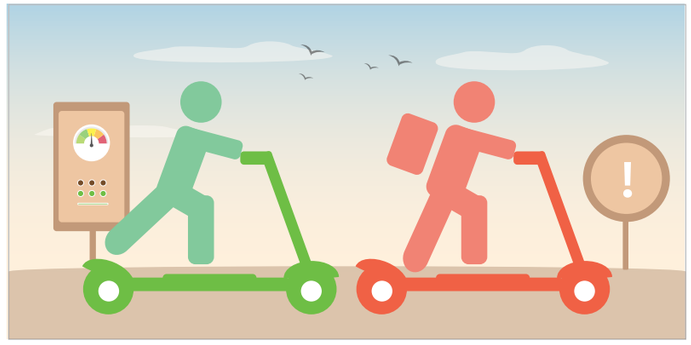
Scenario: Exploring the rail corridoor by scooter

Edmund brings his scooter on the train and alights at the train station.

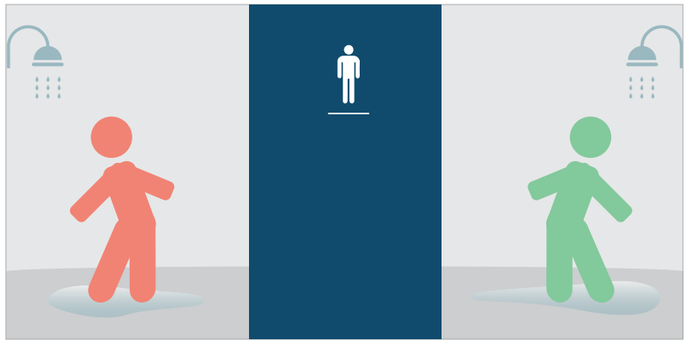
He is early and grabs a coffee while waiting for his friend, Matthew.



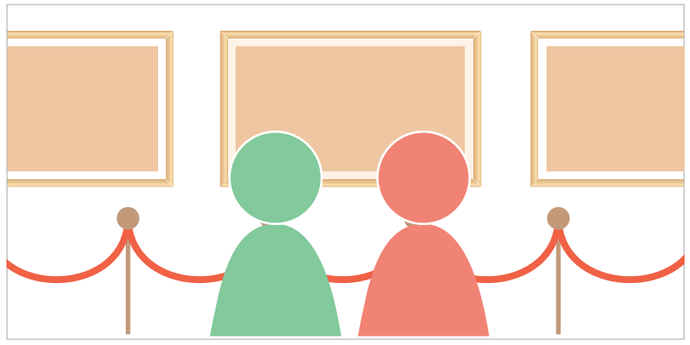
Matthew arrives and rents a scooter at the station.



They ride through the station and explore the rail corridor.



After riding, they take a quick shower at the train station before having lunch.



They pass by an exhibition at the station and learn more about the history of the old rail corridor.

Method

Role Play

CARD 3 Non-attachment

Design Thinking | Presentation

Role play is a method for taking on another's perspective and acting like them in a particular scene that you have constructed with other characters.

Why: You are able to focus on the person-to-person interactions you are having as that character, empathise with the character, and gain insights from the experience.

Procedure

1 Consider what you are testing for

and how you will measure success.

2 Plan and build

such as actor assignment, outcomes, props, touchpoints, etc.

3 Run the play

where each team member assumes his or her role trying different approaches where necessary.

4 Wrap up and analyse

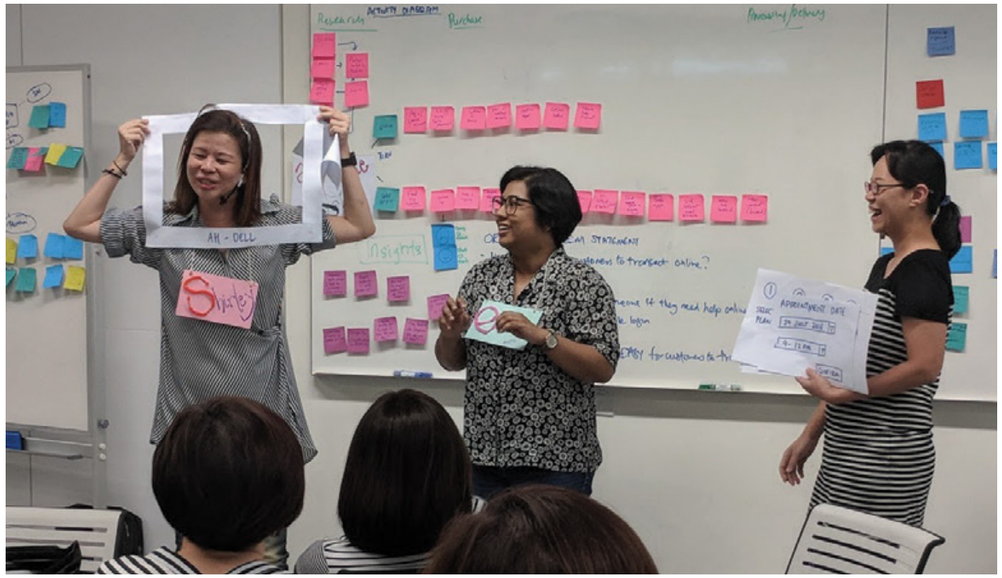
the outcomes, discussing how learnings can be applied.

Useful Tips

- While costumes and props can be effective tools in role playing, do not spend too much time on them.
- Make key elements in your role play tangible, to better understand how these elements interact in the entire scenario (e.g. if your product is a Smart wristband, have something to stand in for it. Don't just pretend that it is invisible).
- Consider running your role play in context to gather more information. This enables you to consider how the physical environment might have an impact.

Worked Example 1

Simulating a telemedical call



Role play between a customer service officer and customer to gather deeper insights on the use of a telemedical service.

Worked Example 2

Role-playing the onboarding process in a company

Role playing different stakeholders in the onboarding process of a company. The name of the stakeholder is written on a piece of paper and pasted on the back of the participants.

Method

Wireframing

Design Thinking | Core Prototyping Techniques

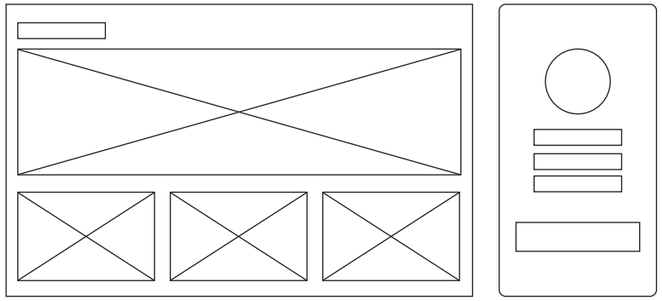
A wireframe is a static, graphical representation of different layouts of an app or website ranging from low to high fidelity.

Why: Wireframes are used to communicate content (elements on the page) and functionality (how the page will work) taking into consideration a user's needs and experience.

Materials: Web application such as Prott, Marvelapp, Figma, Adobe XD and Wireframing Template

Complementary method: Prototyping Canvas

Acronym: UI - User Interface



Procedure

1 **Consolidate**
previous user research

2 **Consider the elements of a page**
such as the information to be displayed, the layout, buttons, interactivity etc.

3 **Sketch**
an initial draft of the intended layout

4 **Connect elements to pages**
by drawing arrows where the elements should point to.

Tools and apps

Marvel App	**Figma**	**Sketch**
Prott	**Adobe XD**	**Justinmind**

CARD 2
Non-attachment

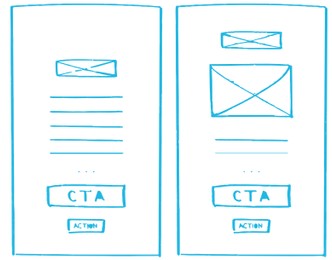
Scan or click here for a digital copy of the template

Worked Example

Mobile app (E-commerce)

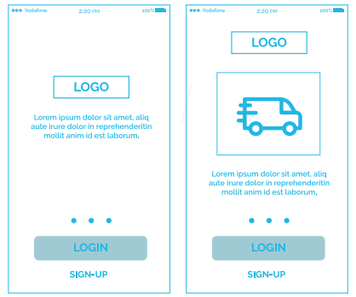
Low Fidelity

- A sketch of an app or website that visualises the basic structure of the user interface (UI).
- Focuses on concept and layout, not details.
- Created quickly.
- Typically black and white.



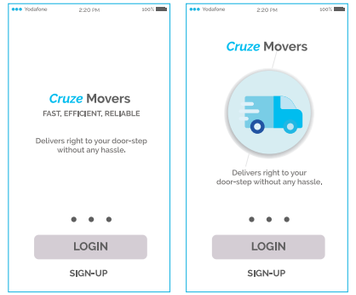
Medium Fidelity

- Uses placeholder icons, images, and description texts for more accurate depiction of layout.
- Shades of grey to show different visual prominence of UI elements.



High Fidelity

- Uses real images, content and colours to clarify how the final UI will function and look.
- Can be used to get accurate feedback from users.
- Usually called a 'Mockup'.
- Called a 'prototype' if clickable.



Method

Physical Model

CARD 7 Non-attachment

Design Thinking | Core Prototyping Techniques

A physical model is a three-dimensional prototype of a product, which simulates the functions and/or form of an idea. It allows for better testing as it enables users to interact physically with an idea, which in turn helps designers gain deeper insights.

Why: It allows for better testing as it enables users to interact physically with an idea, which in turn helps designers gain deeper insights.

Complementary methods: Prototyping Canvas

Procedure

1 **Consolidate a list**

of key information you require to measure the success of the model you intend to build.

2 **Visualise what you intend to build**

and the required functions and concepts the prototype should be able to demonstrate or perform.

3 **Construct the prototype**

4 **Test your model**

Outcomes

- Enables intuitive interactions between designers and the prototype
- Enables high level concept refinement
- Identifies latent user needs

Useful Tip

- Hack commercial products to reduce the effort and cost required to achieve functionality.
- If it is too difficult to fit all the intended features into one prototype based on your material limitations, consider splitting it up into multiple prototypes to test features and functionalities separately.

Worked Example

Low, medium and high fidelity prototype

- Hack commercial products to reduce the effort and cost required to achieve functionality.
- If it is too difficult to fit all the intended features into one prototype based on your material limitations, consider splitting it up into multiple prototypes to test features and functionalities separately.

Low fidelity hybrid wallet prototype: Using low-cost materials and without the creation of the all required functions this low fidelity prototype simulates the appearance of the digital interface (left) and the feel of the conventional wallet (right) without the development costs.

Medium fidelity energy usage monitoring prototype: Acquiring existing products that are available on the market to construct a high fidelity prototype allows for designers to demonstrate, benchmark and test the core functions of a product.

Mock up of a fully functional, multi-material 3D printer for hybrid rocket full grains, Gilmour Space Technologies. Printer is capable of printing proprietary fuel grain material modules that provide expected thrust profiles for launching payloads to lower Earth orbit.

Method

Wizard-of-Oz

Design Thinking | Core Prototyping Techniques

CARD 5 Non-attachment

Wizard-of-Oz prototypes are prototypes with 'faked' functions, i.e. humans mimicking the interactive functions of a computer, with users unaware of it.

Why: They are quickly made, tested, and refined with users, before investing the time and resources used to actually create those functions.

Acronym: AI - Artificial Intelligence

Procedure

1 Determine test features

Determine what you intend to explore and test (interactions, actions, etc.).

2 Decide 'fake' functions

Decide which aspects of the prototype will be 'faked' to present functionality (humans mimicking functionality without users' awareness).

3 Build prototype

Build only the key functions, keeping them low fidelity and avoid spending too much time on details.

4 Run prototype

Run the prototype with users to get feedback.

Do you know...

that this method is named after the show The Wizard of Oz? More details in the Worked Example on the next page!

Worked Example 1

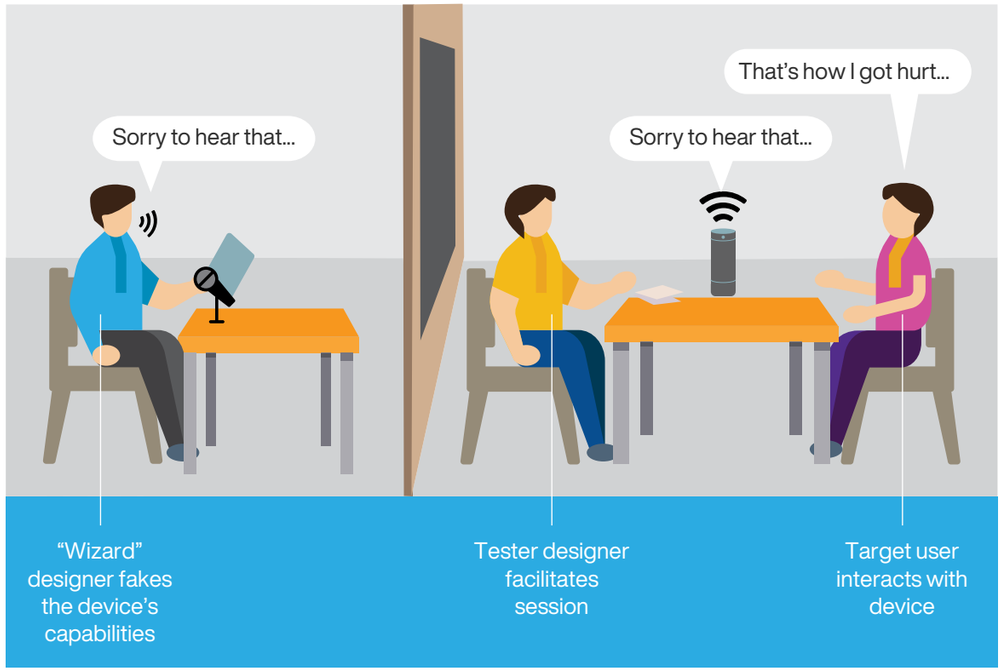
Smart device voice tones

This example shows how a design team might set up and run a Wizard-of-Oz prototype to test the appeal of the dynamic tone of voice capabilities of a smart device.

Aspects to be 'faked'

The smart device prototype voice responses would be faked, where a human mimics the device's ability to change its voice according to the content of the conversation.

In the user testing session, two separate rooms are set up. A designer in one room listens to a target user talking in the other room. The designer responds without the user's awareness.



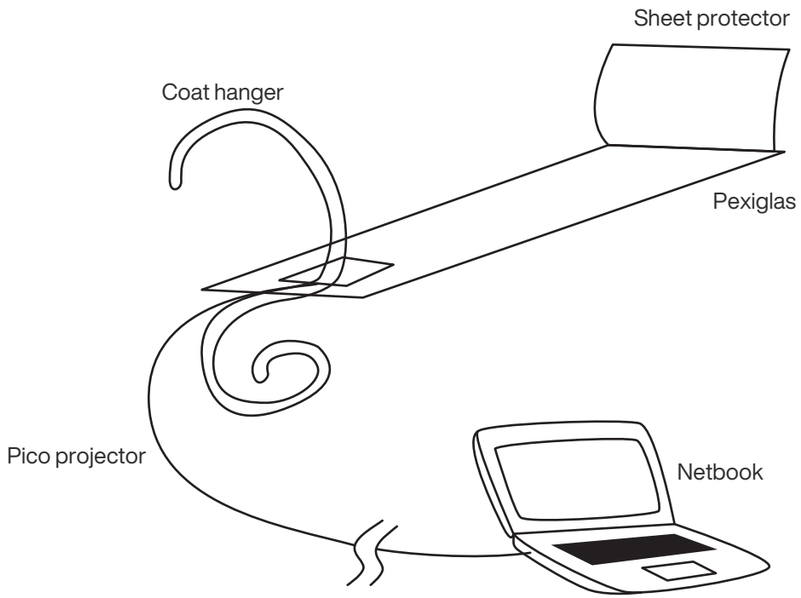
Prototyping of key function (change in tone of voice)

A script containing several response options along with several different tones of voice prompt words (e.g. monotonous, excited, surprised, confused, grateful) is drafted to guide the 'Wizard' designer's response tone.

Worked Example 2

Google Glass

To experience overlaying images with our reality, Tom Chi from Google X used a transparent sheet protector, connected to a Pico projector and a netbook within a single day to quickly test out the experience of the Google Glass. It resembled the Google Glass functionally, using the existing resources and technology he has on hand. He was able to display different screens and later, test interactions that the users with the Google Glass.

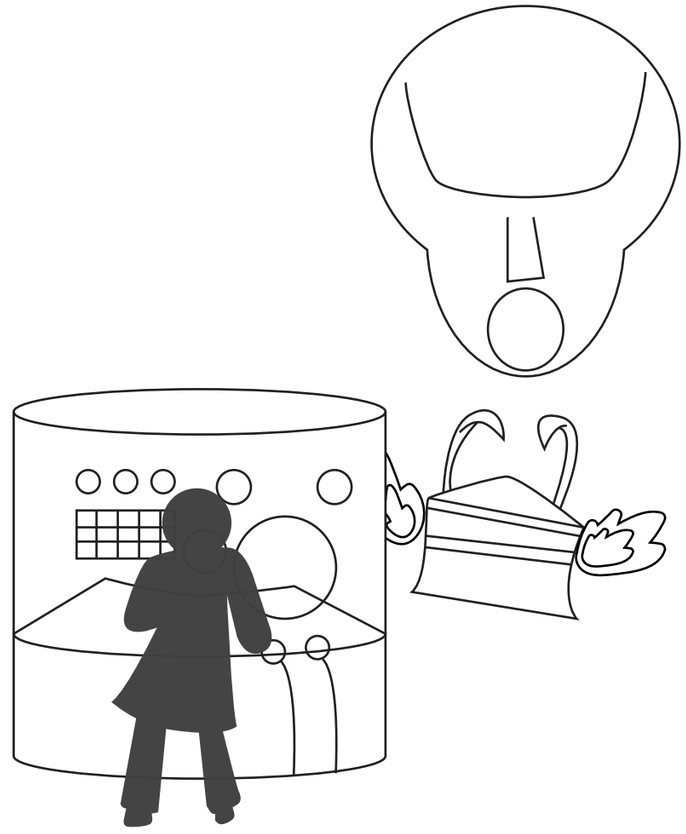


A traceover of the original sketch from Tom Chi

Worked Example 3

Wizard-of-Oz the movie

For anyone who has watched the film that was famous for the use of Technicolour, the ghastly image projected on the screen to meet Dorothy and her friends was created by an old man operating in front of a wall of switches and knobs. Fire and smoke were activated by the switches hidden behind the curtain, invisible to Dorothy. In effect, Dorothy was frightened and thought the image was the true form wizard, only to find out, when Toto pulled the curtain, the wizard was an ordinary human being. The use of the trick to hide the underlying mechanism was clever, and the design method was named after this appearance in the movie as well.



The ordinary human being was operating in front of a wall of switches and knobs to control the ghastly image projected in the movie Wizard of Oz

Every great design begins with an even better story.

Lorinda Mamo

Designer and official partners of the Michelangelo Foundation, representing the very best in Malta-based artisanal talent and craftsmanship.

Method

Mockups (Paper Prototypes)

CARD 6 Non-attachment

Design Thinking | Core Prototyping Techniques

Mockups method is used to create a high-level resemblance of the Products, Services and Systems (PSS). It is a low cost model that is easy and quick to construct and modify.

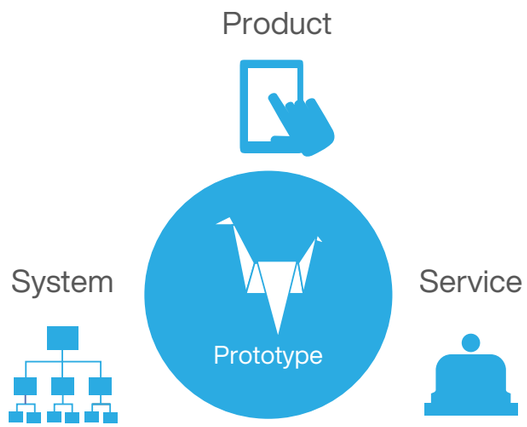
Why: Mockups can be used to identify latent needs of users and to communicate ideas in a short amount of time.

Time: 1 - 3 hours

Materials: Prototyping Kit

Complementary methods: Prototyping Canvas

Acronyms: DI - Design Innovation
PSS - Product, Service, or System



Procedure

1 **Identify Key Assumptions and Questions**

that the prototype would have to answer using Prototyping Canvas.

