Deliver

Iteratively prototype and test concepts and models with users

MINSET

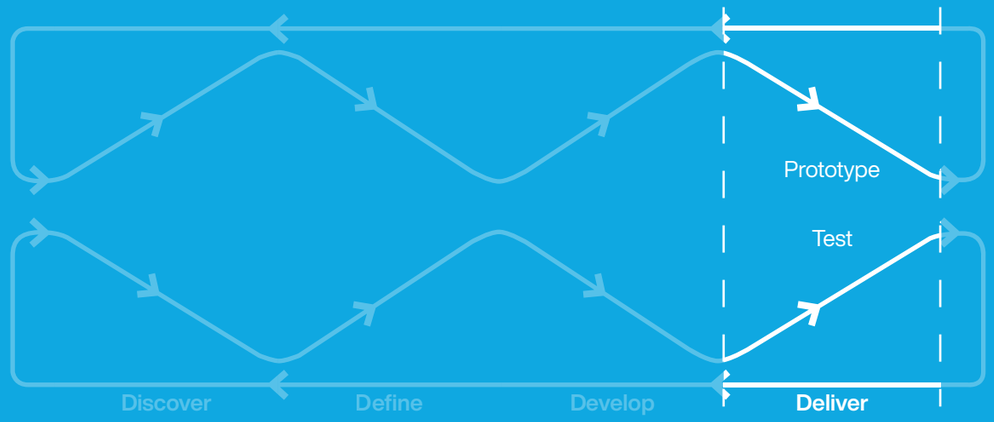
Non-attachment

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.

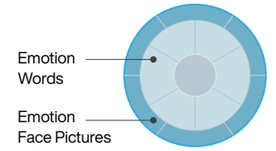
Sketch a Build Plan
10

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

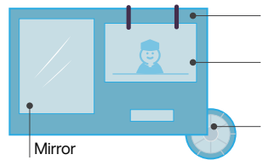


"Spin the wheel and try to align word with emotion"

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

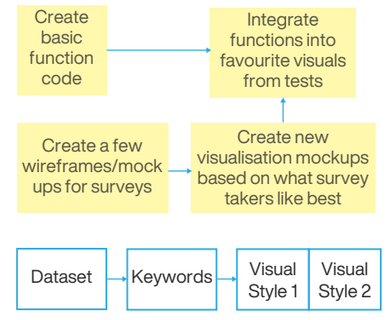
License for survey software; Adobe suite; CSS/Javascript

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

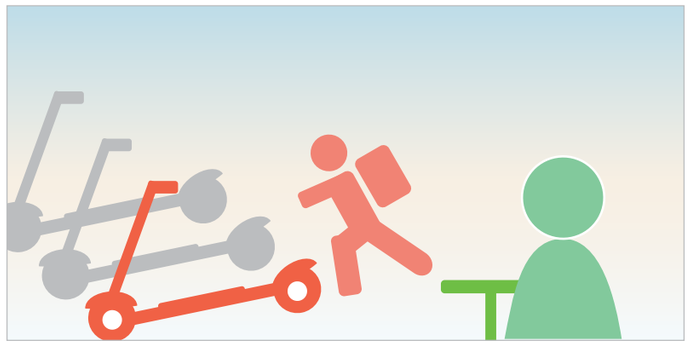
Worked Example

Re-illustrated sketch of a DI team member's Storyboarding sheet

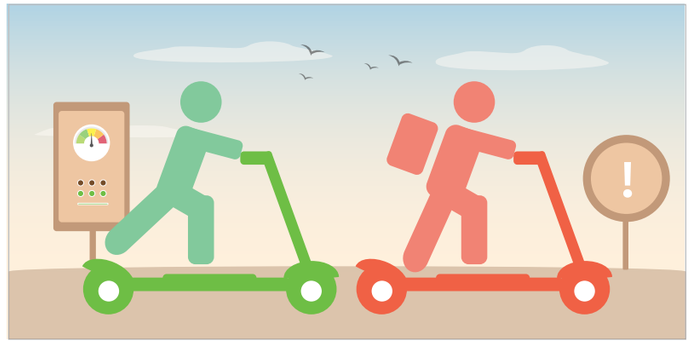
Scenario: Exploring the rail corridoor by scooter

Edmund brings his scooter on the train and alights at the train station.

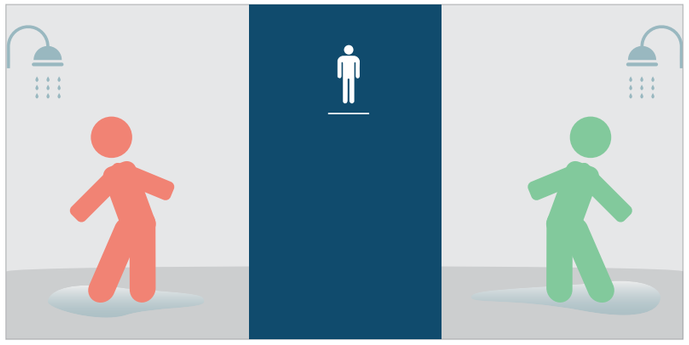
He is early and grabs a coffee while waiting for his friend, Matthew.