2 **Construct Mockup**

with the available resources to bring out the key details of the prototype.

3 **Identify Areas**

for further high-fidelity prototyping.

Best Practices

Be creative with the resources available

Use everything that is available to you, without constraining it to its original use.

Make it fast with minimal details

Prioritise and decide 1 most important detail before creating the mockups.

Represent the solution well

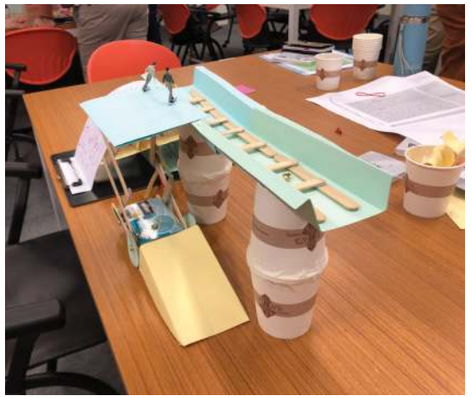
Create mockups that closely resemble the actual PSS by thinking of the crucial functions/features that each part is supposed to represent.

Be clear

Explain any limitation of the mockups to represent the actual PSS to avoid confusion.

Worked Example 1

DI team creating and displaying mockups

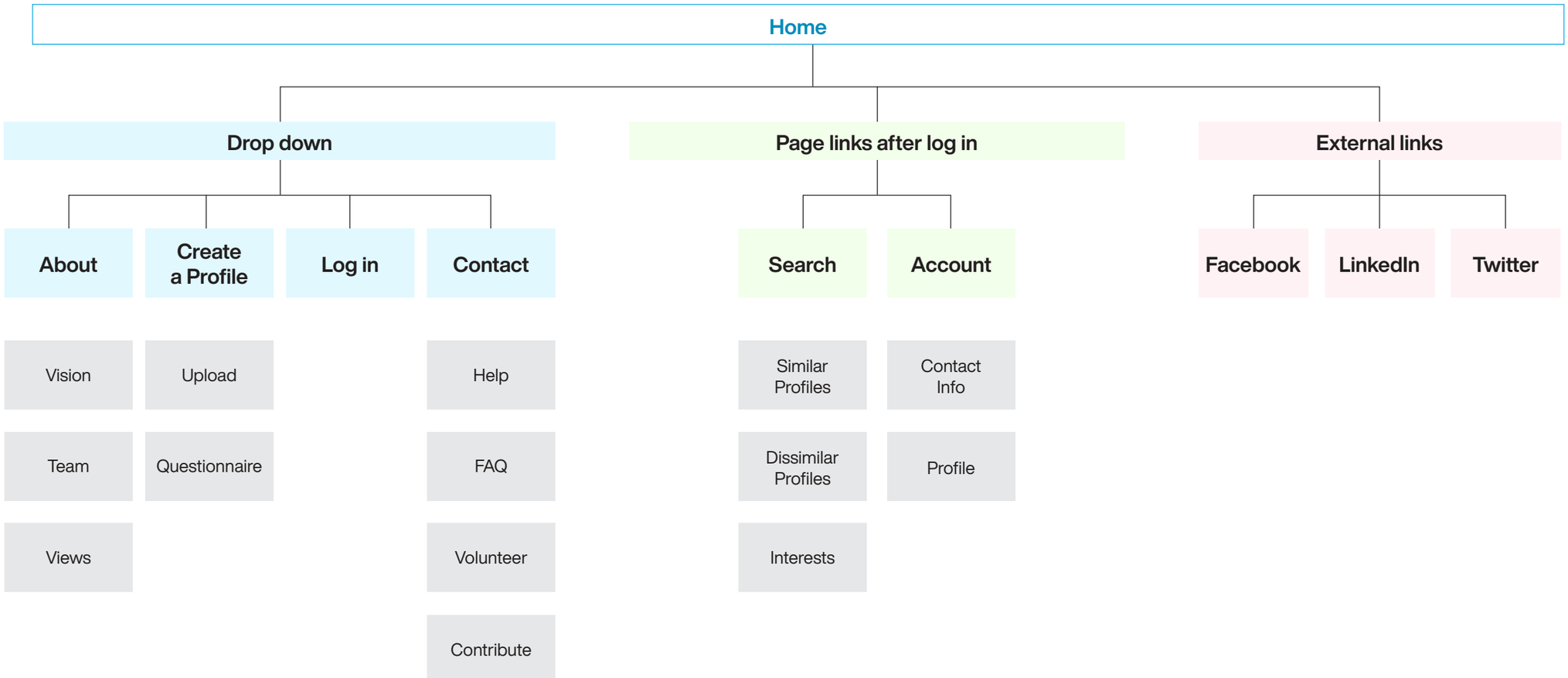


Worked Example 2

This mockup is a website site map, a simple block model that focuses conversation on just web pages and their relationship to each other. As a digital file, blocks can also be rapidly rearranged to dynamically discuss alternatives with stakeholders.

DIGITAL DESIGN
refer to page 2

How might we design a collaborative web platform around sharing, visualising, and comparing data for the future of young professionals and potential organisations for employment?

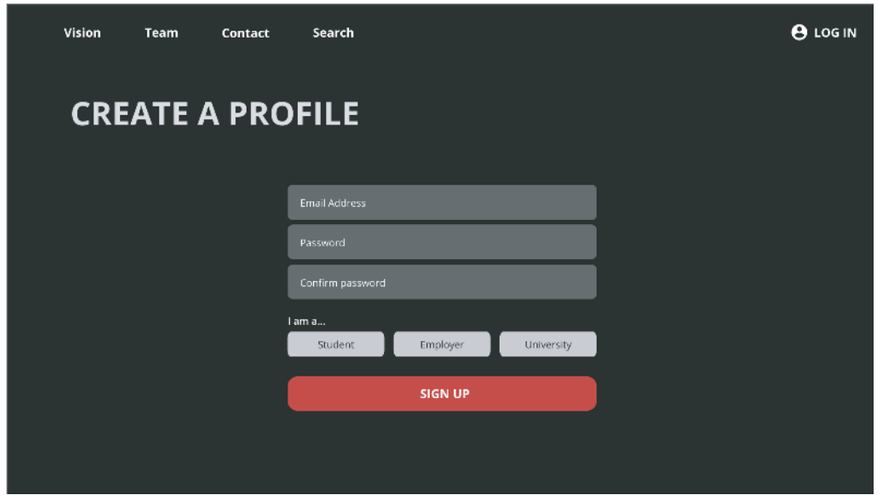


Worked Example 3

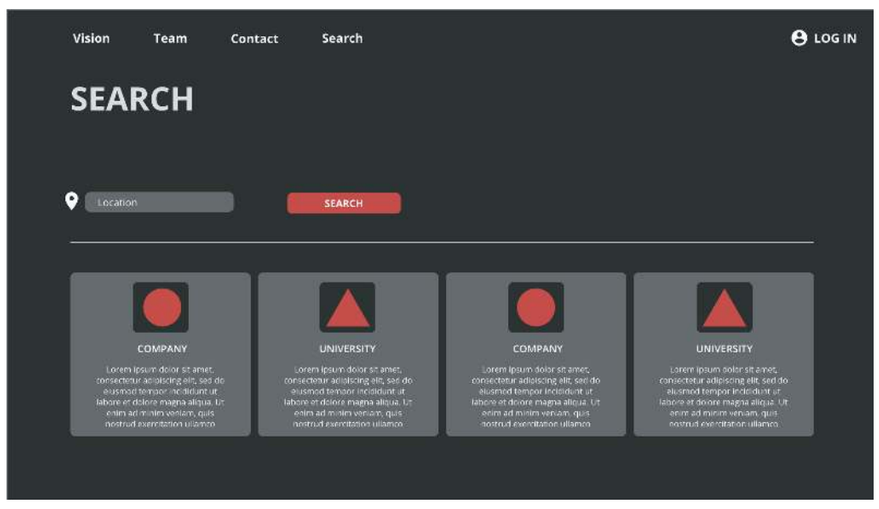
This experience prototype is a basic website that users were encouraged to explore, and their feedback was collected on specific page elements via an online discussion format. The purpose of this experience prototype is to allow users to fully explore a web application on the web, bringing the experience to the context it is expected to be in. The three pages shown here correspond to three pages in the website site map on the previous page. Images A to D correspond to pages in the site map under 'Create a Profile', 'Search', and 'Account'.

An experience prototype ensures users give natural feedback on their likes and dislikes, and surfaces many latent needs and examples that can be leveraged for design insights. Image D shows an online evaluation session to gather feedback from users after their experience using the prototype.

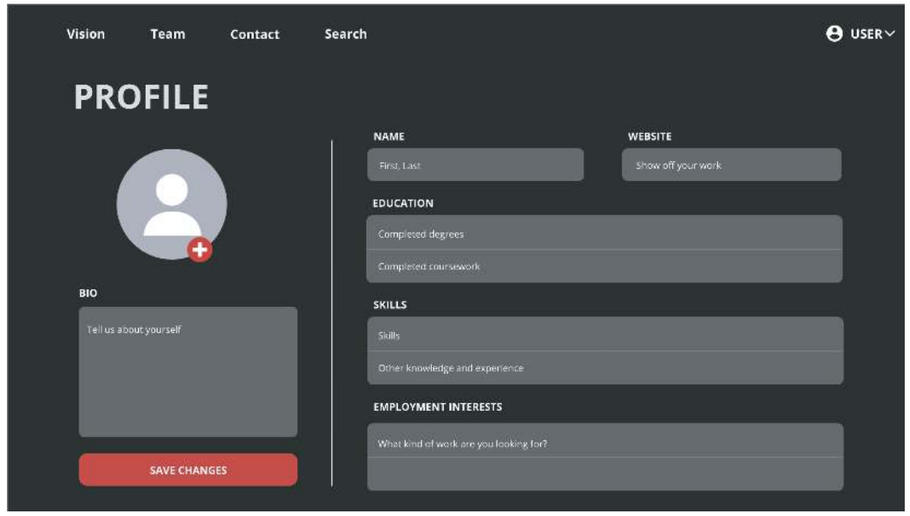
A



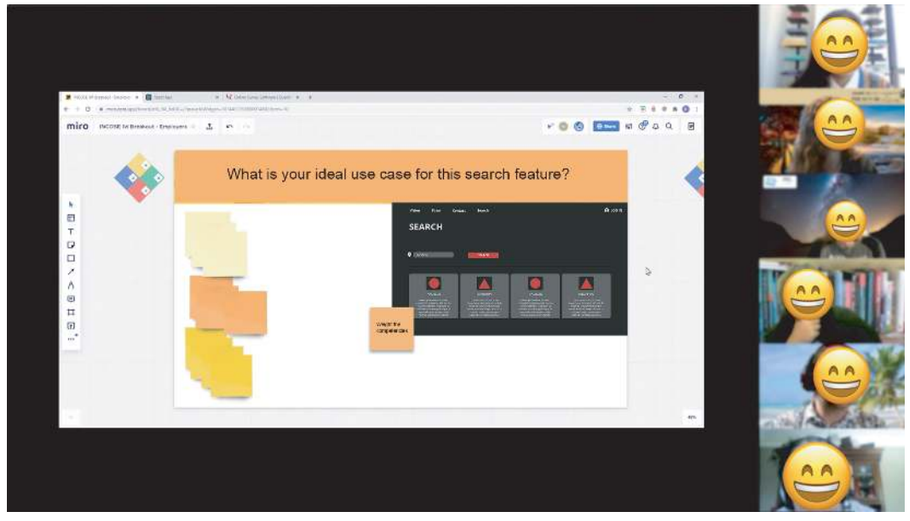
B



C



D



Method

Scaled Model

CARD 8 Non-attachment

Systems Thinking | Core Prototyping Techniques

Scaled Model is a method to build models that have much larger or smaller parameters than a typical prototype or an actual model, while maintaining proportion with other components in the system (which may not be physical dimensions).

Why: Scaled Model may be experienced (tested, inspected, modelled and varied) at the scale that is convenient for human interaction.

Time: 1 - 3 hours

Complementary methods: Prototyping Canvas

Procedure

1 **Identify Key Parameters**

of the system that the model should emulate.

2 **Employ Scaling**

methodologies to reproduce this behavior at the desired scale.

3 **Construct Scale Model**

and use validation tests to ensure that the simulation is accurate.

4 **Evaluate the model**

Benefits

- Reduced construction time
- Reduced construction cost
- Enables iteration
- Enables parallel testing of key systems
- Enables intuitive interactions between design member and model

Best Practices

Use software wisely

Use software/scaled measuring ruler to assist with scale conversion.

Be flexible

Different parts of the model can be and most likely should be scaled and built differently. Remember that the main idea of building scaled models is to be able to experience the model convenient for human interaction.

Communicate well

Use conventional scale that is understood by the industry to communicate effectively.

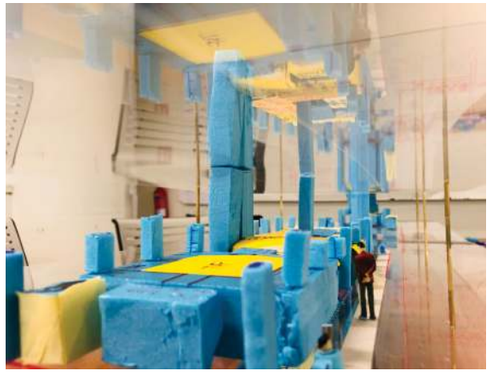
Represent the prototype well[2]

Every physical phenomenon can be described by a set of fundamental dimensions, namely:

Mass	M
Length	L
Time	T
Temperature	θ
Current	I
Luminous intensity	ψ
Solid angle	σ

It is important to know what the model is used for, so that we can scale the appropriate fundamental dimensions. Length may be a common fundamental dimension to be considered but not necessarily the only one.

Worked Examples



Scaled model of a train station built using blue foam. The human figure is placed to estimate the amount of space required for movement.

A second iteration of the scaled model, built using 3D printed parts, which is of higher fidelity.

Method

Isolated Subsystem Model

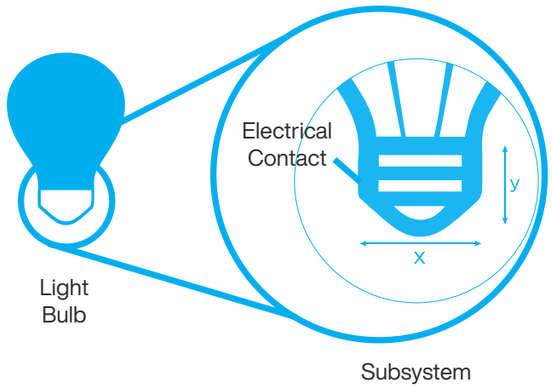
CARD 9 Non-attachment

Systems Thinking | Core Prototyping Techniques

Isolated subsystem models are typically a one-to-one or high fidelity prototype where a single subsystem (or group of subsystems) is explored in isolation.

Why: Isolated subsystem modelling reduces the complexity by removing the interaction across different elements. Sources of problems could be identified and tracked easily by looking separately at each subsystem. It also accelerate the progress of the improvement that needs to be made as clarity is higher in the isolated subsystem.

Complementary methods: Prototyping Canvas



Procedure

1 Identify subsystems

Identify key subsystems that are either drivers of performance or less well understood than other subsystems.

2 Inputs and Outputs

List inputs and outputs to this subsystem from the full system.

3 Prototype & Simulate

Prepare the prototype of the isolated subsystem, simulate external outputs and supply these to the mode.

E.g. bench top testing, CAD models with boundary conditions, component testing

4 Evaluate

Evaluate the subsystem performance and record the results.

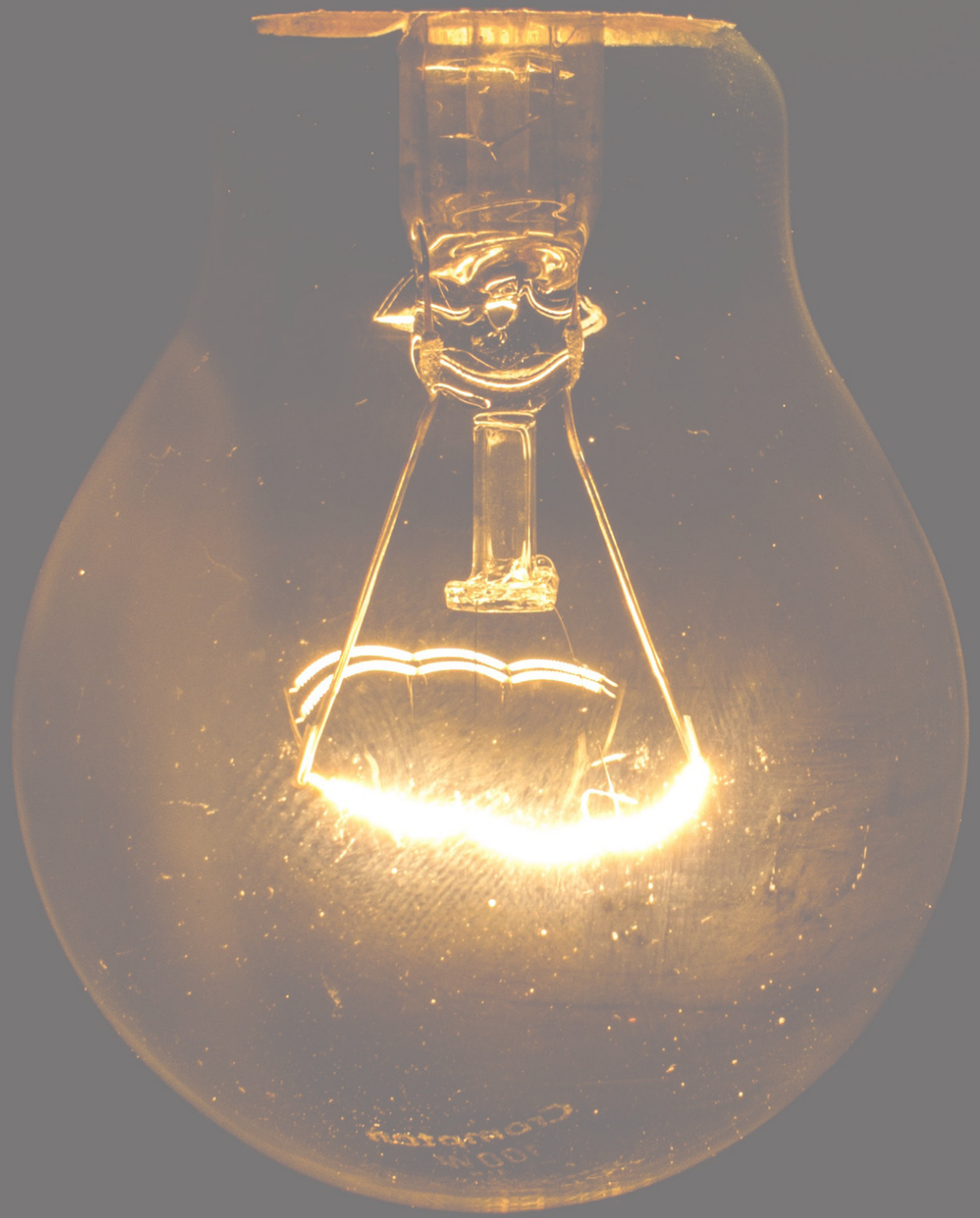
Outcomes

- Reduced construction time
- Reduced construction cost
- Enables iteration
- Enables parallel testing of key system
- Reduction of risk

Worked Example

Electrical Vehicle Drive Train

Prototype to test the performance of an electric drive train subsystem (motorized wheel).



I have not failed
10,000 times.

I have not failed once.

I have succeeded in
proving that those
10,000 ways will
not work.

Thomas Edison

*Inventor of the
incandescent light bulb*

Method

Business Model Canvas

CARD 14
Non-attachment

Business Model Innovation | Planning

Business Model Canvas (BMC) is a strategic management document that describes the rationale of how an organisation creates, delivers and captures value.

Why: BMC can be used as a Single Source of Truth for the strategies of the company or organisation to align the policies and structure of the organisation. It can also be used to identify points of intervention to create innovations for the users and customers.

Materials: Business Model Canvas Template

Acronyms: API - Application Programming Interface
AV - Autonomous Vehicle
BMC - Business Model Canvas
LTA - Land Transport Authority of Singapore

Scan or click here for a digital copy of the template

Procedure

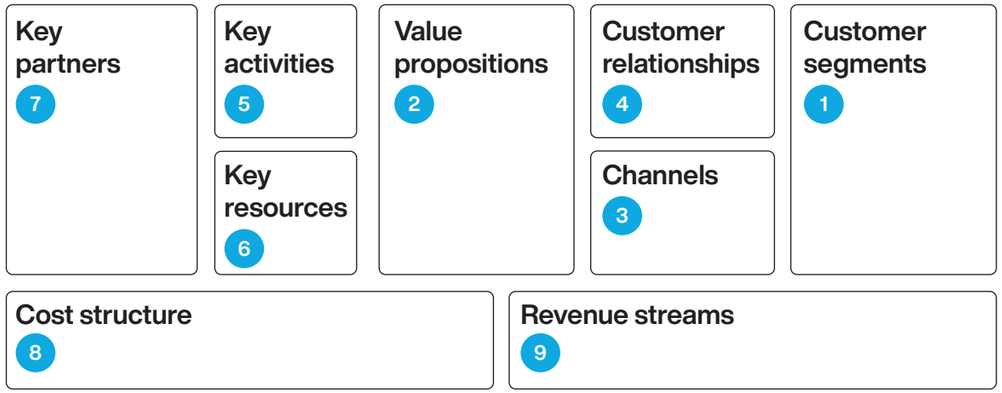
1 **Fill in the canvas**
based on the organisation's current business model.

2 **Evaluate**
each of the nine areas of the business model and select areas that can be strengthened or modified.

3 **Make changes to the business model**
starting with the value propositions and customer segments.

4 **Make changes to the rest of the business model**
according to the new value proposition and customer segments.

Template Structure



The 9 Different Elements

1 Establish Customer Segments

One or several specific customer segments served by the business.

- For whom are we creating value?
- Who are our most important customers?

2 State Value Propositions

How the firm solves customer problems and satisfies customer needs? Eg. newness, performance, brand, price, etc.

- What value do we deliver to the customer?
- Which customer's pain-point or needs are we addressing?
- What bundles of products and services are we offering to each customer segment?

3 Create Channels

How company communicates with and reaches customers to deliver value proposition?

- Through which channel do our customer segment want to be reached? E.g. Online, partners, brick and mortar stores, etc.
- How are you getting the value created to your customer segments?
- How are our channels integrated?
- Which one works best?
- Which ones are more cost-efficient?
- How are we integrating them with customer routines?

4 Build Customer Relationships

How customer relationships are established and maintained eg. self-service, personal assistance, automated service etc.

- What type of relationship does each of our Customer Segments expect us to establish and maintain with them?
- Which ones have we established?
- How are they integrated with the rest of our business model?
- How costly are they?

5 Decide Key Activities

Important activities that a company must do to make its business model work.

- What Key Activities do our Value Propositions require?

6 Identify Key Resources

Important assets required to make a business model work.

- What Key Resources do our value propositions require?

7 Connect Key Partners

Network of suppliers and partners that support the business model.

- Who are our Key Partners and key suppliers?
- Which Key Resources are we acquiring from partners?
- Which Key Activites do partners perform?

8 Calculate Cost Structure

Cost drivers within the business model and rationale for how they are organised.

- What are the most important cost drivers in your business model?
- Which Key Resources are most expensive?
- Which Key Activities are most expensive?

9 Determine Revenue Streams

Means of generating revenue from customers and how this revenue stream is organised.

- What are the customers willing to pay and for what value?
- For what do they currently pay?
- How are they currently paying?
- How would they prefer to pay?
- How much does each Revenue Stream contribute to overall revenues?

Worked Example 1

Airbnb Case Study

Key Partners **Network of suppliers and partners that support the business model.**

Blogger/shoppers (sharing stories of their individual travel; advertising for Airbnb)

Legal institutions (Airbnb is prohibited in some countries)

Insurance companies (property insurance for hosts and travellors)

7

Key Activities **Important activities that a company must do to make its business model work.**

Building and maintain the host network

Improvement of matching algorithm (host and traveller)

5

Key Resources **Important assets required to make a business model work.**

- Community of home providers and travellers
- User data and algorithm (search behaviour, pricing)
- Brand

6

Value Propositions **How the firm solves customer problems and satisfies customer needs? Eg. newness, performance, brand, price, etc.**

Travellers can book a homestay for low prices

Hosts can earn money by renting their flat/house effortlessly

Travellers live in local environment away from mass tourism

2

Customer Relationships **How customer relationships are established and maintained eg. self-service, personal assistance, automated service etc.**

- Professional presentation of accommodation (Acquisition of travellers)
- Home insurance (Acquistition increases for hosts)
- Support team and Customer Service (retention)

4

Channels **How company communicates with and reaches customers to deliver value proposition?**

- Mobile app
- Website

3

Customer Segments **One or several specific customer segments served by the business.**

Price-conscious travellers

Hosts (people who can rent out their place)

Travellers looking for a local experience

1

Cost Structure **Cost drivers within the business model and rationale for how they are organised.**

Platform development and design (running costs)

Community management for hosts (conferences, presents)

Branding (brand value)

8

Revenue Streams **Means of generating revenue from customers and how this revenue stream is organised.**

Commission home/apartments owners (3% of each booked place)

Commission renters (6-12% of booking fee)

9

Worked Example 2

Autonomous Vehicale (AV) Case Study

Key Partners — **Network of suppliers and partners that support the business model.**

- Payment processors
- Investors
- Key suppliers
- Product designers
- Mapping API providers
- Land Transport Authority (LTA)
- Insurers
- Lobbyists
- Legal teams

7

Key Activities — **Important activities that a company must do to make its business model work.**

- Marketing and customer acquisition
- Platform development and enhancement
- Safety testing of AVs
- Customer support

5

Key Resources — **Important assets required to make a business model work.**

- Inventory of the AVs
- Brand image
- Digital platforms (app and website)
- Technology and product team
- Data Analytics

6

Value Propositions — **How the firm solves customer problems and satisfies customer needs? Eg. newness, performance, brand, price, etc.**

- Economic option compared to taxi
- Convenient rides with instant bookings
- Personalised travel experience
- Inclusive design offers independent travelling for people wit mobility limitations
- Cashless payment rides
- Lesser carbon footprint with fewer cars

2

Customer Relationships — **How customer relationships are established and maintained eg. self-service, personal assistance, automated service etc.**

- Social media
- Customer support
- Reward points collected from rides
- Online assistance
- Rating and feedback system

4

Channels — **How company communicates with and reaches customers to deliver value proposition?**

- Mobile app for iOS
- Mobile app for Android
- Website

3

Customer Segments — **One or several specific customer segments served by the business.**

- Individuals who want convenient travel options with the privacy offered in a car
- People who want the convenience of having a car at their doorstep
- Those who do not own a car
- Individuals who carry a lot of goods while travelling
- Individuals who are constantly travelling within the country

1

Cost Structure — **Cost drivers within the business model and rationale for how they are organised.**

- Customer acquisition costs
- Marketing and branding
- Product and research development
- Human resources
- Lobbying and compliance
- Insurance and legal

8

Revenue Streams — **Means of generating revenue from customers and how this revenue stream is organised.**

- Ride transaction fees
- Asset sales to transportation companies
- Surge price
- Advertisements
- Service fees for members

9

Method

DI Pitching

Design Thinking | Presentation

CARD 15
Non-attachment

Pitching is a method to convince others to trust the team with their support. It is usually performed with the assistance of presentation slides.

Why: DI Pitching helps to sell the idea to their intended audience by crafting a consistent and clear message and influencing the mood of the presentation to connect the audience with the aspirations and beliefs of the presenter.

Time: 1 - 2 hours

Materials: DI Pitching Template

Complementary methods: All methods under core and advanced prototyping methods

Acronyms: AV - Autonomous Vehicle
DI - Design Innovation
CEO - Chief Executive Officer
COO - Chief Operation Officer
CTO - Chief Technological Officer
LTA - Land Transport Authority of Singapore

Scan or click here for a digital copy of the template

Procedure

1 **List the Main Points**

of the presentation: Elevator, Problem/ Opportunity, Solution, Progress, Team and Conclusion.

2 **Organise and Plan**

the presentation. Keep to a single point for every presentation slide.

3 **Rehearse the Presentation**

A good pitcher will seek to rehearse in front of the audience to remove any confusion.

Useful Tip

A good duration for a pitch is 5 minutes. Consider the strengths and roles of each team member to create and arrange a convincing pitch.

Main Points of A Presentation

Elevator:

Short description of the purpose or value proposition of the solution

Problem/Opportunity:

The challenge or need addressed by the solution

Solution:

The method of tackling the problem or opportunity

Progress:

The working plan of the team and the current state of the solution

Team:

Introduce the talents and contributions of the team to create a successful solution

Conclusion:

Highlight key points

Best Practices

Be Straightforward

Make the presentation deck simple to understand, legible (use big and readable font) and obvious.

Be Multi-modal and Use Multimedia

Show the prototype, use graphics, data analytics and data visualisation, pictures or short video to help the audience understand the solution.

Be Bold, Creative and Tell a Convincing Story

A convincing pitch is more than the content. It is logical and appeals to human emotion and human principles. It concentrates on the users and stakeholders, as well as distinctiveness and differential elements in intellectual property.

Add Labels

Adding the main point to the slide and labels to graphs or images greatly help the audience to understand the focus of the slide.

Pitching Slide Deck from Successful Start-up Companies[1]

Due to the length of the example, a link is provided to share the content of pitching slide deck by AirBnB, Uber and Facebook.

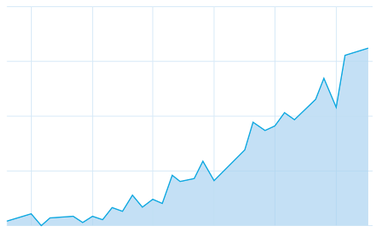
Useful Tip

Use diagrams, videos or illustrations to highlight important information.

Worked Example

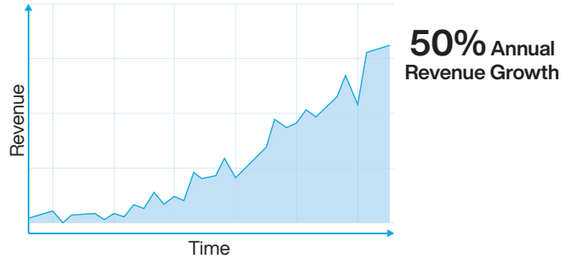
Adding labels to graph

Negative Example



This example shows just the graph, does not provide much information of the graph.

Positive Example



By adding labels to the axis and the graph. it helps audiences to understand the graph better.

WORKED EXAMPLE
Autonomous Vehicle

Elevator

Short description of your purpose/value proposition

Imagine being able to travel in your own magic vehicle where it converts to everything of your preference from the music you hear to the type of seat you sit on all while riding without a driver. AND you would be paying only a fraction of a cost that you currently pay for taxis, in Singapore.

You would not need to imagine anymore. We at DIAV have been working hard the past year and made this a reality.

Opportunity

What challenge or need are you addressing?

In Singapore, owning a car or a private vehicle is expensive. However, there are very few or hardly any alternative options that provide the same value and convenience as a private vehicle.

Individuals who are constantly travelling around the country, parents with children who require a safe travel option and people with limited mobility who with limited mobility who all face the same challenge - they would like the convenience and privacy offered in a private vehicle while it still being an economical option.

Currently, apart from taxis and similar service providers, there are no alternatives. And these options are expensive and heavily rely paying, low skilled jobs resulting in lack of job reformation in the country.

Solution

How are you solving the problem?

Our solution - DIAV - will revolutionise the future of transportation in Singapore!

DIAV or “Design Innovation Autonomous Vehicle” will be an economical option compared to taxis and other similar service providers. Our modular design of DIAV will provide for inclusivity, offering independent travelling for people with mobility limitations. Our proprietary software technology will provide a personalised travel experience to every user when they scan their unique code on their mobile devices when entering the AV.

Existing taxi drivers will be trained and upskilled to do the maintenance of the AVs. We will also continually co-create with groups of drivers to learn from their experience and improve offerings with our AVs.

Progress

What do we have right now?

We have set up strong customer relationships with 100 of our pilot users via social media and physical trials with our AVs. We have set up an excellent customer support and online assistance, and designed a rewards points system that users can benefit from in the future.

Our proprietary software platform has already been developed and being stress tested with 99% success rate. We are currently working with the Land Transport Authority to get the safety assessment for our AVs too.

The factory, partners and lobbyists are all set up. We will be able to produce 20 AV systems per week with our currently capabilities.

Team

Who are you, and why can you pull this off?

Our core team consists of 3 individuals - the CEO, CTO and COO.

All 3 of us have 10-30 years of experience in autonomy and product development, transportation domain knowledge and operations.

The overlap of our skillsets and our passion in the future of transportation in Singapore makes us the best people for this!

Conclusion

Highlight key points?

We strongly believe in the potential of DIAV to enable for the reformation of low paying jobs in Singapore.

We have shown tremendous progress in the last year and with the right investors’ support we will be able to meet our targets in the next 2 years.

We ask for $1m to bring make our dreams a reality, for the future of Singapore!

Method

Feedback Capture Matrix

CARD 11
Non-attachment

Design Thinking | Feedback Gathering

Feedback Capture Matrix is a structured way of collecting and organising feedback that is gathered from your user testing sessions.

Why: Feedback Capture Matrix helps with being systematic about feedback, and being intentional about capturing feedback from the 4 aspects.

Materials: Whiteboard, Feedback Capture Matrix Template

Complementary methods: Storyboarding, Mockups (Paper Prototypes), Scaled Model, Immersive VR/AR, Desktop Walkthrough

Acronyms: AR - Augmented Reality
VR - Virtual Reality

Scan or click here for a digital copy of the template

Procedure

1 Draw a 2 x 2 grid

Label the four quadrants: 'What worked', 'What can be improved', 'Questions', and 'Ideas'.

2 Capture feedback

Ask users to record feedback individually. Write them on sticky notes and place them in the appropriate quadrants in the grid.

3 Cluster similarities

Identify similar feedback and cluster them under one heading.

4 Build on feedback

Evaluate feedback in all the quadrants. Think of ways to address the feedback and add to the 'Ideas' quadrant with your team.

5 Select feedback

Discuss and select a piece of feedback from any quadrant to follow up on.

Useful Tip

Try to make sure that each quadrant has at least a few notes. When using the grid during a test session, for instance, you can steer the conversation towards quadrants that are currently not receiving enough input.

Best Practices

Ways to solicit feedback

Present multiple versions of the prototype so that the users can compare and give their honest opinion. Ask about their likes and dislikes about each version would give a much broader picture.

Test your prototypes on the right people

Choose the group of people to solicit feedback wisely. It is good to consider extreme users and typical users to gather feedback from. The spectrum of users to test with may be narrower at the start but make sure to increase the diversity of testers toward the final phase of the project.

Be neutral when present the ideas

Refrain from selling your prototype, or defending your prototype. This is not a good time to do so because it affects how willing the users will share their honest feedback subsequently. Take their feedback seriously and show the users that their voices are important.

Worked Example

Feedback for proposed new train station layout

What worked	What can be improved
Cargo lift is a good idea Staff room and toilet clustered together Relocating lights along wall and parapet to accessible height	Have at least two maintenance bays Larger space for replacing equipment required Inadequate Ejector Drainage Provide access door for security shutter
Questions	**Ideas**
Storage space under escalator Concierge near platform Add services corridor level	Is it easy enough to install equipment with a centralised room? What is the height of room? Is it spacious enough for smooth passenger flow? Can we transport cable risers easily enough?

Method

Design Impact Canvas

Design Engineering | Feedback Gathering

CARD 16 Non-attachment

The Design Impact Canvas is a strategic planning tool to measure the impact of your product-service-system(s). The canvas and the Design Impact Framework work in tandem to provide insights while proactively planning impact in future designs and projects.

Why: The canvas provides insights while proactively planning impact in future designs and projects.

Materials: Design Impact Canvas Template

Complementary methods: Design Impact Framework

Scan or click here for a digital copy of the template

Procedure

1 Prepare and write your opportunity statements

Ask yourself 'why' it is important to work on this opportunity and what is the impact that you are trying to create

2 Record and fill in the canvas

Fill the template in any order until all segments are completed. Select 1-2 Impact Areas, 1 Outcome per Impact Area and 1-4 key demonstrators per Outcome while completing segments 8 and 9.

3 Share and discuss as a team

Create a plan for how the demonstrators selected and the metrics you will be using in your measurements tie in together. Discuss what your plan will be to collect these data.

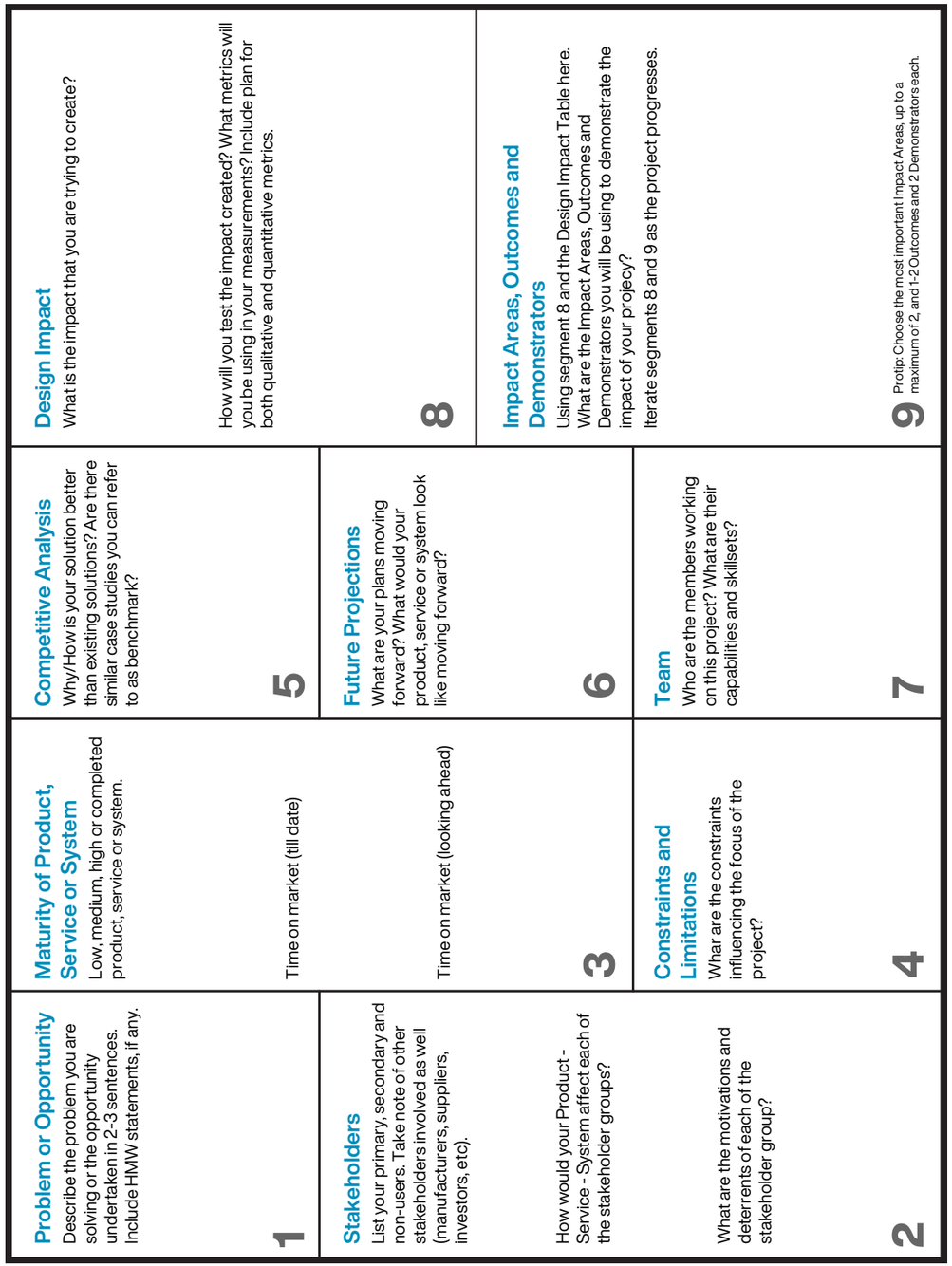
4 Test and Measure, Repeat

Capture results and feedback from testing, both qualitative and quantitative metrics. Reflect on future directions.