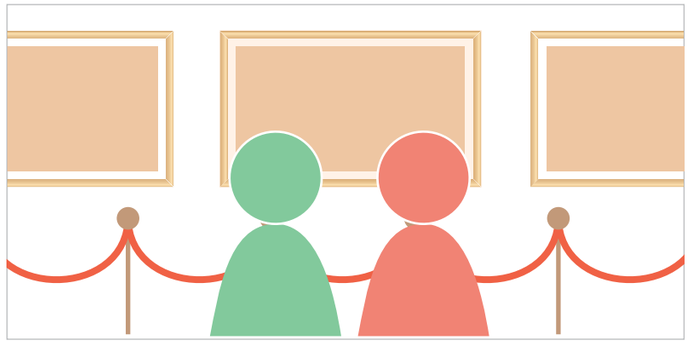
Matthew arrives and rents a scooter at the station.



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

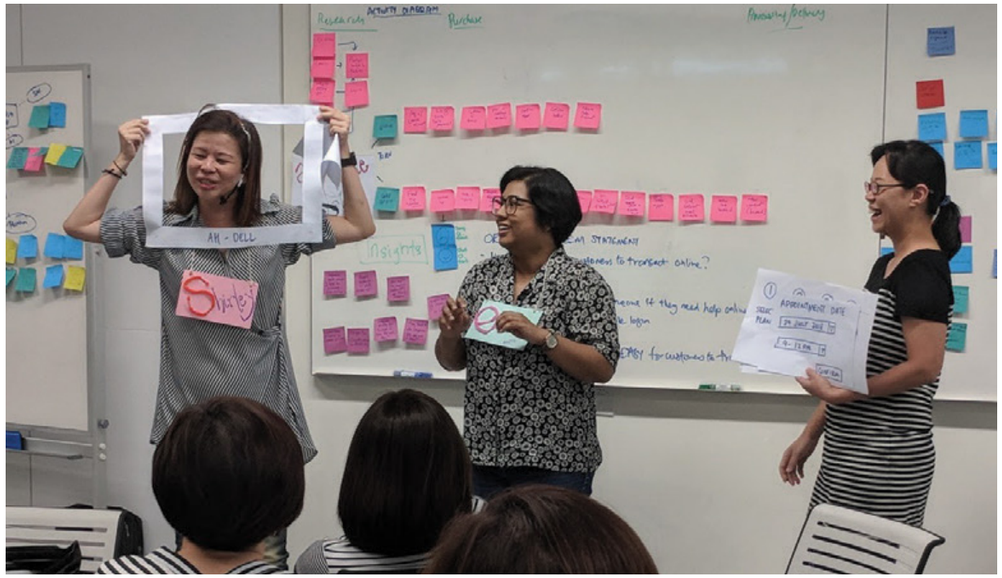
the outcomes, discussing how learnings can be applied.

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

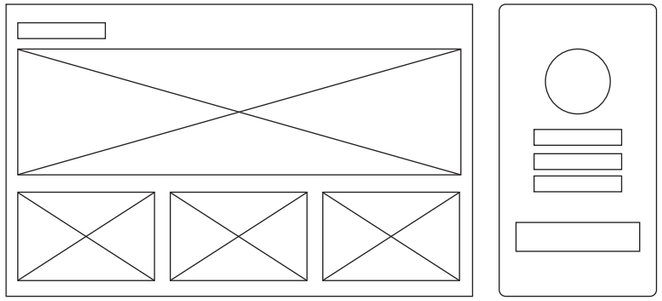
A wireframe is a static, graphical representation of different layouts of an app or website ranging from low to high fidelity.

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

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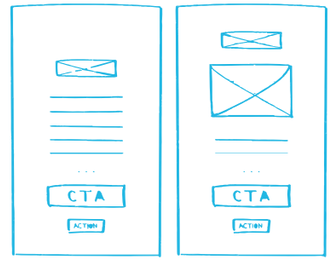
Worked Example

Mobile app (E-commerce)

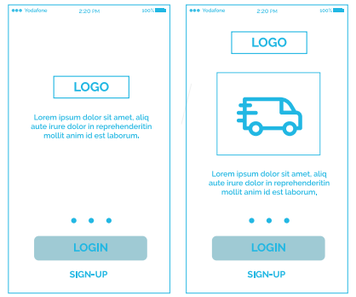
Low Fidelity

- 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.



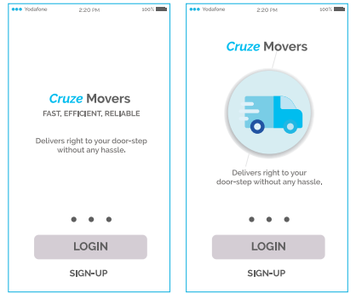
Medium Fidelity

- 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

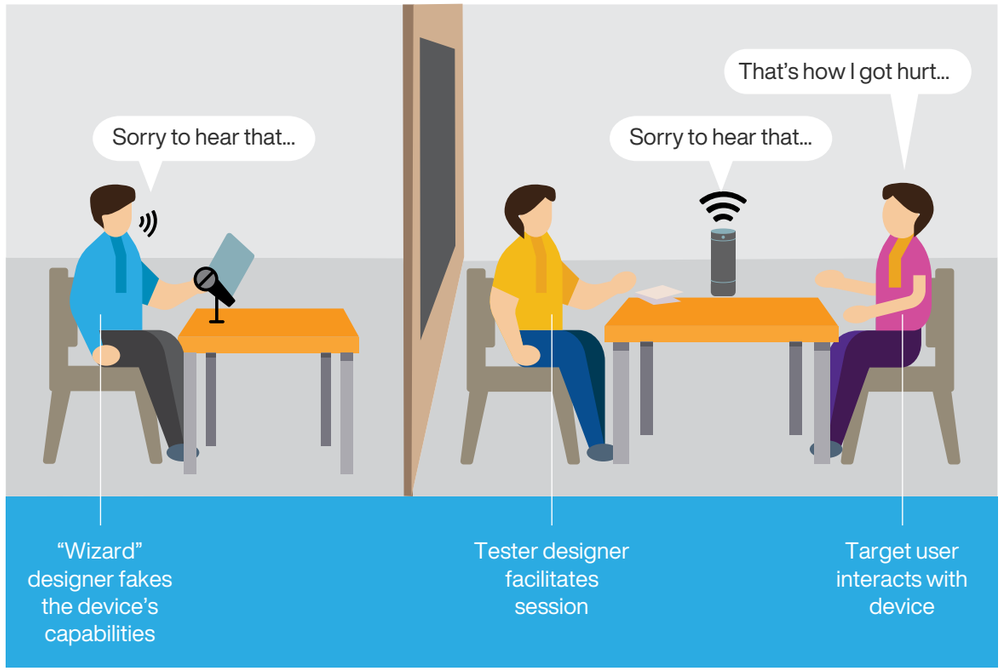
Smart device voice tones

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.



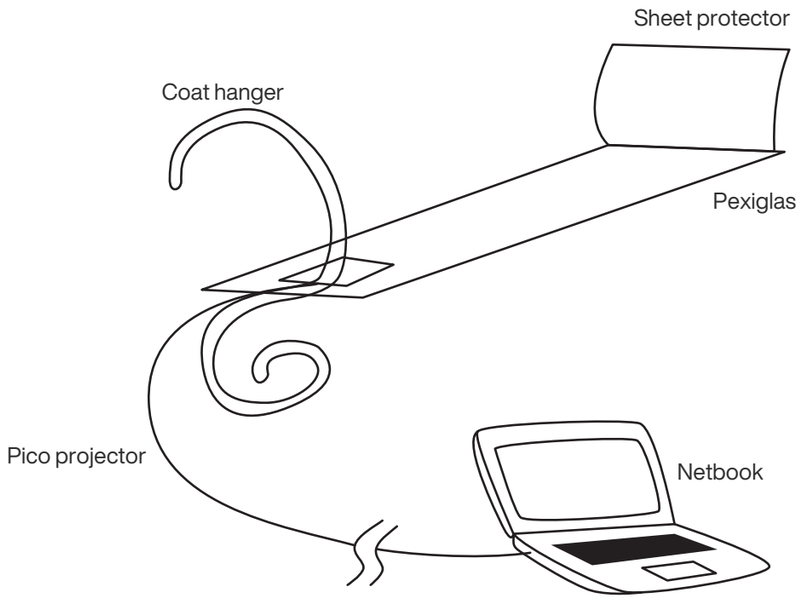
Prototyping of key function (change in tone of voice)

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.

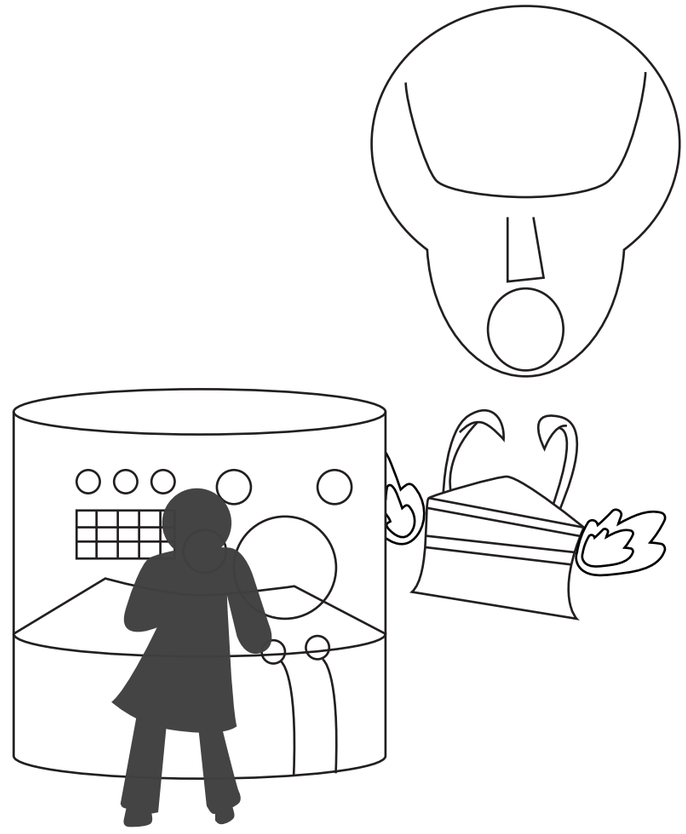


A traceover of the original sketch from Tom Chi

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.

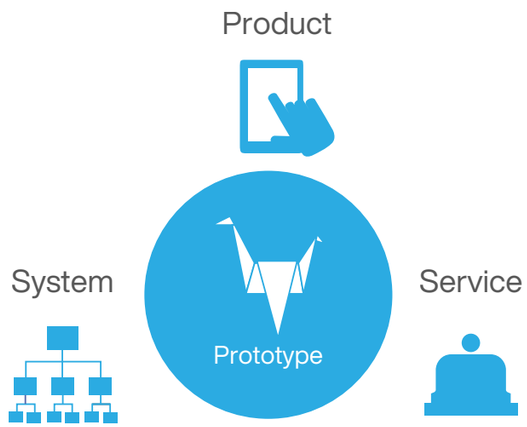
Why: Mockups can be used to identify latent needs of users and to communicate ideas in a short amount of time.