Useful Tip

The canvas can be used at any stage during a project. The impact planned and ways of measurement can be iterated throughout the project to enable the clearest demonstration of impact created.

Template Structure



Method

Usability Testing

CARD 10 Non-attachment

Principle: Design Thinking | Method type: Assessment

Usability Testing is a method where a prototype is tested with users to evaluate its ease of use. Users are asked to perform tasks with the prototype, while their actions and behaviour are observed.

Why: Usability testing, often coupled with behavioural analysis, could identify sources of confusion and improve guidance or ergonomics of the design. Designers and engineers could also compare with the expected behavior to identify effectiveness of the solution.

Materials: Analytical tools

Procedure

1 Develop test plan

Identify research questions, create scenarios and tasks for testing, and establish usability metrics.

2 Identify and recruit target users

Develop recruiting criteria, determine test location and appropriate incentives, and recruit target users.

3 Run test with users

Introduce and moderate tests, present scenarios and tasks, track usability metrics, observe and record insights.

4 Analyse test results

Compile usability metric data, organise and prioritise insights, identify issues and opportunities.

Creating Scenarios and Tasks

- Make them realistic; write things users might actually experience and do.
- Use users' language; avoid obscure technical terms.
- Focus on 'what' the user should do rather than 'how'.

Introducing Tests

- Build rapport with users; explain the purpose of the test, and assure them that it is the prototype that is being tested, and not their competencies.
- Ask users to think aloud, and move at their own pace.

Moderating Tests

- Be neutral in speech and body language to avoid influencing users' responses
- Let users struggle; refrain from excessive moderation

Typical Usability Metrics

- Success (task completion) rate.
- Satisfaction rate (on a number scale).
- Time on task.
- Error and confusion rate.

Best Practices

Use actionable metrics

When defining success metrics, use actionable metrics rather than vanity metrics, e.g. total sign-ups does not tell if users are engaged, but number of users acquired every week allows the design team to run user acquisition experiments with marketing channels.

Segment your users

For the Usability Test, segment your users into groups that shares common characteristics (or persona groups).

Time-dependent test results

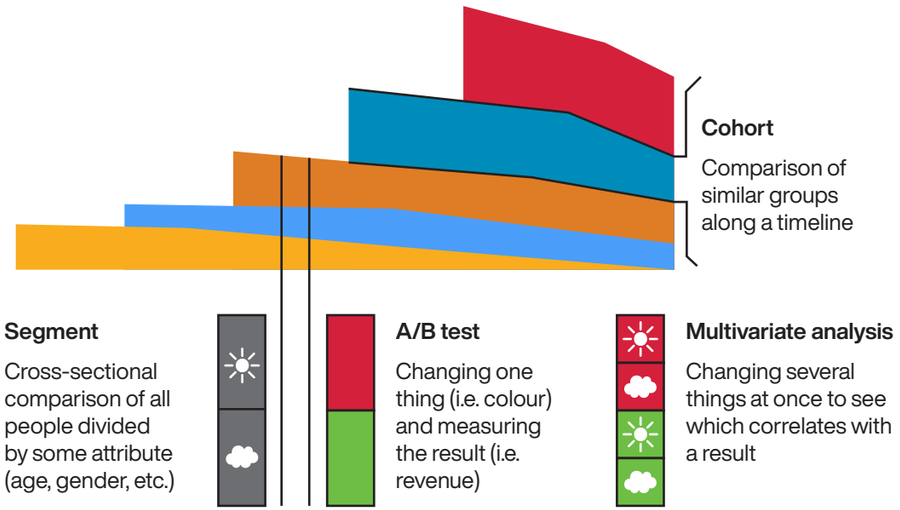
Cohort-based Usability Test, meaning follow a group over a time period, could yield the time-dependent test results.

Deploy A/B Testing

or Multivariate Testing to determine the influence of the design parameter(s) by changing the value of one or more design parameters.

Worked Example 1

Segments, Cohorts, A/B and multivariates



Cohort

Comparison of similar groups along a timeline

Segment

Cross-sectional comparison of all people divided by some attribute (age, gender, etc.)

A/B test

Changing one thing (i.e. colour) and measuring the result (i.e. revenue)

Multivariate analysis

Changing several things at once to see which correlates with a result

Worked Example 2

Travel search engine website

This example shows a sample research question, scenarios, and tasks created for a usability test of a travel search engine website prototype, and the test results that follow.

Sample research question

Are users able to easily discover and use the prototype's money-saving features, booking flights for a chosen range of:

1. dates, without setting a specific destination?
2. destinations, without setting specific dates?

Sample Scenarios and Tasks

#	Scenario	Task
1	Your family is planning to go for a 5-7 day holiday together during the June holidays. Your family does not have a specific destination in mind, but is budget-conscious.	Find the lowest-priced flight in June for a 5-7 day holiday.
2	Your family is planning to go for a 5-7 day holiday together in one of these three countries: Japan, South Korea, and Hong Kong. Your family does not have specific dates in mind, but is budget-conscious.	Find the lowest-priced flight throughout the year for a 5-7 day holiday among these three countries.

Sample Test Results (Based on 9 Users)

#	Usability Metric Data	Issues and Opportunities
1	Success Rate: 67% No. of Errors/Person: 2.3 Time on Task: 3min 35s Task Satisfaction: 3.2/5	Airline carrier had varying peak surcharges (holiday period) that were only displayed after being forwarded to their booking website. This created some confusion, and led some to question the credibility of the prices displayed in the website prototype.
2	Success Rate: 78% No. of Errors/Person: 21.4 Time on Task: 7min 43s Task Satisfaction: 3.7/5	Users found it hard to compare the offerings of each destination with one another, as a separate search had to be initiated for each destination. An opportunity here was to enable multi-destination search on a single page.

Designing products that are useful and designing products that are beautiful, they are really the same thing to me.

The beauty makes them useful, and the practicality makes them beautiful.

Yves Behar

Founder of and CCO of August

Method

Risk Management Process

CARD 12 Non-attachment

Design Engineering | Evaluation

Risk management process is a proactive approach to mitigate risk during project management.

Why: Risk management process helps to recognise, analyse and respond to events that might threaten the project's success. It also provide an overview of the events' risks score for monitoring.

Material: Risk Matrix Template

Acronym: OS - Operating System

Scan or click here for a digital copy of the template

Procedure

1 Identify risks

Identify a list of possible risks through brainstorming, problem identification and risk profiling.

- ☐ Are the requirements stable or risky?
- ☐ Does the design depend on unrealistic or optimistic assumptions?
- ☐ Is the schedule dependant upon the completion of other projects?
- ☐ Are quality considerations incorporated in the design?

2 Rate it

List each of the risk concerns on the assessment form then rate the likelihood and impact.

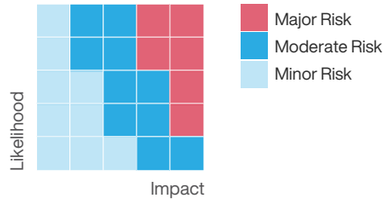
3 Risk mitigation

Develop a risk mitigation strategy

4 Probability matrix

Create a probability and impact matrix. Manage risks by identifying the most critical concerns from the matrix.

Impact x Probability x Detection Difficulty
= **Risk Value**

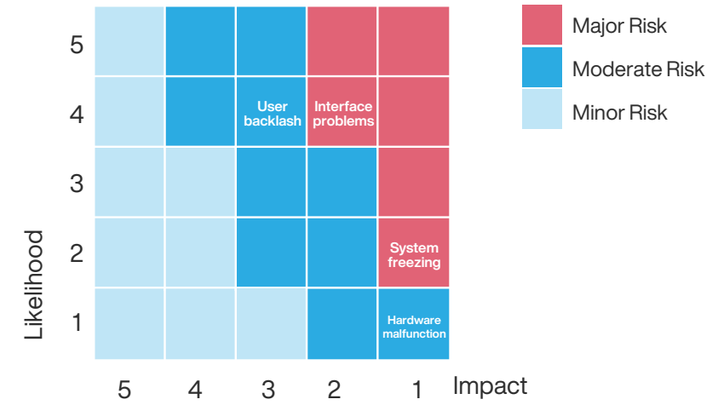


Worked Example

System integration Risk Matrix

Risk event	Likelihood	Impact	Detection difficulty	When
Interface problems	4	4	4	Conversion
System freezing	2	5	5	Start-up
User backlash	4	3	3	Post-installation
Hardware malfunctioning	4	5	5	Installation

Table showing failure modes and risk assessment



Matrix Showing Risk Assessment

Risk event	Likelihood	Impact	Detection difficulty	When
Interface problems	Mitigate: Test prototype	Work around until help comes	Not solved within 24 hours	NIL
System freezing	Mitigate: Test prototype	Reinstall OS	Frozen after 1 hour	Emmy
User backlash	Mitigate: Prototype demonstration	Increase staff support	Call from top management	Eddie
Hardware malfunctioning	Mitigate: Select reliable vendor Transfer: Warranty	Order replacement	Equipment fails	Jim

Table showing risk mitigation strategy

Method

Finite Element Modelling

CARD 13 Non-attachment

Systems Thinking | Evaluation

Finite Element Modeling is a simulation approach. It can be used to model structural, thermal or fluid flow properties of a design through discretisation.

Why: FEM is a visualisation of the properties within a physical body and could be used to identify points or regions of weakness and strength upon loading. It supports limit testings such as lifecycle analysis through fatigue loading or impact loading simulation.

Materials: Modelling and Analysis Tools (see below)

Acronyms: CAD - Computer-aided Design
FEM - Finite Element Modelling

Procedure

1 Critical behaviour

Determine the critical behaviour to model. E.g. vibrational modes, yield strength.

2 Generate CAD

Generate a simplified CAD model of the product, or system removing irrelevant geometric details.

- Geometrical Details
- Interfaces
- Material Properties

3 From CAD model

Develop Finite Element Mesh with appropriate material Properties.

4 Test run

Impose boundary conditions and loads expected in various operating conditions.

5 Analyse

Run appropriate analysis.

6 Study & compare

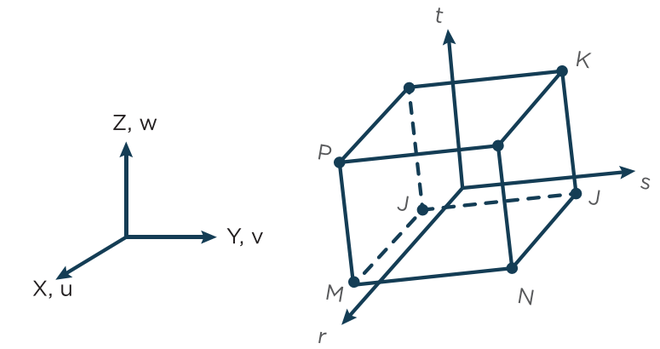
Results across different design concepts.

Modelling and Analysis Tools

Autodesk
Fusion 360
Creo Rhino
Abaqus

Template Structure

The mesh is based on a network of discrete elements, Linearised equations describe the relationship between each node

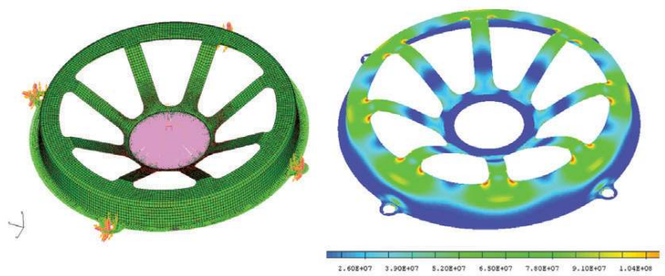


Worked Example

Loudspeaker housing analysis

Left: Discretised CAD model of the housing

Right: Results of the analysis, showing tensional stress experienced by the loudspeaker housing when in enclosed car



FEM of a loudspeaker driver housing

Method

Immersive VR/AR

CARD 17 Non-attachment

Systems Thinking | Advanced Prototyping

Immersive VR/AR is a system tool that accepts a 3D model as an input and allows virtual walkthrough of spaces and rooms. It has accompanying glasses enable stereoscopic imaging (similar to movies presented in 3D) and enhance the depth perception of the model.

Why: Immersive VR/AR helps to quickly identify spatial relationships and allows life-sized model to appear in our environment. It can reveal errors that may be hard to spot in a 2D drawing or 3D computer model.

Materials: 3D file saved as .fbx format and VR system

Complementary methods: Prototyping Canvas, Storyboarding, Mockups (Paper Prototypes), Scaled Model, Desktop Walkthrough

Acronyms: AR - Augmented Reality
MR - Mixed Reality
PSS - Product, Service, or System
VR - Virtual Reality

Procedure

1 Generate the CAD model

in .fbx format. It is recommended to isolate subsystem to view so that the file is optimised for rendering.

2 Open the model

in Unreal Engine, which is a suite of creation tools, to make the environment and the CAD model more realistic. Add features that are important and do not add unnecessary details.

3 Import the system

into the VR environment and inspect the model with the users. Record any observations made and insights gained from the inspection.

4 Repeat

inspection process with a different group of users representing another set of personas.

SUTD's own VR Cave[1] is a tri-projector setup developed by Aviation Virtual Pte Ltd, who also built Changi Airport Group's VR system for aerobridge training. The system allows users to view the front, left and right side of the environment with a pair of glasses. Each projector screen is about 2m by 2m, which allows users to be immersed in the environment itself. The glasses are equipped with sensors that can detect head movement and increases the visual accuracy relative to position of the users.

Definitions

Virtual Reality (VR)

VR is a computer-generated environment with scenes and/or objects that appear real, immersing users in a virtual world.

Augmented Reality (AR)

AR is an enhanced version of reality created by overlaying visual, auditory, or other sensory information into a user's real-world environment in real time.

Mixed Reality (MR)

MR is a hybrid of AR and augmented virtuality where virtual objects interact with real-life objects in user's physical space to produce an environment where physical and digital objects coexist and interact in real time.

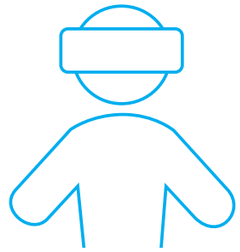
Tools and Apps

VR mobile applications

Cardboard:

Allows you to turn panaromic pictures into VR experiences.

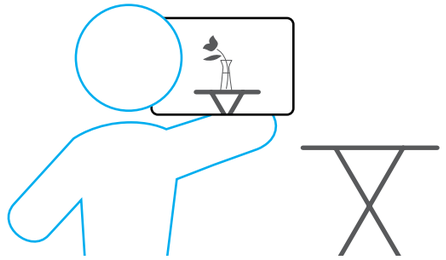
- Take (or upload) a panoramic picture and overlay a voice to describe an experience.
- You can use an already taken panoramic picture and make edits to it in, such as using You Doodle, Sketch, Inkboard, or Let's Draw.
- Idea to paint or draw on the panoramic picture to show the 'prototype experience' using any photo editor software.



AR mobile applications

Augment:

Place any 3D object into a real-world environment through AR, so that you can test how your PSS might look or feel in a current space.



Method

Additive Manufacturing (AM) Principle Design

Design Thinking | Advanced Prototyping

The purpose of this method to engage professionals with the topic of an Additive Manufacturing (AM)-centric Design Innovation Process. Pragmatic and research-validated AM principles guide a process to create designs that are buildable using AM.

Why: Principle-driven development of prototypes and production parts or products are a key skill for Design Innovation. Proven AM principles provide an approach and structure for developing creative prototypes and products that are buildable, effective, and efficient.

Materials: AM process or processes, such as 3D printing workstations; AM materials for use in the processes; CAD software to translate design concepts to readable files for use in the AM processes.

Acronyms: AM – Additive Manufacturing
DIwAM – Design Innovation with Additive Manufacturing
HRFG – Hybrid Rocket Fuel Grain

Procedure (DIwAM)

1. Understand the market
2. Understand the users
3. Validate assumptions about the users
4. Validate assumptions about functionality
5. Prioritise needs and functions
6. Scope opportunity
7. Ideate potential solutions
8. Downselect best potential solutions
9. Validate solutions
10. Refinement of solutions
11. Production ready solutions

Worked Example

Rocket Fuel Grain Printer

Market analysis of satellite launch space revealed an opportunity to use hybrid rocket engines as a practical and safe and differentiable means of propulsion.

Interviews and research from hybrid rocket producers revealed that hybrid engines were produced using a casting process that limited size and geometric complexity of the engines which was identified as an opportunity for AM to help.

Initial user research revealed that users were interested in the type of launch (size, frequency, and altitude) enable by hybrid rocket engines.

System architectures and specifications of current Hybrid Rocket Fuel Grain (HRFG) manufacturing were recorded, yet revisited after ideation.

All functions were perceived as critical so there was no need to prioritise function in this case study.

Using the AM opportunities, the problem was scoped to create an AM process for the production of hybrid rocket fuel grains.

Multiple rounds of ideation were executed to determine the system architecture, material deposition strategies, and material distribution strategies in the rockets themselves.

Candidate ideas we down selected using a gallery method approach and a pugh chart comparison.

A prototyping strategy was used in multiple iterations to test the motions platforms of the HRFG printer, the material depositions systems, and the actual firing of the fuel grain.

Optimisation is used to explore how the distribution of propellant materials could be adjusted to provide the required thrust.

Further characterisation of the HRFG printer is performed to ensure reliability in printing fuel grains. Further work would implement these constraint into the fuel grain optimisation system. The final solution resulted in the successfully firings of HRFG-based rocket engines.

AM Principle Cards

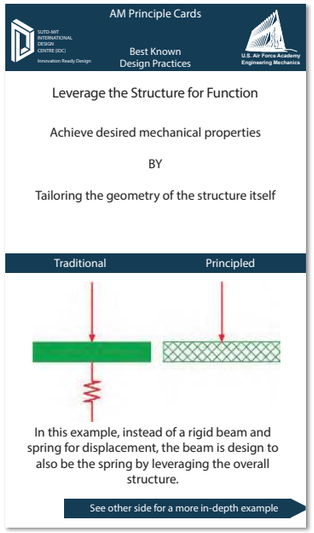
These cards are designed to be used as an education and creativity aid for AM.

Full set of AM Principle Cards can be found here

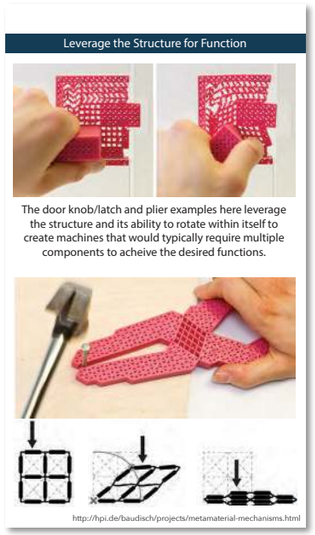
Structure of cards

Textual description of design principle constructed with a consistent syntax and lexicon

Before and after-styled analytical graphic to illustrate the design principle with simple description



Front



Back

Multiple examples of design principle applied in a real-world scenario with short description

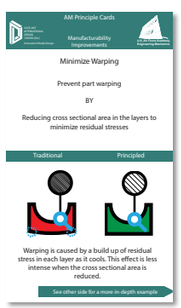
Four categories of AM Principle Cards

Process Capabilities

Red cards

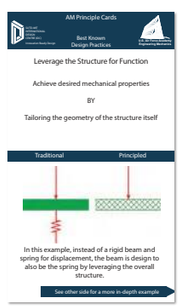
Manufacturability Improvements

Green cards



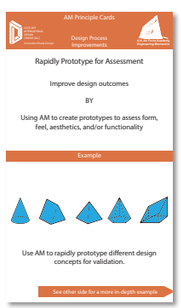
Best Known Design Practices

Blue cards



Design Process Improvements

Orange cards



Additional procedure with AM Principle Cards

1 Build on the ideas/concepts

created during the Develop phase of DI, and apply AM principles to develop alternative, creative forms of the concepts.

2 Consider and study the full set of AM Principle Cards

Choose the applicable cards, for example:

- Combine Parts or Components
- Integrate Functions and Components
- Leverage Cellular or Lattice Structures
- Enable 3D Scanned Personal Interfaces
- Create Functional Joints and Interfaces
- Design Modular Components
- Incorporate Internal Functionality
- Incorporate Snap Fits (Quick Connects)

Discuss the principles as a team.