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

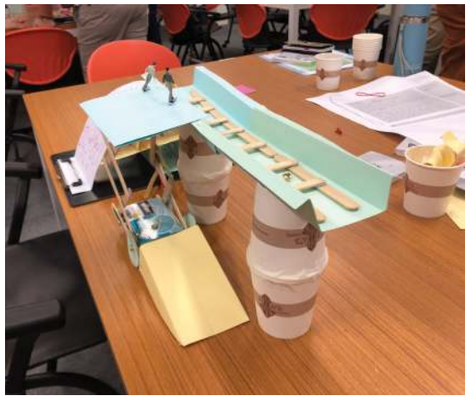
Create mockups that closely resemble the actual PSS by thinking of the crucial functions/features that each part is supposed to represent.

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

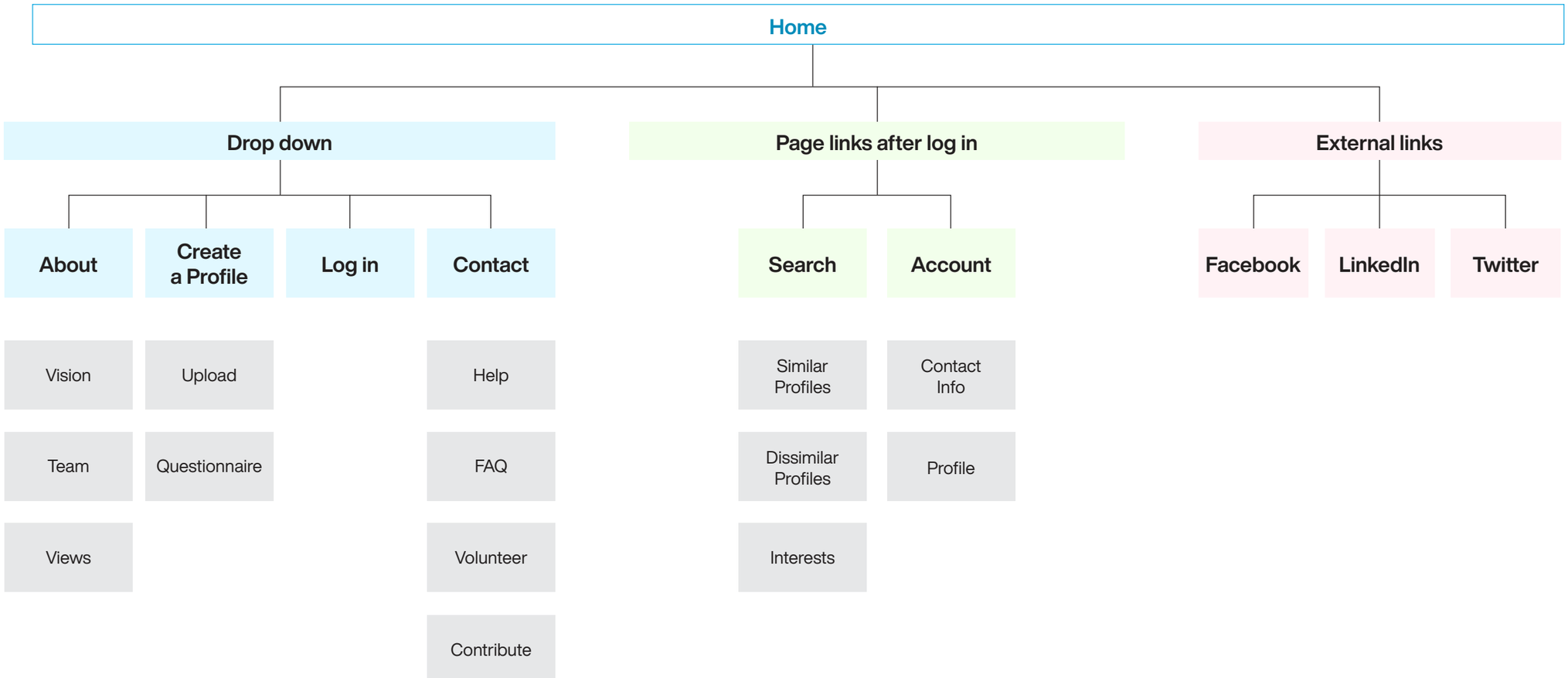


Worked Example 2

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?

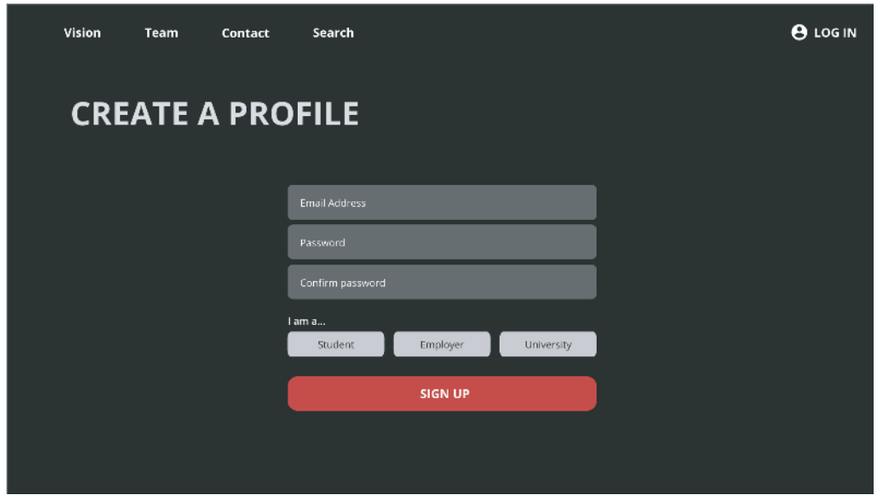


Worked Example 3

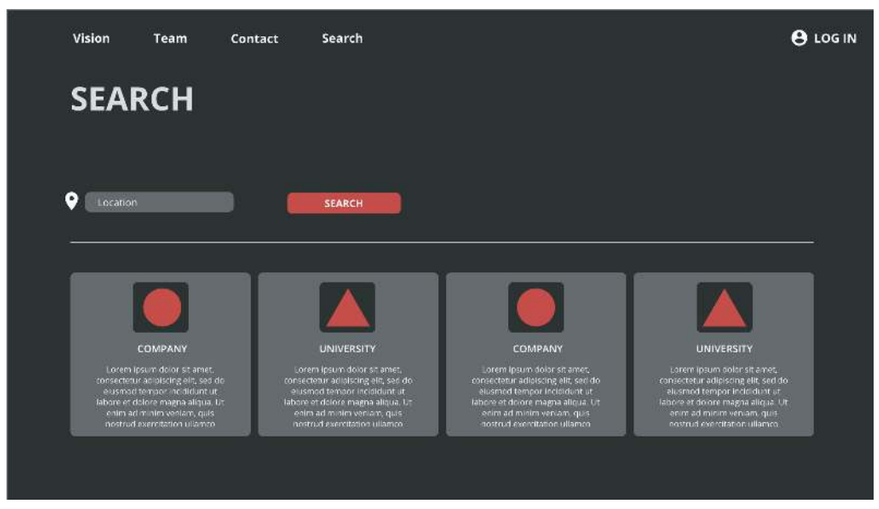
This experience prototype is a basic website that users were encouraged to explore, and their feedback was collected on specific page elements via an online discussion format. The purpose of this experience prototype is to allow users to fully explore a web application on the web, bringing the experience 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.

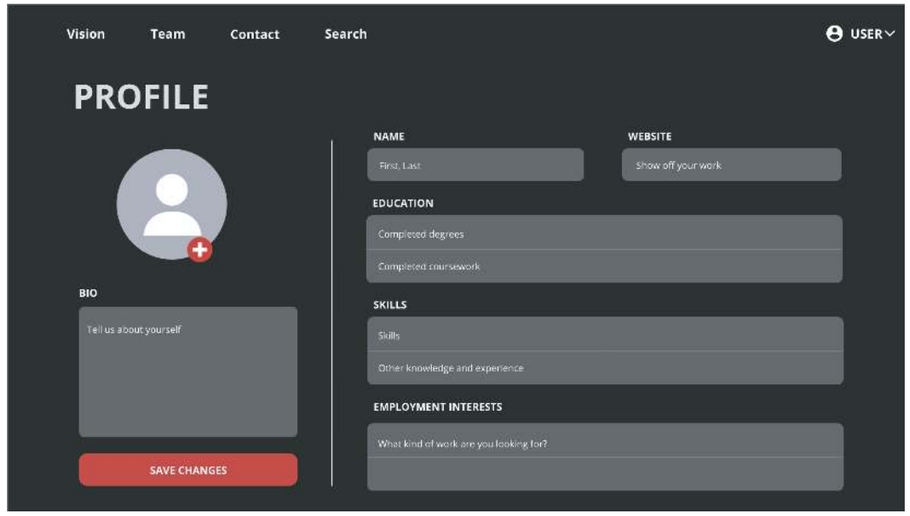
A



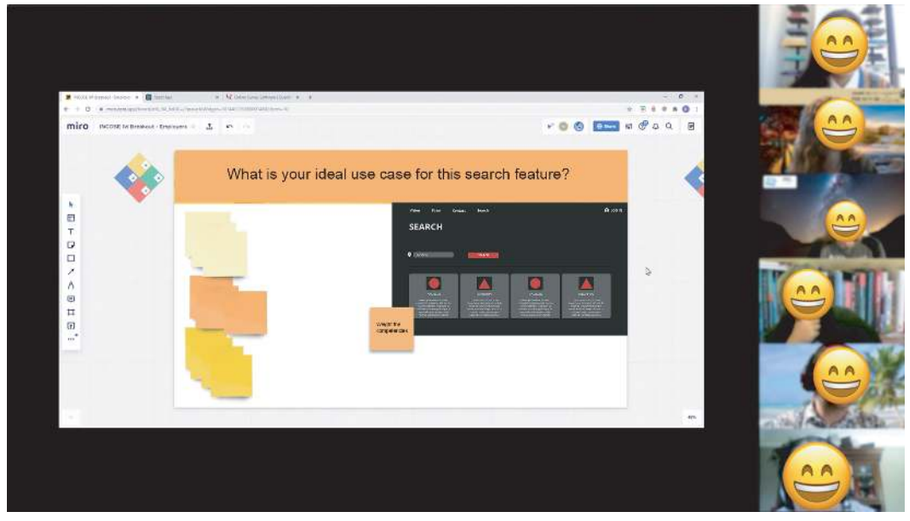
B



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.