3 Generate alternative ideas/ concepts

Using the chosen AM Principle Cards, generate alternative ideas/concepts to enhance the capabilities of your concepts using AM.

- Individually write-sketch five ideas inspired by the AM Principle Cards
- Add sticky notes/sketches to a virtual/ physical white board or flip chart, discuss as a team, and refine/generate more concepts

4 Choose a preferred idea or two

and create refined sketches.

5 Convert the concepts

to CAD models and generate AM models (such as the STL file format), capable of being produced with the chosen AM process(es).

6 Fabricate the concepts and evaluate them

based on user and performance testing.

AM Design Principles

1	Preserve small features by printing them in an orientation which requires no support material
2	Preserve surface finish by printing artefacts in an orientation which requires no support material
3	Prevent part warping by minimizing cross sectional area and residual stresses
4	Improve print success by orienting a part with the lowest vertical aspect ratio
5	Reduce weight, material cost, and preserve stability by replacing solid volumes with cellular structures
6	Eliminate assembly steps and time by printing functional joints and interfaces directly
7	Integrate additional functionality by incorporating components or features in unused internal volumes
8	Enable custom processes (i.e. low-medium volume production) by identifying features that are complex or require high levels of user-based customization
9	Achieve desired mechanical properties by tailoring the geometry of the mesostructure
10	Reduce print time by orienting the shortest dimension parallel to the slowest fabrication direction
11	Ensure printability by scaling artefacts and removing non-critical volumes
12	Improve accuracy of critical curves and profiles by orienting critical curves and profiles in the plane of highest resolution
13	Satisfy alternative functional requirements by scaling the artefact
14	Satisfy different parametric requirements by scaling the artefact
15	Minimize design time and effort by reusing already-designed component geometry
16	Leverage the capabilities of the selected AM technology by using comparably high resolution .STL files
17	Accommodate different AM technologies' capabilities by using high-resolution .STL files
18	Improve printability by designing with the resolution limitations of the selected AM process in mind
19	Add function(s) to artefacts by incorporating functional features into non-functional aesthetic models
20	Minimize assembly time and number of components by incorporating snaps fits when possible
21	Reduce production time by standardizing the assembly process
22	Incorporate existing low-cost components by integrating the necessary standard interfaces
23	Improve manufacturability by dividing the artefact into smaller components

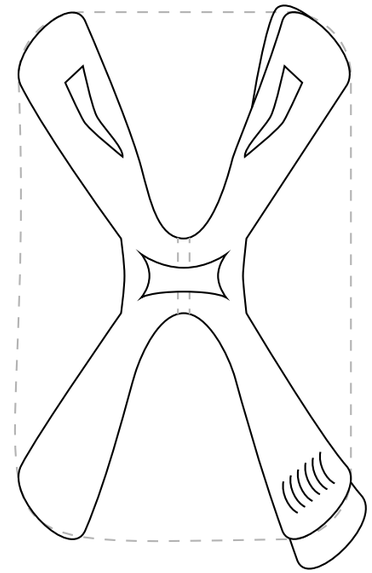
Worked Example with AM Principle Cards

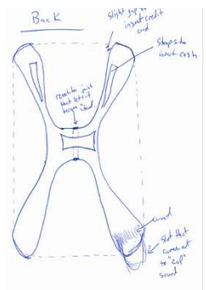
How might we enhance the user-centered capabilities of next generation mobile phones using additive manufacturing, such as charging, viewing, protecting, carrying, listening, talking, and texting?

Example preliminary sketches from an actual design teams A and B.

A This design has 5 features:

- credit card holder
- cash holder
- phone stand
- special geometry
- mechanical sound amplification

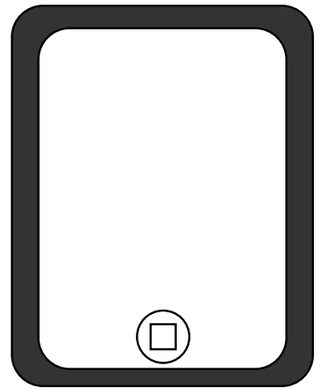


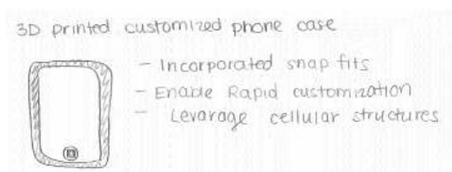


Original sketch

B This design has 3 features:

- snap fit connections
- customizable geometries
- lightweight/strong cellular structures





Original sketch

Method

Desktop Walkthrough

Systems Thinking | Advanced Prototyping

Desktop Walkthrough simulates a service experience using simple props like toy figurines on a small-scale stage, testing and exploring common scenarios and alternatives[1].

Why: Desktop Walkthrough helps make the experiential process nature of a service tangible, and allows service concepts to go through fast iterations.

Materials: Markers, Scissors, Glue, Paper, Cardboard, Plasticine, Toy figurines, Flipchart Paper, Sticky Notes, Digital camera, Site map/Floor plan

Complementary methods: User Journey Map, Site Analysis , Scenarios, Activity Diagram , Service Blueprinting , Adjacency Diagram, Prototyping Canvas, Scaled Model

Procedure

1 **Set up a workspace**
with spaces, props and figurines to run through selected scenarios.

2 **Do a walkthrough**
of the scenarios. Play out the user journeys of each role, moving the figurines around and acting out the dialogue and interactions involved.

3 **Identify**
insights and ideas.

4 **Decide**
on the changes and iterate.

Best Practices

Include observers in the walkthrough

Observers serve to give additional perspective to the user experience.

Avoid skipping steps

Be mindful of how each user gets to where they are, step by step.

Include a facilitator

Let the facilitator direct the walkthrough, and control when to pause the walkthrough to discuss and resolve issues.

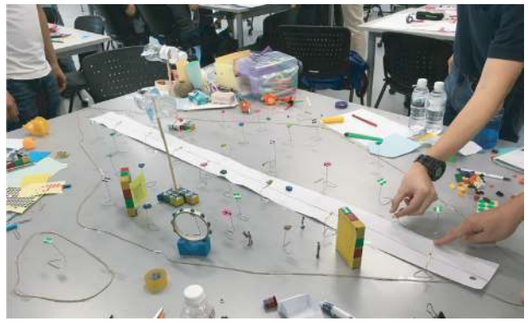
Assign a scribe

Get the scribe to document insights, ideas and issues that come along during the walkthrough.

Keep it running

Strive to complete the walkthrough, and avoid getting carried away by heavy discussions of ideas and issues midway in the walkthrough.

Simulating the experience of the services in a mixed-use waterfront



Simulating the response of autonomous drone swarms in tackling security threats to protect a vicinity

Method

Lifecycle Analysis

Design Engineering | Evaluation

Lifecycle analysis or sustainability analysis is a way to analyze your design across all stages of design, manufacturing, use, and disposal.

Why: Creating a benchmark for your design of its expected sustainability impact is key to improving its sustainability impact, and may inform partnerships that are core to producing your design sustainably.

Material: Lifecycle Analysis Template

Complementary method: Benchmarking

Acronym: LiDS - Life-cycle Design Strategy

Scan or click here for a digital copy of the template

Procedure

1 Identify

for each phase of your design concept's lifecycle, what materials are needed and what waste would be produced. A lifecycle starts from raw material sourcing and continues through material fabrication, design, manufacturing and assembly, sales and distribution, use, to disposal or retirement.

2 Score

your design concept using a model like the LiDS Wheel to assess high (1/5) and low impact (5/5) in each lifecycle stage. A high score is higher sustainability, and a lower score is lower sustainability.

3 Develop a quantitative model (Optional)

that connects design choices (e.g., materials, manufacturing locations) to sustainability, environmental, and climate impacts.

4 Ideate

alternatives available to you to minimise impacts using heuristics and design for environment strategies[1]:

1. Encourage reuse and renewability of resources
2. Improve environmental health and human health
3. Minimise use of resources
4. Minimise operational consumption of resources
5. Maximise product lifetime
6. Facilitate upgrade and reuse of components

Best Practice & Tips

Check multiple sources

to get a good idea of a range of impacts. Lifecycle information can be difficult to find.

Consider user behavior

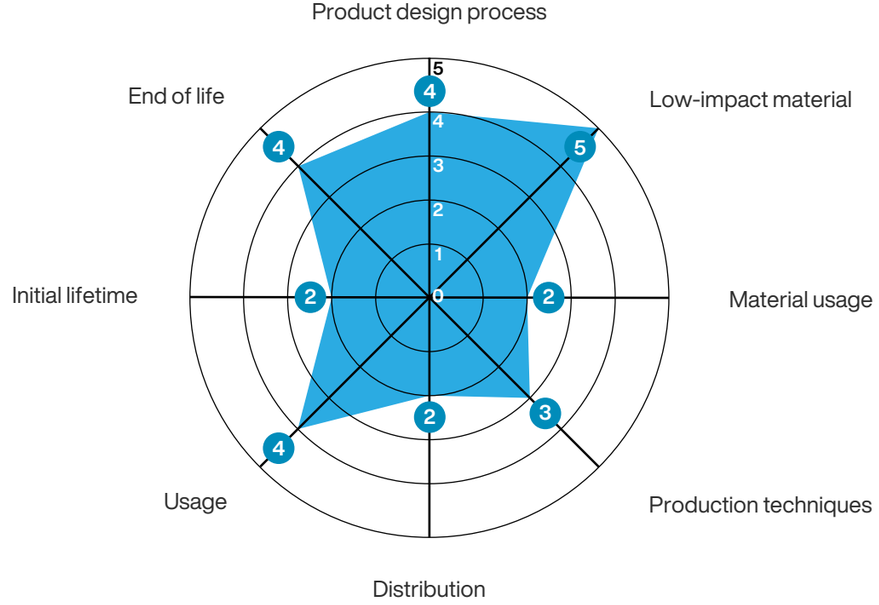
Just because a material or assembly is recyclable doesn't mean it is easy to recycle, or that users will recycle.

Lifecycle impacts are systemic

and can inform partnerships with organisations at multiple points in the supply chain.

Worked Example

LiDS Wheel for a product



Tota score: 26/40

This LiDS Wheel indicates areas for improvement are in material usage, production techniques, distribution, and initial lifetime.

Method

Design of Experiments

Design Engineering | Evaluation

Design of Experiments is the systematic analysis of design variants. This technique has strong statistical underpinning to inform the number of tests needed in order to draw conclusions, as well as to identify irregularities in your data that may tell you something about your design.

Why: Systematic testing using a Design of Experiments approach allows identification of parameter variations that have noticeable impact on a design's performance. This is valuable for informing a selection of parameters, or to test the robustness of your design.

Materials: Prototypes, measurement tools (e.g. ruler or stopwatch), pen and paper to record responses

Complementary methods: Prototyping Canvas and all methods under core and advanced prototyping methods

Acronyms: ANOVA - Analysis of Variance
DOE - Design of Experiments
MAV - Micro Air Vehicle

Procedure

1 **Select parameters**

of your design to vary as part of a test. Each parameter selected should have two or more levels, or values that you will vary.

2 **Determine all possible combinations**

of parameter levels.

3 **Choose an experimental design**

If testing all combinations is unfeasible, a fractional design is recommended. If testing all combinations is possible, a full factorial design is recommended.

4 **Prototype a design concept**

for each combination of parameters to be tested. The prototypes should be allow outcomes of interest to be measured in the same way across all prototypes.

5 **Test all prototypes**

according to a full or fractional factorial design, recording outcome results for each test.

6 **Analyze test results**

using ANOVA to determine whether parameter variation has a statistically significant impact on outcomes.

Best Practices & Tips

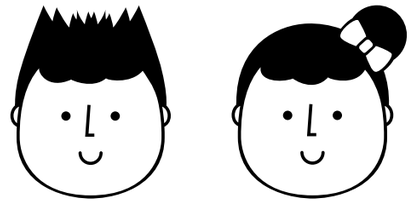
- ANOVA assumptions on distribution
- If your test is experience based, practice your test in advance to not conflate improvement from learning with higher or lower performance of the design

Worked Example 1

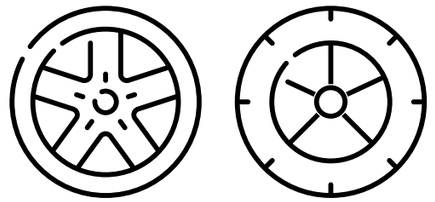
Four different aspects (factors) of a game are represented by the images below: the character, the vehicle, tire, and parachute type. With two options for each aspect, there are 16 different combinations possible, meaning 16 different prototypes are needed to test all combinations. One time playing the game with each combination is a test, and results measured across two tests.

In this test, the results indicated that there is no single factor or interaction between factors that produces a statistically significant result. That means the primary indicator of a better outcome is not the choice of character customization, but the user! For a game where customization is desired but not to the degree it determines the outcome of the game more than the player, design of experiments is a tool to ensure the options for each aspect of character creation are within a set range.

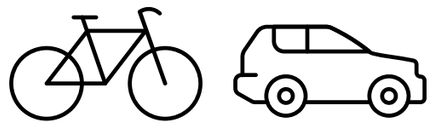
Character



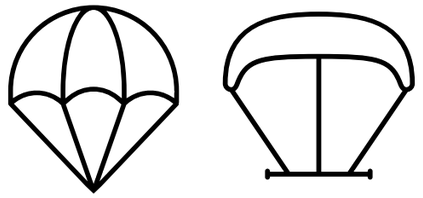
Tire



Vehicle



Parachute



Results

ANOVA test results indicate no factor, or interaction between factors, is statistically significant

Results suggest that the primary factor that yields better performance is not the design, but the user!

Worked Example 2

Effectiveness of rat glue to adhere to wall surface (Weight vs Puck Area)

To further investigate the requirement of puck size for respective MAV weights, an experiment was set up. The setup consisted of circular pucks ranging from 2” to 4” in diameter, connected to a bottle weighted with water ranging from 4oz to 16oz; common weights of popular hobby MAVs. Rat glue was applied to the puck which was firmly attached onto a smooth vertical surface and the time to detachment was recorded twice for each combination of weight and puck area. The results are shown below with each entry showing the mean time in min:sec, and when deviations are significant, the maximum time shown in parentheses.

Weight / Puck Area	4oz	7oz	10oz	13oz	16oz
2” Diameter A=1.57in^2	0:28	0:10	0:02	0:00	0:00
3” Diameter A=3.53in^2	1:58	0:48 (10:00+)	0:21 (1:43)	0:17 (0:29)	0:14 (0:18)
4” Diameter A=6.28in^2	5:56 (10:00+)	1:30 (10:00+)	0:52 (5:58)	0:50 (10:00+)	0:45 (5:36)

Observations

Due to the extreme adhesiveness and viscosity of the glue, it was unfeasible to precisely measure the mass applied per unit area. However, it was found that a thin coat spread as evenly as possible provided a much better attachment time and significantly reduced viscous creep than a generously applied layer. This is likely due to the stronger forces of adhesion between the surface and the glue as compared to the cohesive forces within the glue, which are limited by the weak mechanical properties of the fluid glue.

There were instances where the attachment time far exceeded mean values, while creep was virtually nonexistent. While desirable, the result could not be consistently repeated. The increase in performance could be attributed to the application of rat glue onto the puck. Therefore, the attachment time can potentially be increased drastically by developing a consistent method of application, thereby reducing the required puck area and amount of glue.

It was also found that the glue was insoluble in water and maintained its adhesiveness to surfaces underwater. This shows promise that the system can be used in suboptimal conditions, where surfaces may be wet from condensation or precipitation.

There is no innovation and creativity without failure. Period.

Dr. Brené Brown

World-renowned American professor, author, researcher, and storyteller who's spent the past two decades studying courage, vulnerability, shame, and empathy.

References & Resources

The first section, 'Introduction', contains references relevant to the Design Method Cards, DI Process Framework, as well as DI mindsets and principles.

The remainder of the references and resources are categorised according to the DI methods and follow the order in the handbook.

General references that are useful and relevant to the handbook are placed in the last section, ‘General’.

The reference numbers that appear throughout the handbook follow the numbering in this section.

The 4 types of references and resources are Book, Paper, Web Article and Resources

Introduction

Design Innovation Methodology

1. Camburn, B. A., Auernhammer , J. M., Sng, K. H. E., Mignone, P. J., Arlitt, R. M., Perez, K. B., ... Wood, K. L. (2017). Design Innovation: A Study of Integrated Practice. ASME 2017 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference , 7: *29th International Conference on Design Theory and Methodology*, V007T06A031-V007T06A031. doi: 10.1115/DETC2017-68382
   Paper

2. Foo, D., Choo, P.K., Camburn, B., and Wood, K.L. (2019). *Design Innovation (DI): Design Method Cards (SUTD-MIT IDC)*. doi: 10.13140/RG.2.2.17862.32322
   Resources

Process

1. *Framework for Innovation: Design Council's evolved Double Diamond.* (2019). *Design Council UK*. https://www.designcouncil.org.uk/our-work/skills-learning/tools-frameworks/framework-for-innovation-design-councils-evolved-double-diamond/
   Web Article

Mindsets

1. Liedtka, J. (2019). *MURAL Webinar: Evaluating the Impact of Design Thinking in Action II*. MURAL. https://www.slideshare.net/VisualWorkspace/mural-webinar-evaluating-the-impact-of-design-thinking-in-action-ii
   Resources

Principles

1. Camburn, B. A., Auernhammer , J. M., Sng, K. H. E., Mignone, P. J., Arlitt, R. M., Perez, K. B., ... Wood, K. L. (2017). Design Innovation: A Study of Integrated Practice. ASME 2017 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference , 7: *29th International Conference on Design Theory and Methodology*, V007T06A031-V007T06A031. doi: 10.1115/DETC2017-68382
   Paper

2. Sheard, S., Cook, S., Honour, E., Hybertson, D., Krupa, J., McEver, J., McKinney, D., Ondrus, P., Ryan, A., Scheurer, R. and Singer, J. (2015). *A Complexity Primer for Systems Engineers*. INCOSE Complex Systems Working Group White Paper.
   Paper

Methods

1. Seow, O., Tiong, E., Teo, K., Silva, A., Wood, K.L., Jensen, D.D., and Yang, M.C. (2018, August 26-29). Design Signatures: Mapping Design Innovation Processes. ASME 2018 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference, Quebec, Canada. *Volume 7: 30th International Conference on Design Theory and Methodology*. V007T06A046. ASME. https://doi.org/10.1115/DETC2018-85758
   Paper

2. Luo, J., Yan, B., & Wood, K.L. (2017). InnoGPS for Data-Driven Exploration of Design Opportunities and Directions: The Case of Google Driverless Car Project. *Journal of Mechanical Design*, 139(11).
   Paper

Framework

1. Raviselvam, S., Hwang, D., Camburn, B., Sng, K., Hölttä-Otto, K., & Wood, K. L. (2022). Extreme-user conditions to enhance design creativity and empathy- application using visual impairment. *International Journal of Design Creativity and Innovation, 10(2)*, 75-100. https://doi.org/10.1080/21650349.2021.2024093
   Paper

2. Raviselvam, S., Subburaj, K., Hölttä-Otto, K. et al. (2022). Systematic Application of Extreme-User Experiences: Impact on the Outcomes of an Undergraduate Medical Device Design Module. *Biomed Eng Education 2*, 233–252. https://doi.org/10.1007/s43683-022-00065-4
   Paper

3. Raviselvam, S.. (2021). *Designing with the Extreme-user Experiences* [Dissertation, Singapore University of Technology and Design].
   Paper

Discover

Stakeholder Mapping

1. Mapping Systems. (n.d.). *TiSDD*. https://www.thisisservicedesigndoing.com/methods/mapping-systems
   Web Article

2. Mind Tools Content Team. (n.d.). Stakeholder Analysis: Winning Support for Your Projects. *Mind Tools*. https://www.mindtools.com/aol0rms/stakeholder-analysis
   Web Article

3. Smaply. (n.d.). Stakeholder maps. *Smaply*. https://helpdesk.smaply.com/support/solutions/folders/22000170274
   Resources

Personas

1. Otto, K. N., & Wood, K. L. (2001). *Product design: Techniques in Reverse Engineering and New Product Development*. Prentice Hall.
   Book

2. Personas. (n.d.). *Open Design Kit*. http://opendesignkit.org/methods/personas/
   Web Article

3. Phillimore, B. (2019, May 27). The Fundamentals of Engaging with Extreme Users. *Medium*; UX Collective. https://uxdesign.cc/the-fundamentals-of-engaging-with-extreme-users-45e0033e6b2
   Web Article