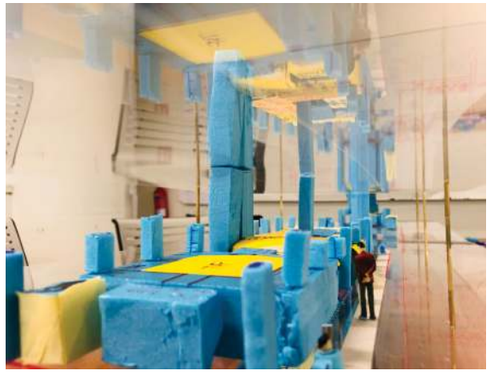
Represent the prototype well[2]

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

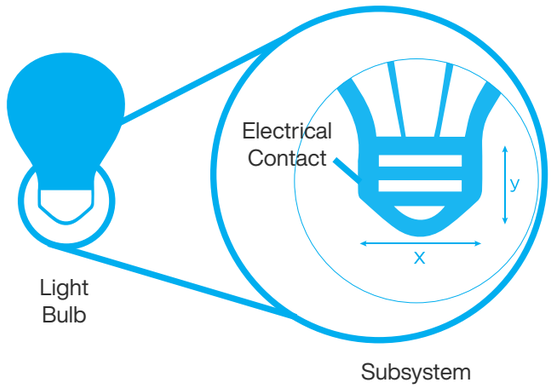
CARD 9 Non-attachment

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.

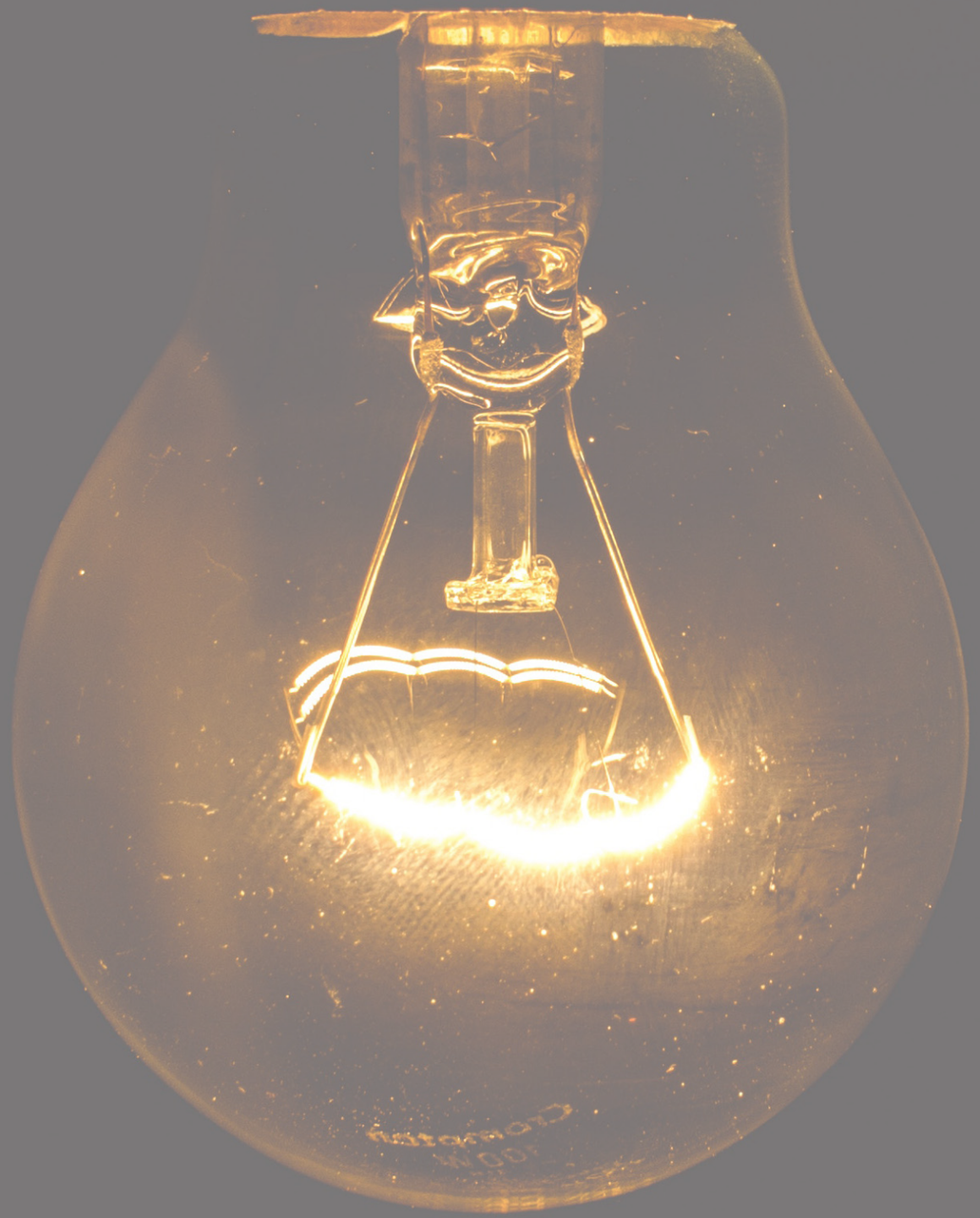
Outcomes

- 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

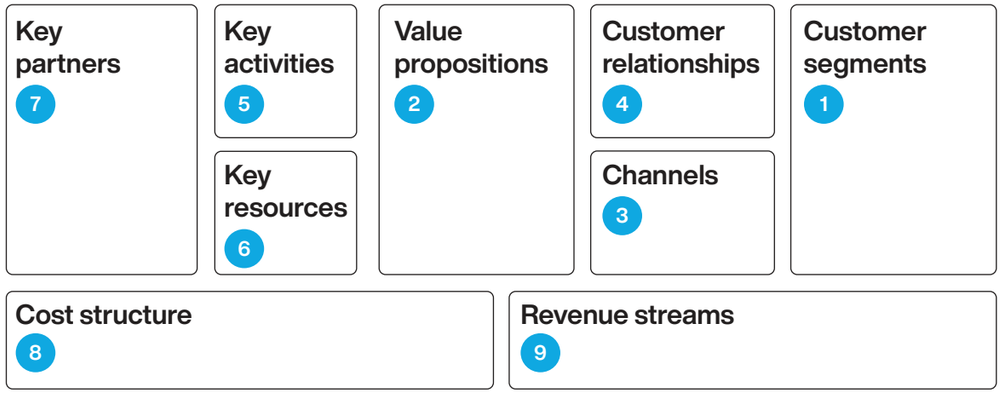
1 **Fill in the canvas**
based on the organisation's current business model.

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.

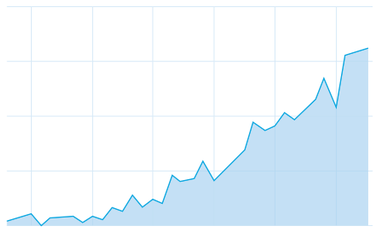
Useful Tip

Use diagrams, videos or illustrations to highlight important information.

Worked Example

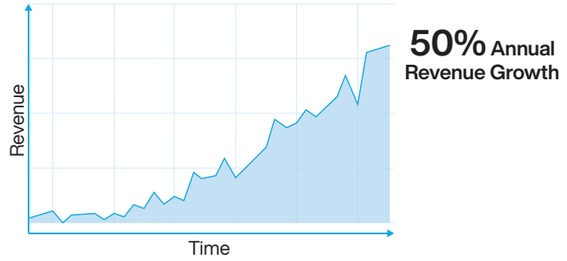
Adding labels to graph

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.