4. Strachan, J. (2017, October 20). Why Use Extreme Users?, *Medium; UX Planet*. https://uxplanet.org/why-use-extreme-users-345e97719e52.
   Web Article

5. Harley, A. (2015, February 16). Personas Make Users Memorable for Product Team Members. *Nielsen Norman Group*. https://www.nngroup.com/articles/persona/
   Web Article

6. Dam, R., Teo, Y.S. (2022). Personas – A Simple Introduction. *Interaction Design Foundation*. https://www.interaction-design.org/literature/article/personas-why-and-how-you-should-use-them
   Web Article

7. Downs, J. (2020, July 30). Guide to Creating User Personas. *Justinmind*. https://www.justinmind.com/blog/user-persona/
   Web Article

8. Ellis, M. (2019). How to Create a User Persona. *99designs*. https://99designs.com/blog/business/how-to-create-user-personas/
   Web Article

9. Harley, A. (2015, February 16). Personas Make Users Memorable for Product Team Members. *Nielsen Norman Group*. https://www.nngroup.com/articles/persona/
   Web Article

Scenarios

1. User Scenarios. (2019). *Interaction Design Foundation*. https://www.interaction-design.org/literature/topics/user-scenarios
   Web Article

2. How to Create Scenarios for Design Thinking: Innovation Training.org. (n.d.). *InnovationTraining.org*. https://www.innovationtraining.org/how-to-create-scenarios-for-design-thinking/
   Web Article

3. Buchenau, M., Suri, J. F. (2000). Experience Prototyping. *Proceedings of the 3rd Conference on Designing Interactive Systems Processes, Practices, Methods, and Techniques - DIS 00*. doi: 10.1145/347642.347802
   Paper

4. Nielsen, L. (n.d.). 30. Personas. *Interaction Design Foundation*. https://www.interaction-design.org/literature/book/the-encyclopedia-of-human-computer-interaction-2nd-ed/personas
   Web Article

5. Cooper, A., Reimann, R., Cronin, D., Noessel, C., Csizmadi, J., & LeMoine, D. (2014). *About Face: The Essentials of Interaction Design*. Wiley.
   Book

6. Barnes, D., Openshaw, K., Smith, K. and Plas, R. (1994). What Makes People Cook With Improved Biomass Stoves? *A Comparative International Review Of Stove Programs. (Energy Series)*. 242.
   Paper

7. Green, M. G., Jensen, D., Seepersad, C. C., & Wood, K. L. (2009). Design for Frontier Contexts: Classroom Assessment of a New Design Methodology with Humanitarian Applications. *International Journal of Engineering Education*, 25(5), 1029–1045.
Paper

8. Green, M. G., Linsey, J. S., Seepersad, C. C., Wood, K. L., & Jensen, D. J. (2006, January). Frontier design: a product usage context method. *International Design Engineering Technical Conferences and Computers and Information in Engineering Conference, 42584*, 99-113).
Paper

User Interviews

1. Otto, K. N., & Wood, K. L. (2001). *Product Design Techniques in Reverse Engineering and New Product Development*. Prentice Hall.
Book

2. Nielsen, J. (2010, July 25). Interviewing Users. *Nielsen Norman Group*. https://www.nngroup.com/articles/interviewing-users/
Web Article

3. Kolko, J. (2015). Design Thinking Comes of Age. *Harvard Business Review*. https://hbr.org/2015/09/design-thinking-comes-of-age
Web Article

4. What is the Iceberg theory? (2018, August 26). *embracetheplanetnl*. https://embracetheworldsite.wordpress.com/2018/08/26/what-is-the-iceberg-theory/
Web Article

5. Green, M. G., Jensen, D., Seepersad, C. C., & Wood, K. L. (2009). Design for Frontier Contexts: Classroom Assessment of a New Design Methodology with Humanitarian Applications. *International Journal of Engineering Education, 25*(5), 1029–1045.
Paper

6. Otto, K. N., & Wood, K. L. (1999). Customer Integrated Systematic Design. *Transactions of the SDPS, 3*(4), 61–74.
Paper

7. Green, M. G., Linsey, J. S., Seepersad, C. C., Wood, K. L., & Jensen, D. J. (2006). Frontier Design: A Product Usage Context Method. *Volume 4a: 18th International Conference on Design Theory and Methodology*, 99–113. doi: 10.1115/detc2006-99608
Paper

8. Osterwalder, A., Pigneur, Y., Bernarda, G., Smith, A., & Papadakos, T. (2014). *Value Proposition Design: How to Create Products and Services Customers Want (The Strategyzer Series)* . Wiley.
Book

9. Wilson, C. (2014). *Interview Techniques for UX Practitioners: A User-Centered Design Method*. Morgan Kaufmann.
Book

10. Pernice, K. (2018, October 7). User Interviews: How, When, and Why to Conduct Them. *Nielsen Norman Group*. https://www.nngroup.com/articles/user-interviews
Web Article

Survey Design

1. Wolf, C., Joye, D., Smith, T. W., and Fu, Y., Eds. (2016). *The SAGE Handbook of Survey Methodology*. SAGE Publications Ltd.
Book

2. Farrell, S. (2016, September 25). 28 Tips for Creating Great Qualitative Surveys. *Nielsen Norman Group*. https://www.nngroup.com/articles/qualitative-surveys/
Web Article

User Journey Map

1. What are Customer Touch Points & Why Do They Matter. (n.d.). *Interaction Design Foundation*. https://https://www.interaction-design.org/literature/article/customer-touchpoints-the-point-of-interaction-between-brands-businesses-products-and-customers
Web Article

2. Grocki, M. (2014, September 16). How to Create a Customer Journey Map. *UX Mastery*. https://uxmastery.com/how-to-create-a-customer-journey-map/
Web Article

3. Salazar, K. (2016, December 4). How Channels, Devices, and Touchpoints Impact the Customer Journey. *Nielsen Norman Group*. https://www.nngroup.com/articles/channels-devices-touchpoints/
Web Article

4. Camburn, B. A., Auernhammer , J. M., Sng, K. H. E., Mignone, P. J., Arlitt, R. M., Perez, K. B., ... Wood, K. L. (2017, November 3). Design Innovation: A Study of Integrated Practice. *ASME 2017 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference*, Cleveland, Ohio. doi: 10.1115/DETC2017-68382
Paper

5. Kaplan, K. (2016, July 31). When and How to Create Customer Journey Maps. *Nielsen Norman Group*. https://www.nngroup.com/articles/customer-journey-mapping/
Web Article

6. Mapping Journeys. (n.d.). *TiSSD*. https://www.thisisservicedesigndoing.com/methods/mapping-journeys
Web Article

7. Quattlebaum, P. (2017, February 8). Download Our Guide to Experience Mapping. Medium; *One Design Community*. https://medium.com/capitalonedesign/download-our-guide-to-experience-mapping-624ae7dffb54
Web Article

8. Gibbons, S. (2018, December 9). Journey Mapping 101. *Nielsen Norman Group*. https://www.nngroup.com/articles/journey-mapping-101/
Web Article

Contextual Needs Analysis

1. Green, M. G., Linsey, J. S., Seepersad, C. C., Wood, K. L., & Jensen, D. J. (2006, January). Frontier Design: A Product Usage Context Method. In *ASME 2006 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference (Vol. 42584*, pp. 99-113). The University of Texas, Austin, Texas. doi: 10.1115/DETC2006-99608
Paper

Empathic Lead User

1. Raviselvam, S., Anderson, D., Hölttä-Otto, K., & Wood, K. L. (2018). Systematic Framework to Apply Extraordinary User Perspective to Capture Latent Needs Among Ordinary Users. Volume 7: *30th International Conference on Design Theory and Methodology*, V007T06A013-V007T06A013. doi: 10.1115/detc2018-86263
Paper

2. Raviselvam, S. L., Wood, K. L., Katja Hölttä-Otto, K. L., Tam, V. L., & Nagarajan, K. L. (2016). A Lead User Approach to Universal Design – Involving Older Adults in the Design Process. *Studies in Health Technology and Informatics* 229, 131. doi: 10.3233/978-1-61499-684-2-131
Paper

3. Lin, J., & Seepersad, C. C. (2007). Empathic Lead Users: The Effects of Extraordinary User Experiences on Customer Needs Analysis and Product Redesign. *Volume 3: 19th International Conference on Design Theory and Methodology; 1st International Conference on Micro- and Nanosystems; and 9th International Conference on Advanced Vehicle Tire Technologies, Parts A and B*, 289–296. doi: 10.1115/detc2007-35302
Paper

4. Johnson, D. G., Genco, N., Saunders, M. N., Williams, P., Seepersad, C. C., & Hölttä-Otto, K. (2014). An Experimental Investigation of the Effectiveness of Empathic Experience Design for Innovative Concept Generation. *Journal of Mechanical Design, 136*(5). doi: 10.1115/1.4026951
Paper

5. Urban, G. L., & Hippel, E. V. (1988). Lead User Analyses for the Development of New Industrial Products. *Management Science, 34*(5), 569–582. doi: 10.1287/mnsc.34.5.569
Paper

Video Ethnography

1. Kaplan, K. (2016, July 31). When and How to Create Customer Journey Maps. *Nielsen Norman Group*. https://www.nngroup.com/articles/customer-journey-mapping/
Web Article

2. Mapping Journeys. (n.d.). *TiSSD*. https://www.thisisservicedesigndoing.com/methods/mapping-journeys
Web Article

Discover

Site Analysis

1. Francis, R. L., McGinnis, L. F., & White, J. A. (1992). *Facility Layout and Location: An Analytical Approach*. Prentice Hall.
   Book

2. Architecture Site Analysis Guide. (n.d.). First In Architecture. https://www.firstinarchitecture.co.uk/architecture-site-analysis-guide-2/
   Web Article

Semantic Inquiry

1. Hanington, B., & Martin, B. (2012). *Universal Methods of Design: 100 Ways to Research Complex Problems, Develop Innovative Ideas, and Design Effective Solutions*. Rockport Publishers.
   Book

Shadowing

1. Shadowing. (n.d.). *Think Design Collaborative*. https://think.design/user-design-research/shadowing/
   Web Article

2. Shadowing in User Research - Do You See What They See? (n.d.). *Interaction Design Foundation*. https://www.interaction-design.org/literature/article/shadowing-in-user-research-do-you-see-what-they-see
   Web Article

Multisensory Analysis

1. Williams, A., Barrett, P. (2010). Creating Sensory-Sensitive Creative Spaces. In Williams, A., Jones, D., Robertson, J., (Eds.), *BITE: Recipes for Remarkable Research*. (76-77) Brill. https://www.jstor.org/stable/10.1163/j.ctv2gjwn0p.27
   Book Chapter

Paticipatory Radar Map

1. What's on Your Radar? (n.d.). *Luma Institute*. https://www.luma-institute.com/whats-on-your-radar/
   Web Article

Cognitive Walkthrough

1. Mahatody, T., Sagar, M., Kolski, C. (2010). State of the Art on the Cognitive Walkthrough Method, Its Variants and Evolutions. *International Journal of Human–Computer Interaction, 26* (8), 741–785. https://doi.org/10.1080/10447311003781409
   Journal

2. Salazar, K. (2022, February 13). Evaluate Interface Learnability Through Cognitive Walkthroughs. *Nielsen Norman Group*. https://www.nngroup.com/articles/cognitive-walkthroughs/
   Web Article

3. System Usability Scale (SUS). (n.d.) *Usability.gov*. https://www.usability.gov/how-to-and-tools/methods/system-usability-scale.html
   Web Article

Regulatory Context

1. Shefelbine, S., Clarkson, J., Farmer, R., Eason, S. (2002). *Good Design Practice for Medical Devices and Equipment: Requirements Capture. Engineering Design Centre, Cambridge Consultants Ltd. (Eds.*) Cambridge Engineering Design Centre, Cambridge.
   Book

2. Parvizi, N., Woods, K. (2014). Regulation of Medicines and Medical Devices: Contrasts and Similarities. *Clinical Medicine (London, England), 14*(1), 6–12. https://doi.org/10.7861/clinmedicine.14-1-6
   Paper

Define

Affinity Analysis

1. Kano, N., Seraku, N., Takahashi, F. and Tsuji, S. (1984) Attractive Quality and Must-Be Quality. *Journal of the Japanese Society for Quality Control, 41*, 39-48.
   Paper

2. Otto, K. N., & Wood, K. L. (2001). *Product Design Techniques in Reverse Engineering and New Product Development*. Prentice Hall.
   Book

3. Han, J., Pei, J., & Kamber, M. (2011). *Data Mining: Concepts and Techniques* (3rd Edition). Elsevier.
   Book

Activity Diagram

1. Otto, K. N., & Wood, K. L. (2001). *Product Design Techniques in Reverse Engineering and New Product Development*. Prentice Hall.
   Book

Systems Function Model

1. Stone, R. B., & Wood, K. L. (1999). Development of a Functional Basis for Design. *Journal of Mechanical Design, 122*(4), 359–370. doi: 10.1115/1.1289637
   Paper

2. Hirtz, J., Stone, R. B., Mcadams, D. A., Szykman, S., & Wood, K. L. (2002). A Functional Basis for Engineering Design: Reconciling and Evolving Previous Efforts. *Research in Engineering Design, 13*(2), 65–82. doi: 10.1007/s00163-001-0008-3
   Paper

3. Otto, K. N., & Wood, K. L. (2001). *Product Design Techniques in Reverse Engineering and New Product Development*. Prentice Hall.
   Book

4. Hauser, J. R., & Clausing, D. (1988). The House of Quality. *Harvard Business Review*. https://hbr.org/1988/05/the-house-of-quality
   Web Article

How Might We

1. Dam, R., & Siang, T. (n.d.). Define and Frame Your Design Challenge by Creating Your Point Of View and Ask "How Might We". *Interaction Design Foundation*. https://www.interaction-design.org/literature/article/define-and-frame-your-design-challenge-by-creating-your-point-of-view-and-ask-how-might-we
   Web Article

2. Tran, N. (n.d.). *Design Thinking Playbook: For Change Management in K12 Schools*. Hasso Plattner Institute of Design at Stanford University. https://dschool.stanford.edu/resources/design-thinking-playbook-from-design-tech-high-school
   Resources

3. How Might We. (n.d.). *Design Kit*. https://www.designkit.org/methods/3
   Web Article

5 Whys

1. The Five Whys. (n.d.). *Design Kit*. https://www.designkit.org/methods/66
   Web Article

Service/UX Blueprinting

1. Remis, N. (2016, November 5). Download Our Guide to Service Blueprinting. Medium; *One Design Community*. https://medium.com/capitalonedesign/download-our-guide-to-service-blueprinting-d70bb2717ddf
   Web Article

2. Remis, N., Adaptive Path Team. (2016). *A Guide to Service Blueprinting*. Adaptive Path.
   Resources

3. Gibbons, S. (2017, August 27). Service Blueprints: Definition. *Nielsen Norman Group*. https://www.nngroup.com/articles/service-blueprints-definition/
   Web Article

Benchmarking

1. HyperDia | *Timetable and Route Search in Japan*. (n.d.). http://www.hyperdia.com/
   Resources

2. EE Broadway Local. (2010, March 25). Subway System Average Speed, By Line. [Online Forum Post] *nyctransitforums*. https://www.nyctransitforums.com/topic/17313-subway-system-average-speed-by-line/
Resources

3. Johnson, M. (2010, March 16). Average schedule speed: How does Metro compare? *GGWash*. https://ggwash.org/view/4524/average-schedule-speed-how-does-metro-compare
Web Article

4. Otto, K. N., & Wood, K. L. (2001). *Product Design Techniques in Reverse Engineering and New Product Development*. Upper Saddle River: Prentice Hall.
Book

5. Vorhies, D. W., & Morgan, N. A. (2005). Benchmarking Marketing Capabilities for Sustainable Competitive Advantage. *Journal of Marketing, 69*(1), 80–94. doi: 10.1509/jmkg.69.1.80.55505
Paper

6. Mtattrain. (2019). *MTA NYC Subway F-express train at Fourth Ave.jpg*. [Photograph] Wikimedia Commons. https://commons.wikimedia.org/wiki/File:MTA_NYC_Subway_F-express_train_at_Fourth_Ave.jpg
7. Fg2. (2005). *JRWestTrainNaraStation0300.jpg*. [Photograph] WIkimedia Commons. https://commons.wikimedia.org/wiki/File:JRWestTrainNaraStation0300.jpg
8. Valereee. (2019). *Dried sorana bean on a ruler showing inches and centimeters.jpg*. [Photograph] WIkimedia Commons. https://commons.wikimedia.org/wiki/File:Dried_sorana_bean_on_a_ruler_showing_inches_and_centimeters.jpg
Resources

Hierarchy of Purpose

1. Otto, K. N., & Wood, K. L. (2001). *Product Design Techniques in Reverse Engineering and New Product Development*. Prentice Hall.
Book

2. Granger, C. H. (1964). The Hierarchy of Objectives. *Harvard Business Review*. https://hbr.org/1964/05/the-hierarchy-of-objectives
Web Article

3. Goal hierarchy or Goal Breakdown Structure. (n.d.). *DTU ProjectLab*. http://wiki.doing-projects.org/index.php/Goal_hierarchy_or_Goal_Breakdown_Structure
Web Article

Influence Diagram

1. Agogino, A. M., & Rege, A. (1987). IDES: influence diagram based expert system. *Mathematical Modelling, 8*, 227–233. doi: 10.1016/0270-0255(87)90579-3
Paper

2. Howard, R. A. (1989). Knowledge Maps. *Management Science, 35*(8), 903–922. doi: 10.1287/mnsc.35.8.903
Paper

3. Howard, R. A., & Matheson, J. E. (2005). Influence Diagram Retrospective. *Decision Analysis, 2*(3), 144–147. doi: 10.1287/deca.1050.0050
Paper

4. Shachter, R. D. (1986). Evaluating Influence Diagrams. *Operations Research, 34*(6), 871–882. doi: 10.1287/opre.34.6.871
Paper

5. Diekmann, J. E., Featherman, W. D., Moody, R., Molenaar, K., & Rodriguez-Guy, M. (1996). Project cost risk analysis using influence diagrams. *Project Management Journal, 27*(4), 23–30.
Paper

6. Kenley, C. R. (1986). *Influence Diagram Models With Continuous Variables* [Dissertation]. Stanford University.
Paper

7. Clemen, R. T., & Reilly, T. (2001). *Making Hard Decisions with Decision Tools* (2nd ed.). South-Western Cengage Learning.
Book

8. McNamee, P., & Celona, J. (2007). *Decision Analysis For The Professional* (4th ed.). SmartOrg, Inc.
Book

House of Quality

1. Blanchard, B. S., & Fabrycky, W. J. (2011). *Systems Engineering and Analysis* (5th ed.). Pearson.
Book

2. Hauser, J. R., & Clausing, D. (1988, May). The House of Quality. *Harvard Business Review*. https://hbr.org/1988/05/the-house-of-quality
Web Article

3. Chan, L.-K., & Wu, M.-L. (2002). Quality function deployment: A literature review. *European Journal of Operational Research, 143*(3), 463–497. doi: 10.1016/s0377-2217(02)00178-9
Paper

4. Otto, K. N., & Wood, K. L. (2001). *Product design: Techniques in Reverse Engineering and New Product Development*. Prentice Hall.
Book

Ishikawa (Fishbone) Diagram

1. Ishikawa, K. (1982). *Guide to Quality Control*. Asian Productivity Organization.
Book

2. Kenett, R. S. (2008). *Cause-and-Effect Diagrams. Encyclopedia of Statistics in Quality and Reliability*. doi: 10.1002/9780470061572.eqr413
Paper

3. Fishbone Diagram. (n.d.). *ASQ Quality Press*. https://asq.org/quality-resources/fishbone
Web Article

4. Otto, K. N., & Wood, K. L. (2001). *Product design: Techniques in Reverse Engineering and New Product Development*. Prentice Hall.
Book

Map the System

1. Mapping Systems. (n.d.). *TiSSD*. https://www.thisisservicedesigndoing.com/methods/mapping-systems
Web Article

2. Meadows, D. H. (2008). *Thinking in Systems: A Primer* (D. Wright, Ed.). Chelsea Green Publishing.
Book

3. Acaroglu, L. (2017, September 21). Tools for Systems Thinkers: Systems Mapping. *Medium; Disruptive Design*. https://medium.com/disruptive-design/tools-for-systems-thinkers-systems-mapping-2db5cf30ab3a
Web Article

System Architecture

1. Systems Approach Applied to Engineered Systems. (2019). *SEBoK*. https://www.sebokwiki.org/w/index.php?title=System_Architecture&oldid=57992.
Web Article

2. Walden, D. D., Roedler, G. J., Forsberg, K., Hamelin, R. D., & Shortell, T. M. (2015). *Systems engineering handbook a guide for system life cycle processes and activities*; Incose-Tp-2003-002-04, 2015. Wiley.
Book

3. Friedenthal, S., Griego, R., & Sampson, M. (2009). *INCOSE Model Based Systems Engineering (MBSE) Initiative*.
Paper

4. Maier, M. W., & Rechtin, E. (2009). *The art of systems architecting*. CRC Press.
Book

5. Hein, A. M., Chazal, Y. M., Boutin, S. M., & Jankovic, M. M. (2018). A Methodology for Architecting Collaborative Product Service System of Systems. *2018 13th Annual Conference on System of Systems Engineering (SoSE)*, 53–59. doi: 10.1109/sysose.2018.8428697
Paper

6. Jackson, P. L. (2010). *Getting Design Right: A Systems Approach*. CRC Press.
Book

7. Sage, A. P., & Lynch, C. L. (1998). *Systems Integration and Architecting: An Overview of Principles, Practices, and Perspectives. Systems Engineering, 1*(3), 176–227. doi: 10.1002/(sici)1520-6858(1998)1:3<176::aid-sys3>3.0.co;2-l
Paper

Define

8. Introduction to Arcadia with Capella. (2019, January 15). Engineering Systems Architecture course at Engineering Systems and Design, Singapore University of Technology and Design. https://esd.sutd.edu.sg/40014-capella-tutorial/index.html
Resources

Participatory Valuation Game

1. Buy a Feature. (n.d.). *LUMA Institute*. https://www.luma-institute.com/buy-a-feature/
Webpage

Design Structure Matrix & Modularisation

1. Browning, T.R. (2001, September). Applying The Design Structure Matrix To System Decomposition And Integration Problems: A Review And New Directions. *IEEE Transactions on Engineering Management*, 48, 292–306. https://doi.org/10.1109/17.946528
Paper

2. Project Business. (2020, July 3). Design structure matrix DSM — Jere Lehtinen [Video]. YouTube. https://www.youtube.com/watch?v=RzjLUzgN5Lo
Resources

3. Project Business. (2020, July 3). Teaching note: Design structure matrix (DSM) – Jere Lehtinen [Video]. YouTube. https://www.youtube.com/watch?v=qOmrmperRWA
Resources

4. Eppinger S. D. & Browning T. R. (2016). *Design Structure Matrix Methods and Applications*. The MIT Press. 2016
Book

Kansei Engineering

1. Horiguchi, A., Suetomi, T. (1995). A Kansei Engineering Approach to a Driver/Vehicle System. *International Journal of Industrial Ergonomics*, 15, 25–37. https://doi.org/10.1016/0169-8141(94)00054-7
Paper

Develop

Brainstorming

1. Brainstorming. (n.d.). *Interaction Design Foundation*. https://www.interaction-design.org/literature/topics/brainstorming
Web Article

2. Osborn, A. F. (1953). *Applied Imagination: Principles and Procedures of Creative Thinking*. Charles Scribner's Sons.
Book

3. Osborn, A. F. (1963). *Applied Imagination: Principles and Procedures of Creative Problem-solving*. Charles Scribner's Sons.
Book

4. Paulus, P. B., & Yang, H.-C. (2000). Idea Generation in Groups: A Basis for Creativity in Organizations. *Organizational Behavior and Human Decision Processes, 82*(1), 76–87. doi: 10.1006/obhd.2000.2888
Paper

5. Otto, K. N., & Wood, K. L. (2001). *Product Design Techniques in Reverse Engineering and New Product Development*. Prentice Hall.
Book

6. Paulus, P. (2000). Groups, Teams, and Creativity: The Creative Potential of Idea-generating Groups. *Applied Psychology, 49*(2), 237–262. doi: 10.1111/1464-0597.00013
Paper

DI Mindmapping

1. Otto, K. N., & Wood, K. L. (2001). *Product Design Techniques in Reverse Engineering and New Product Development*. Prentice Hall.
Book

2. Buzan, T., & Buzan, B. (2006). *The Mind Map Book*. Essex: BBC Active.
Book

3. Marshall, K. S., Crawford, R., & Jensen, D. (2016). Analogy Seeded Mind-Maps: A Comparison of Verbal and Pictorial Representation of Analogies in the Concept Generation Process. Volume 7: *28th International Conference on Design Theory and Methodology*. doi: 10.1115/detc2016-60100
Paper

4. Anderson, M., Onyechi, J., Yamazaki, T., Wood, K., & Jensen, D. (2017). *Mind Map for Biologically Inspired Covert Visual Systems: A Pilot Study*. In Proceedings of the SW Regional ASEE Conference.
Book

5. Simple Collaborative Mind Maps. (n.d.). *CoggleIt*. https://coggle.it/
Resource

6. White, C. K., Wood, K. L., & Jensen, D. (2012). From Brainstorming to C-Sketch to Principles of Historical Innovators: Ideation Techniques to Enhance Student Creativity. Journal of STEM Education: Innovations and Research, 13(5).
Paper

7. SUTD-MIT International Design Centre (2015, May 21). Concept Generation Tools - Mind Mapping. [Video]. YouTube. https://www.youtube.com/watch?v=qYIQWTlmnhY
Resource

Design by Analogy

1. Moreno, D. P., Blessing, L., Yang, M., & Wood, K.L. (2015). The Potential of Design-by-Analogy Methods to Support Product, Service and Product Service Systems Idea Generation. *DS 80-5 Proceedings of the 20th International Conference on Engineering Design (ICED 15) Vol 5*: Design Methods and Tools-Part 1, Milan, Italy, 27-30.07. 15, 93-104.
Paper

2. Gentner, D. (1983). Structure-Mapping: A Theoretical Framework for Analogy. *Cognitive Science, 7*(2), 155-170.
Paper

3. Moreno, D. P., Yang, M. C., Hernández, A. A., Linsey, J. S., & Wood, K. L. (2015). A Step Beyond to Overcome Design Fixation: A Design-by-Analogy Approach. *Design Computing and Cognition 14*, 607–624. doi: 10.1007/978-3-319-14956-1_34
Paper

4. Linsey, J. S., Markman, A. B., & Wood, K. L. (2012). Design by Analogy: A Study of the WordTree Method for Problem Re-Representation. *Journal of Mechanical Design, 134*(4). doi: 10.1115/1.4006145
Paper

5. Daly, S. R., Yilmaz, S., Christian, J. L., Seifert, C. M., & Gonzalez, R. (2012). Design Heuristics in Engineering Concept Generation. *Journal of Engineering Education, 101*(4), 601–629. doi: 10.1002/j.2168-9830.2012.tb01121.x
Paper

6. Hey, J., Linsey, J., Agogino, A. M., & Wood, K. L. (2008). Analogies and Metaphors in Creative Design. *International Journal of Engineering Education, 24*(2), 283–294.
Paper

7. Analogous Inspiration. (n.d.). *Design Kit*. https://www.designkit.org/methods/6
Web Article

8. Linsey, J. S., Wood, K. L., & Markman, A. B. (2008). Modality and Representation in Analogy. *AI EDAM, 22*(2), 85–100. doi: 10.1017/s0890060408000061
Paper

9. Altshuller, G., O, P. A., & Goguel , O. (2014). TRIZ Matrix / 40 Principles / TRIZ contradictions table. *Triz40*. http://www.triz40.com/
Resources

10. Vercruysse, S. (2010). *WordVis*, the visual dictionary. WordVis. http://wordvis.com/
Resources

11. Benyus , J., & Schwan , B. (2008). *AskNature*. https://asknature.org/
Resources

12. Regazzoni D., Pezzotta G., Persico S., Cavalieri S., Rizzi C. (2013) Integration of TRIZ Problem Solving Tools in a Product-Service Engineering Process. In: Shimomura Y., Kimita K. (eds) The Philosopher's Stone for Sustainability. Springer, Berlin, Heidelberg
Paper

13. Moreno, D. P., Hernández, A. A., Yang, M. C., Otto, K. N., Hölttä-Otto, K., Linsey, J. S., ... Linden, A. (2014). Fundamental Studies in Design-by-Analogy: A Focus on Domain-Knowledge Experts and Applications to Transactional Design Problems. *Design Studies, 35*(3), 232–272. doi: 10.1016/j.destud.2013.11.002
Paper

14. High Speed Train Inspired by the Kingfisher. (n.d.). *AskNature*. https://asknature.org/idea/shinkansen-train/
Web Article

15. Moreno, D. P., Yang, M. C., & Wood, K. L. (2014). Design Creativity for Every Design Problem: A Design-by-Analogy Approach. Design Computing and Cognition DCC'14. JS Gero (Ed.).
Paper

C-sketch (3-6-5)

1. Shah, J. J., Vargas-Hernandez, N., Summers, J. D., & Kulkarni, S. (2001). Collaborative Sketching (C-Sketch) - An Idea Generation Technique for Engineering Design. *The Journal of Creative Behavior, 35*(3), 168–198. doi: 10.1002/j.2162-6057.2001.tb01045.x
Paper

2. Linsey, J. S., Clauss, E. F., Kurtoglu, T., Murphy, J. T., Wood, K. L., & Markman, A. B. (2011). An Experimental Study of Group Idea Generation Techniques: Understanding the Roles of Idea Representation and Viewing Methods. *Journal of Mechanical Design, 133*(3). doi: 10.1115/1.4003498
Paper

3. Otto, K. N., & Wood, K. L. (2001). *Product Design Techniques in Reverse Engineering and New Product Development*. Prentice Hall.
Book

4. Tversky, B., & Suwa, M. (2009). Thinking with Sketches. In A. B. Markman & K. L. Wood (Eds.), *Tools for Innovation: The Science Behind The Practical Methods That Drive New Ideas* (pp. 75-84). Oxford University Press.
Book

Real-Win-Worth

1. Day, G. (2007, December). Is It Real? Can We Win? Is It Worth Doing?: Managing Risk and Reward in an Innovation Portfolio. *Harvard Business Review*. https://hbr.org/2007/12/is-it-real-can-we-win-is-it-worth-doing-managing-risk-and-reward-in-an-innovation-portfolio
Web Article

2. Ulrich, K. T., & Eppinger, S. D. (2012). *Concept selection. Product Design and Development* (5th ed.). McGraw-Hill/Irwin, 1, 145-161.
Book

Rip & Rap

1. Bicks, B. (2016, January 27). 10 Ideation Techniques And Methods. https://www.coursehero.com/file/23303240/ideation-technique/
Resources

Mashup

1. Ideation Method: Mash-Up. (n.d.). *IDEOU*. https://www.ideou.com/pages/ideation-method-mash-up
Resources

SCAMPER

1. Eberle, B. (1996). *Scamper Games for Imagination Development*. Prufrock Press Inc.
Book

2. Moreno, D. P., Hernández, A. A., Yang, M. C., & Wood, K. L. (2014, May 19-22). Creativity in Transactional Design Problems: Non-intuitive Findings of an Expert Study Using Scamper. *International Design Conference: Design 2014*. Dubrovnik, Croatia. http://web.mit.edu/~mcyang/www/papers/2014-morenoEtal.pdf
Paper

3. Chulvi, V., González-Cruz, M. C., Mulet, E., & Aguilar-Zambrano, J. (2013). Influence of the type of idea-generation method on the creativity of solutions. *Research in Engineering Design, 24*(1), 33–41. doi: 10.1007/s00163-012-0134-0
Paper

4. Serrat, O. (2017). *The SCAMPER Technique. In Knowledge Solutions* (pp. 311–314). Springer. doi: 10.1007/978-981-10-0983-9
Book

Morph Matrix

1. Otto, K. N., & Wood, K. L. (2001). *Product Design Techniques in Reverse Engineering and New Product Development*. Prentice Hall.
Book

TRIZ

1. Otto, K. N., & Wood, K. L. (2001). *Product Design Techniques in Reverse Engineering and New Product Development*. Prentice Hall.
Book

Core-periphery Word Cloud

1. He, Y., Camburn, B., Luo, J., Yang, M. C., & Wood, K. L. (2019, July). Visual Sensemaking of Massive Crowdsourced Data for Design Ideation. *In Proceedings of the Design Society International Conference on Engineering Design, 1*(1):409-418. Cambridge University Press.
Paper

Product-Service-System Design (PSS)

1. Vijaykumar, A. V. G., Komoto, H., Hussain, R., Roy, R., Tomiyama, T., Evans, S., ... & Williams, S. (2013). A Manufacturing Framework for Capability-Based Product-Service Systems Design. *Journal of Remanufacturing, 3*(1), 8.
Paper

2. Sakao, T., & Lindahl, M. (Eds.). (2009). *Introduction to Product/Service-System Design*. Springer Science & Business Media.
Book

3. Yoon, B., Kim, S., & Rhee, J. (2012). An Evaluation Method for Designing a New Product-Service System. *Expert Systems with Applications, 39*(3), 3100-3108. https://doi.org/10.1016/j.eswa.2011.08.173
Paper

Paired Comparison Chart

1. Takai, S. (2010). A Game-Theoretic Model of Collaboration in Engineering Design. *Journal of Mechanical Design, 132*(5). doi: 10.1115/1.4001205
Paper

2. Sabater-Grande, G., & Georgantzis, N. (2002). Accounting for risk aversion in repeated prisoners' dilemma games: an experimental test. *Journal of Economic Behavior & Organization, 48*(1), 37–50. doi: 10.1016/s0167-2681(01)00223-2
Paper

3. Pugh, S. (1991). *Total design: integrated methods for successful product engineering*. Addison-Wesley.
Book

Prioritisation Matrix

1. Takai, S. (2010). A Game-Theoretic Model of Collaboration in Engineering Design. *Journal of Mechanical Design, 132*(5). doi: 10.1115/1.4001205
Paper

2. Sabater-Grande, G., & Georgantzis, N. (2002). Accounting for Risk Aversion in Repeated Prisoners' Dilemma Games: An Experimental Test. *Journal of Economic Behavior & Organization, 48*(1), 37–50. doi: 10.1016/s0167-2681(01)00223-2
Paper

3. Pugh, S. (1991). *Total Design: Integrated Methods for Successful Product Engineering*. Addison-Wesley.
Book

4. Gibbons, S. (2018, May 27). Using Prioritization Matrices to Inform UX Decisions. *Nielsen Norman Group*. https://www.nngroup.com/articles/prioritization-matrices/
Web Article

5. Oppong, T. (2017, August 21). The Eisenhower Method For Taking Action (How to Distinguish Between Urgent and Important Tasks). *Thrive Global*. https://community.thriveglobal.com/the-eisenhower-method-for-taking-action-how-to-distinguish-between-urgent-and-important-tasks/
Web Article

Pugh Chart

1. Pugh, S. (1991). *Total Design: Integrated Methods for Successful Product Engineering*. Addison-Wesley.
Book

2. Ulrich, K. T., & Eppinger, S. D. (2016). Product Specifications. *In Product Design and Development* (pp. 91-116). McGraw-Hill Education.
Book

Develop

3. Otto, K. N., & Wood, K. L. (2001). *Product Design: Techniques in Reverse Engineering and New Product Development*. Prentice Hall.
Book

4. Pugh, S. (1991). *Total Design: Integrated Methods for Successful Product Engineering*. Addison-Wesley.
Book

SWOT Analysis

1. Kenton, W. (2022, August 10). SWOT Analysis: How To With Table and Example. *Investopedia*. https://www.investopedia.com/terms/s/swot.asp
Web Article

2. Mind Tools Content Team. (n.d.). SWOT Analysis. *Mind Tools*. https://www.mindtools.com/pages/article/newTMC_05.htm
Web Article

3. Levine, D. (2016, April 21). Hacking the SWOT Analysis. *Medium; Digital Experience Design*. https://medium.com/digital-experience-design/hacking-the-swot-analysis-61746815e189
Web Article

4. Jackson, T. (n.d.). What Is A SWOT Analysis? A Thorough Explanation With Examples. *ClearPoint Strategy*. https://www.clearpointstrategy.com/swot-analysis-examples/
Web Article

5. Parsons, N. (2021). What Is a SWOT Analysis, and How to Do It Right (With Examples). *LivePlan*. https://www.liveplan.com/blog/what-is-a-swot-analysis-and-how-to-do-it-right-with-examples/
Web Article

Adjacency Diagram

1. Adjacency Matrix Decoded. (2017, February 7). *carolyndaut.com*. https://carolyndaut.com/2017/02/07/adjacency-matrix-decoded/
Web Article

2. Davis, B. (2010, March 31). spatial adjacencies. *DAB510:ARCHITECTURAL_DESIGN_5 BEAU DAVIS*. https://beaudavis510.blogspot.com/2010/03/spatial-adjacencies.html
Web Article

3. Watts, S. (2022). Bubble Diagrams in Architecture & Interior Design. *Study.com*. https://study.com/academy/lesson/bubble-diagrams-in-architecture-interior-design.html
Web Article

Design Optimisation

1. Papalambros, P.Y., Wilde, D.J., 2017. *Principles of Optimal Design: Modeling and Computation*, 3rd ed. Cambridge University Press.
Book

2. Bayrak, A.E., Collopy, A.X., Papalambros, P.Y., Epureanu, B.I., 2018. Multiobjective Optimization of Modular Design Concepts for a Collection of Interacting Systems. *Struct Multidisc Optim 57*, 83–94. https://doi.org/10.1007/s00158-017-1872-4
Paper

3. Gero, J.S. (Ed.), 1985. *Design Optimization (Notes and Reports in Mathematics in Science and Engineering, V. 1)*. Academic Press.
Book

Deliver

Prototyping Canvas

1. "Lauff, C., Menold, J., & Small, M. (2016). Two design cases exploring development of social emotional learning solutions. In S. F. Fokkinga, H. van Zuthem, G. D. S. Ludden, N. Cila, & P. M. A. Desmet (Eds.), Proceedings - D and E 2016: 10th International Conference on Design and Emotion - Celebration and Contemplation (pp. 503-507). (Proceedings - D and E 2016: 10th International Conference on Design and Emotion - Celebration and Contemplation). Universidad de los Andes.
Paper

2. Lauff, C., Menold, J., & Wood, K. L. (2019). Prototyping Canvas: Design Tool for Planning Purposeful Prototypes. *Proceedings of the Design Society: International Conference on Engineering Design, 1*(1), 1563–1572. doi: 10.1017/dsi.2019.162
Paper

3. Camburn, B., Dunlap, B., Gurjar, T., Hamon, C., Green, M., Jensen, D., ... Wood, K.L. (2015). A Systematic Method for Design Prototyping. *Journal of Mechanical Design, 137*(8). doi: 10.1115/1.4030331
Paper

4. Camburn, B., & Wood, K.L. (2018). Principles of maker and DIY fabrication: Enabling design prototypes at low cost. *Design Studies*, 58, 63–88. doi: 10.1016/j.destud.2018.04.002
Paper

5. Tiong, E., Seow, O., Camburn, B., Teo, K., Silva, A., Wood, K. L., ... Yang, M. C. (2019). The Economies and Dimensionality of Design Prototyping: Value, Time, Cost, and Fidelity. *Journal of Mechanical Design, 141*(3). doi: 10.1115/1.4042337
Paper

Storyboarding

1. Otto, K. N., & Wood, K. L. (2001). P*roduct Design Techniques in Reverse Engineering and New Product Development*. Prentice Hall.
Book

Wireframing

1. Manandhar, I. (2018, June 29). Introduction to Wireframing and its Principles. *Medium; theuxblog.com*. https://medium.theuxblog.com/introduction-to-wireframing-and-its-principles-a43b19f97807
Web Article

2. Murphy, C. (2018, March 1). A Comprehensive Guide To Wireframing And Prototyping. *Smashing Magazine*. https://www.smashingmagazine.com/2018/03/guide-wireframing-prototyping/
Web Article

3. What is wireframing? (2015). *Experience UX*. https://www.experienceux.co.uk/faqs/what-is-wireframing/
Web Article

4. Jia, G. (2017, August 11). Prototype Design: What is a Wireframe, and What is a Prototype?. *Mockplus.Com*. https://www.mockplus.com/blog/post/what-is-a-wireframe-what-is-a-prototype
Web Article

5. Babich, N. (2017, October 30). Wireframe. *InVisionApp*. https://www.invisionapp.com/defined/wireframes
Web Article

6. Low Fidelity Wireframes vs High Fidelity Wireframes. (2018, May 08). *MentorMate Inc*. https://mentormate.com/blog/low-fidelity-wireframes-vs-high-fidelity-wireframes/
Web Article

Physical Model

1. Otto, K. N., & Wood, K. L. (2001). *Product Design: Techniques in Reverse Engineering and New Product Development*. Prentice Hall.
Book

Wizard-of-Oz

1. Dam, R. F., & Teo, Y. S. (2022). 5 Common Low-Fidelity Prototypes and Their Best Practices. *Interaction Design Foundation*. https://www.interaction-design.org/literature/article/prototyping-learn-eight-common-methods-and-best-practices
Web Article

Deliver

2. Geison, C. (2019, August 20). What in the UX is "Wizard of Oz Testing"? *AnswerLab*. https://www.answerlab.com/insights/wizard-of-oz-testing
   Web Article

3. TED-Ed. (2013, January 23). *Rapid prototyping Google Glass - Tom Chi* [Video]. YouTube. https://www.youtube.com/watch?v=d5_h1VuwD6g
   Video

Mockups (Paper Prototypes)

1. Otto, K. N., & Wood, K. L. (2001). *Product Design: Techniques in Reverse Engineering and New Product Development*. Prentice Hall.
   Book

2. Camburn, B., Viswanathan, V., Linsey, J., Anderson, D., Jensen, D., Crawford, R., ... Wood, K.L. (2017). Design Prototyping Methods: State of the Art in Strategies, Techniques, and Guidelines. *Design Science, 3*. doi: 10.1017/dsj.2017.10
   Paper

3. Camburn, B., Dunlap, B., Gurjar, T., Hamon, C., Green, M., Jensen, D., ... Wood, K. (2015). A Systematic Method for Design Prototyping. *Journal of Mechanical Design, 137*(8). doi: 10.1115/1.4030331
   Paper

Scaled Model

1. Dutson, A. J., & Wood, K. L. (2005). Using Rapid Prototypes for Functional Evaluation of Evolutionary Product Designs. *Rapid Prototyping Journal, 11*(3), 125–131. doi: 10.1108/13552540510601246
   Paper

2. White, F. M. (2011). *Dimensional Analysis and Similarity. In Fluid Mechanics* (7th ed., pp. 293–346). McGraw-Hill Education.
   Book

3. Cho, U., Dutson, A. J., Wood, K. L., & Crawford, R. H. (2005). An Advanced Method to Correlate Scale Models With Distorted Configurations. *Journal of Mechanical Design, 127*(1), 78–85. doi: 10.1115/1.1825044
   Paper

4. Cho, U., Wood, K. L., & Crawford, R. H. (1998). Online Functional Testing with Rapid Prototypes: A Novel Empirical Similarity Method. *Rapid Prototyping Journal, 4*(3), 128–138. doi: 10.1108/13552549810223000
   Paper

5. Otto, K. N., & Wood, K. L. (2001). *Product Design: Techniques in Reverse Engineering and New Product Development*. Prentice Hall.
   Book

Isolated Subsystem Model

1. Camburn, B., Dunlap, B., Gurjar, T., Hamon, C., Green, M., Jensen, D., ... & Wood, K. (2015). A Systematic Method for Design Prototyping. *Journal of Mechanical Design, 137*(8).
   Paper

Business Model Canvas

1. Osterwalder, A., & Pigneur, Y. (2010). *Business model canvas*. Self published.
   Book

DI Pitching

1. Caya. (2022, December 6). 35+ Best Pitch Deck Examples from Successful Startups like Airbnb, Uber, Tesla + FREE Templates. *Slidebean Inc*. https://slidebean.com/blog/startups-pitch-deck-examples
   Web Article

Feedback Capture Matrix

1. Dam, R. F., & Teo, Y. S. (2022). Test Your Prototypes: How to Gather Feedback and Maximise Learning. *Interaction Design Foundation*. https://www.interaction-design.org/literature/article/test-your-prototypes-how-to-gather-feedback-and-maximise-learning
   Web Article

2. Feedback Grid. (n.d.). *IBM; Enterprise Design Thinking*. https://www.ibm.com/design/thinking/page/toolkit/activity/feedback-grid
   Web Article

Usability Testing

1. Moran, K. (2019, December 1). Usability Testing 101. *Nielsen Norman Group*. https://www.nngroup.com/articles/usability-testing-101/
   Web Article
2. Usability testing: your 101 introduction. (2022, February 2). *hotjar*. https://www.hotjar.com/usability-testing/
   Web Article

3. Mohamed, M. (n.d.). Skyscanner: Usability Study. *Behance; Mohamed, M*. https://www.behance.net/gallery/85070101/Skyscanner-Usability-Study
   Web Article

Finite Element Modeling

1. Zorriassatine, F., Wykes, C., Parkin, R., & Gindy, N. (2003). A Survey of Virtual Prototyping Techniques for Mechanical Product Development. Proceedings of the Institution of Mechanical Engineers, Part B: *Journal of Engineering Manufacture, 217*(4), 513-530.
   Paper

Immersive VR/AR

1. Aviation Virtual. (n.d.). *Aviation Virtual*. https://www.aviationvirtual.com.sg/
   Resources

2. Google LLC. (n.d.). Google Cardboard. App Store; Google LLC. https://apps.apple.com/app/id987962261
   Resources

3. Google LLC. (2022, 13 July). Google Cardboard. Google Play Store; Google. https://play.google.com/store/apps/details?id=com.google.samples.apps.cardboarddemo&hl=en_SG&gl=US
   Resources

4. Augment. (n.d.). Augment - 3D Augmented Reality. https://apps.apple.com/us/app/augment-3d-augmented-reality/id506463171
   Resources

5. Augment. (n.d.). Augment - 3D Augmented Reality. Google Play Store; Augment. https://play.google.com/store/apps/details?id=com.ar.augment
   Resources

6. Tokareva, J. (n.d.).The Difference Between Virtual Reality, Augmented Reality And Mixed Reality. *Forbes; Tokareva, J*. https://www.forbes.com/sites/quora/2018/02/02/the-difference-between-virtual-reality-augmented-reality-and-mixed-reality/?sh=bed203c2d07c
   Web Article

Additive Manufacturing (AM) Principle Design

1. Perez, K. B., Anderson, D. S., & Wood, K. L. (2015,). Crowdsourced Design Principles for Leveraging the Capabilities of Additive Manufacturing. *In The Proceedings of the 20th International Conference on Engineering Design (ICED15)*, Milan.
   Paper

2. Perez, B., Hilburn, S., Jensen, D., & Wood, K. L. (2018). Design principle-based stimuli for improving creativity during ideation. *Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science*, 0954406218809117.
   Paper

3. Perez, K.B., Lauff, C., Camburn, B., and Wood, K.L. (2019). Design Innovation with an Additive Manufacturing Methodology. In *ASME 2019 International Design Engineering Technical Conferences & Computers and Information in Engineering Conference (IDETC/CIE 2019)*, DETC2019-97400, Anaheim Convention Center, Anaheim, USA.
   Paper

4. Lauff, C., Perez, K.B., Camburn, B., and Wood, K.L. (2019). Design Principle Cards: Toolset to Support Innovations with Additive Manufacturing. In *ASME 2019 International Design Engineering Technical Conferences & Computers and Information in Engineering Conference (IDETC/CIE 2019)*, DETC2019- 97231, Anaheim Convention Center, Anaheim, USA.
   Paper

5. Perez, K.B. (2019). Design Innovation with Additive Manufacturing (AM): An AM-centric Design Innovation Process [*PhD Dissertation*]. Singapore University of Technology and Design.
   Paper

Deliver

6. Hwang, D., Lauff, C., Perez, K. B., Camburn, B. A., & Lee, W. K. (2020). Comparing the Impacts of Design Principles for Additive Manufacturing on Student and Experienced Designers. *International Journal of Engineering Education*, 36(6).
Paper

7. Hwang, D., Blake Perez, K., Anderson, D., Jensen, D., Camburn, B., & Wood, K. (2021). Design Principles for Additive Manufacturing: Leveraging Crowdsourced Design Repositories. *Journal of Mechanical Design*, 143(7).
Paper

Desktop Walkthrough

1. Desktop Walkthrough. (n.d.) *TiSSD*. https://www.thisisservicedesigndoing.com/methods/desktop-walkthrough
Web Article

Lifecycle Analysis

1. Telenko, C., O'Rourke, J.M., Seepersad, C.C., Webber, M.E., 2016. A Compilation of Design for Environment Guidelines. *Journal of Mechanical Design vol. 138* no. 3. doi: 10.1115/1.4032095
Paper

2. Wever R., Vogtländer J. (2014) Design for the Value of Sustainability. In: van den Hoven J., Vermaas P., van de Poel I. (eds) Handbook of Ethics, Values, and Technological Design. Springer, Dordrecht. doi: 10.1007/978-94-007-6994-6_20-1
Paper

Design of Experiments

1. *NIST/SEMATECH e-Handbook of Statistical Methods, Chapter 5: Process Improvement*. doi: 10.18434/M32189
Book

2. Design of Experiments. (n.d.). *JMP Statistical Discovery LLC*. https://www.jmp.com/en_ph/statistics-knowledge-portal/what-is-design-of-experiments.html
Web Article

3. Otto, K. N. and Wood, K. L. (2001). *Product Design: Techniques in Reverse Engineering, Systematic Design, and New Product Development*, Chapter 18, Prentice-Hall, NJ.
Book

Icons

4. Dando. (2018). *Character* (boy) [Icon]. The Noun Project. https://thenounproject.com/icon/character-1668804

5. Dando. (2018). *Character* (girl) [Icon]. The Noun Project. https://thenounproject.com/icon/character-1668808

6. Jackvisual assets. (2022). *rim* [Icon]. The Noun Project. https://thenounproject.com/icon/rim-5172889

7. Jackvisual assets. (2022). *tire* [Icon]. The Noun Project. https://thenounproject.com/icon/tire-5172891

8. Bernd Lakenbrink. (2022). *Bike* [Icon]. The Noun Project. https://thenounproject.com/icon/bike-4730647

9. Bernd Lakenbrink. (2022). *Car* [Icon]. The Noun Project. https://thenounproject.com/icon/car-4612505

10. Berkah Icon. (2020). *Food Delivery* [Icon]. The Noun Project. https://thenounproject.com/icon/food-delivery-4093324

11. Berkah Icon. (2020). *Parachute* [Icon]. The Noun Project. https://thenounproject.com/icon/parachute-4093483

General

1. Ahmed, P. K. (1998). Culture and Climate for Innovation. *European Journal of Innovation Management, 1*(1), 30–43. doi: 10.1108/14601069810199131
Paper

2. Arteaga, R., & Hyland, J. (2013). *Pivot: How Top Entrepreneurs Adapt and Change Course to Find Ultimate Succe*. John Wiley & Sons.
Book

3. Blank, S. (2013, May). Why the Lean Start-Up Changes Everything. *Harvard Business Review*. https://hbr.org/2013/05/why-the-lean-start-up-changes-everything
Web Article

4. Brown, T. (2008, June). *Design Thinking*. https://hbr.org/2008/06/design-thinking
Web Article

5. Brown, T., & Katz, B. (2011). Change by Design. *Journal of Product Innovation Management, 28*(3), 381–383. doi: 10.1111/j.1540-5885.2011.00806.x
Paper

6. Brown, T., & Wyatt, J. (2010). Design Thinking for Social Innovation. *Development Outreach, 12*(1), 29–43. doi: 10.1596/1020-797x_12_1_29
Paper

7. Buchanan, R. (1992). Wicked Problems in Design Thinking. *Design Issues, 8*(2), 5–21. doi: 10.2307/1511637
Paper

8. Camburn, B. L., Mignone, P. L., Arlitt, R. L., Venkataraman, S. L., & Wood, K. L. (2016). Design and Maker-Based Learning: From Known Knowledge to Creating New Knowledge. The Exchange. Ministry of Education (MOE), Singapore, (2), 3-16.
Paper

9. Catmull, E. E., & Wallace, A. (2014). *Creativity, Inc.: Overcoming the Unseen Forces that Stand in the Way of True Inspiration*. Random House.
Book

10. Chesbrough, H. (2010). Business Model Innovation: Opportunities and Barriers. *Long Range Planning, 43*(2-3), 354–363. doi: 10.1016/j.lrp.2009.07.010
Paper

11. Christensen, C. M. (2016). *The Innovators Dilemma: When New Technologies Cause Great Firms to Fail*. Harvard Business Review Press.
Book

12. Drucker, P. F. (2002, August). The Discipline of Innovation. *Harvard Business Review*. https://hbr.org/2002/08/the-discipline-of-innovation
Web Article

13. Dyer, J., Hal Gregersen, H., & Christensen, C. M. (2019). *Innovators Dna, Updated, with a New Preface: Mastering the Five Skills of Disruptive Innovators*. Harvard Business Review Press.
Book

14. Dym, C. L., Agogino, A. M., Eris, O., Frey, D. D., & Leifer, L. J. (2005). Engineering Design Thinking, Teaching, and Learning. *Journal of Engineering Education, 94*(1), 103–120. doi: 10.1002/j.2168-9830.2005.tb00832.x
Paper

15. Fu, K. K., Yang, M. C., & Wood, K. L. (2016). Design Principles: Literature Review, Analysis, and Future Directions. *Journal of Mechanical Design, 138*(10). doi: 10.1115/1.4034105
Paper

16. Fu, K., Moreno, D., Yang, M., & Wood, K. L. (2014). Bio-Inspired Design: An Overview Investigating Open Questions From the Broader Field of Design-by-Analogy. *Journal of Mechanical Design, 136*(11). doi: 10.1115/1.4028289
Paper

17. Harman, J. (2014). *The Sharks Paintbrush: Biomimicry and How Nature is Inspiring Innovation*. White Cloud Press.
Book

18. Johansson, F., & Amabile, T. (2017). *The Medici Effect, With a New Preface and Discussion Guide What Elephants and Epidemics Can Teach Us About Innovation*. Harvard Business Review Press.
Book

19. Kelley, T., & Kelley, D. (2013). *Creative Confidence: Unleashing the Creative Potential Within Us All*. Crown Business.
Book

General

20. Kelley, T., & Littman, J. (2001). T*he Art of Innovation: Lessons in Creativity from Ideo, America's Leading Design Firm*. Currency/Doubleday.
Book

21. Knapp, J., Zeratsky, J., & Kowitz, B. (2016). *Sprint: How to Solve Big Problems and Test New Ideas in Just Five Days*. Simon & Schuster Paperbacks.
Book

22. Lehrer, J. (2012). *Imagine: How Creativity Works*. Houghton Mifflin Harcourt.
Book

23. Markman, A. B., & Wood, K. L. (2009). *Tools for Innovation*. Oxford University Press.
Book

24. Norman, D. A. (2013). *The Design of Everyday Things*. Basic Books.
Book

25. OConnor, G. C. (2008). *Grabbing Lightning: Building a Capability for Breakthrough Innovation*. Jossey-Bass.
Book

26. Osterwalder, A., & Pigneur, Y. (2010). Business Model Canvas. Self published.
Resources

27. Osterwalder, A., & Pigneur, Y. (2013). *Business Model Generation A Handbook for Visionaries, Game Changers, and Challengers*. Wiley & Sons.
Book

28. Otto, K. N., & Wood, K. L. (2001). *Product Design Techniques in Reverse Engineering and New Product Development*. Prentice Hall.
Book

29. Pink, D. H. (2012). *A Whole New Mind: Why Right-Brainers Will Rule the Future*. Riverhead Books.
Book

30. Ries, E. (2011). *The Lean Startup: How Today's Entrepreneurs Use Continuous Innovation to Create Radically Successful Business*. Currency.
Book

31. Sng, K. H. E., Raviselvam, S., Anderson, D., Blessing, L. T., Camburn, B., & Wood, K. L. (2017). A Design Case Study: Transferring Design Processes and Prototyping Principles into Industry for Rapid Response and User Impact. DS 87-1 Proceedings of the 21st International Conference on Engineering Design , 1: Resource Sensitive Design, Design Research Applications and Case Studies, Vancouver, Canada, 21-25.08.2017, 349–358.
Paper

32. Stewart, S., Giambalvo, J., Vance, J., Faludi, J., & Hoffenson, S. (2020). A Product Development Approach Advisor for Navigating Common Design Methods, Processes, and Environments. *Designs, 4*(1), 4.
Paper

33. Telenko, C., Wood, K., Otto, K., Elara, M. R., Foong, S., Pey, K. L., ... Frey, D. (2015). Designettes: An Approach to Multidisciplinary Engineering Design Education. *Journal of Mechanical Design, 138*(2). doi: 10.1115/1.4031638
Paper

Images used for quotes

1. Pixabay. (2017). *Light Painting at Night* [Photograph]. Pexels. https://www.pexels.com/photo/light-painting-at-night-327509/

2. Agustin, J. (2019). *Yellow, White and Gray Background* [Photograph]. Pexels. https://www.pexels.com/photo/yellow-white-and-gray-background-2340254/

3. Knight, A. (2019). *High-Angle Photo of Robot* [Photograph]. Pexels. https://www.pexels.com/photo/high-angle-photo-of-robot-2599244/

4. Voortman, S.A. (2017). **Woman Jumping Wearing Green Backpack** [Photograph]. Pexels. https://www.pexels.com/photo/woman-jumping-wearing-green-backpack-214574/

5. Kumtanom, T. (2017). *Black Ball-point Pen With Brown Spiral Notebook* [Photograph]. Pexels. https://www.pexels.com/photo/black-ball-point-pen-with-brown-spiral-notebook-733852/

6. Clark, T. (2016). *Classic Car in Grayscale Photography* [Photograph]. Pexels. https://www.pexels.com/photo/classic-car-in-grayscale-photography-141500/

7. Arenas, J. (2018). *Selective Focus Photography of Child's Hand* [Photograph]. Pexels. https://www.pexels.com/photo/selective-focus-photography-of-child-s-hand-1250452/

8. Navarro, N (nubikini). (2017). *Selective Focus Photography of Yellow School Bus Die-cast* [Photograph]. Pexels. https://www.pexels.com/photo/selective-focus-photography-of-yellow-school-bus-die-cast-386009/

9. Ann H. (2019). *Yellow and Blue Coloured Pencils* [Photograph]. Pexels. https://www.pexels.com/photo/yellow-and-and-blue-colored-pencils-1762851/

10. Johnson, S. (2018). *Multicolored Abstract Painting* [Photograph]. Pexels. https://www.pexels.com/photo/multicolored-abstract-painting-1570779/

11. Plavalaguna, D. (2020). *Close Up Photo of People Holding Puzzle Pieces* [Photograph]. Pexels. https://www.pexels.com/photo/close-up-photo-of-people-holding-puzzle-pieces-6147381/

12. Ungaro, F. (2017). *Blue, Green, Orange and Red Rainbow Design Decoration* [Photograph]. Pexels. https://www.pexels.com/photo/blue-green-orange-and-red-rainbow-design-decoration-673648/

13. Rahul. (2017). *Close Up Photo Off Light Bulb* [Photograph]. Pexels. https://www.pexels.com/photo/close-up-photo-ofg-light-bulb-716398/

14. Karol D. (2017). *Close-up of a Cable Car*[Photograph]. Pexels. https://www.pexels.com/photo/close-up-of-a-cable-car-323645/

15. Ulltang, N. (2017). *Close Up of Blue Paint* [Photograph]. Pexels. https://www.pexels.com/photo/close-up-of-blue-paint-323933/

Citing this handbook

Lauff, C., Wee, Y. H., See, A., Raviselvam, S., Collopy, A., Jensen, D. Teo, K., Png, S., Swee, A. and Wood, K. L. (2023). *Design Innovation Methodology Handbook* (2nd ed.). ISBN: 978-981-19-7593-9. doi: https://doi.org/10.59977/VQPH8086

The DI team is constantly improving our methods and would like to hear from you if you have suggestions!

Let us know your feedback here!
or email us at designinnovation@sutd.edu.sg