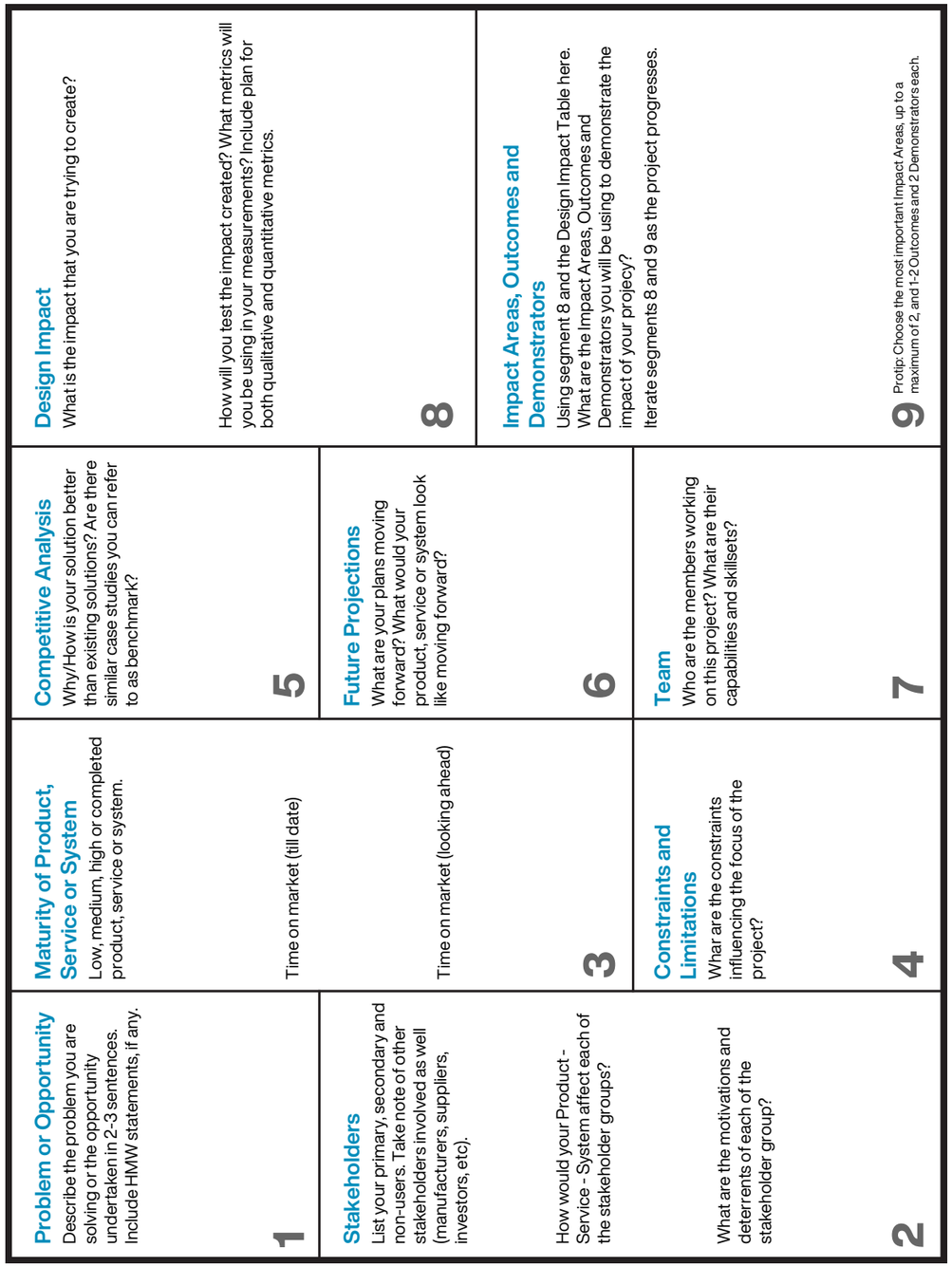
4 Test and Measure, Repeat

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

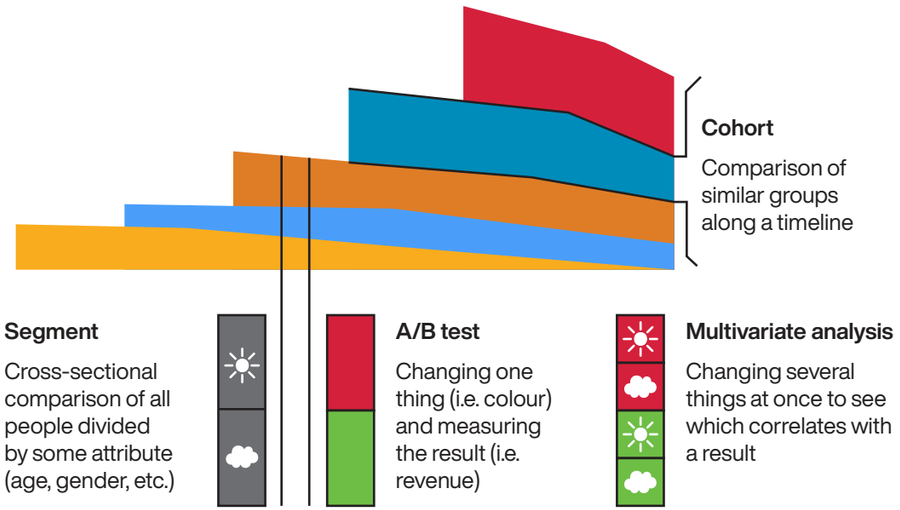
Cohort-based Usability Test, meaning follow a group over a time period, could yield the time-dependent test results.

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.

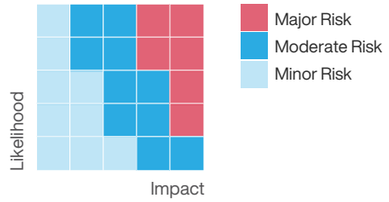
3 Risk mitigation

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**

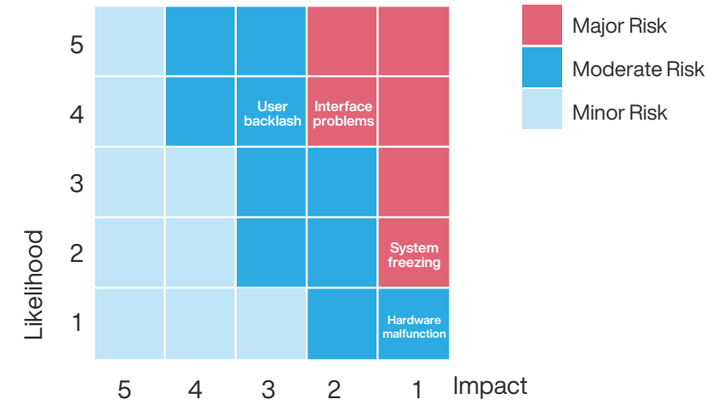


Worked Example

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

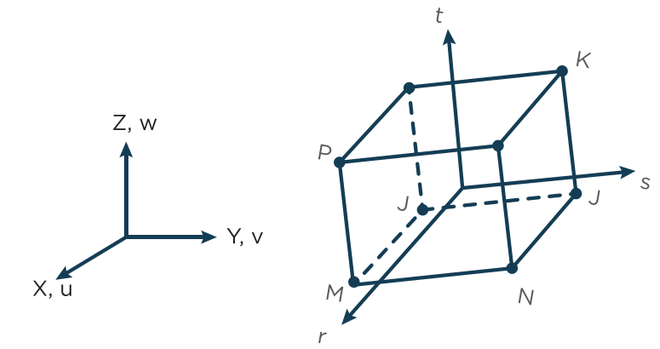
Results across different design concepts.

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

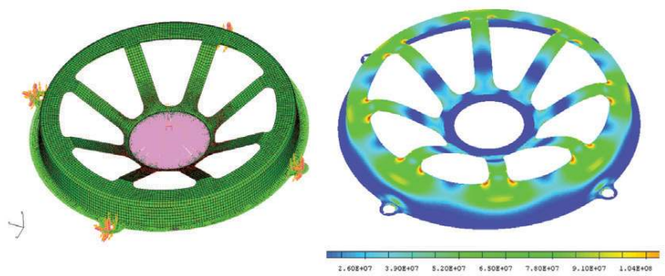


Worked Example

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.

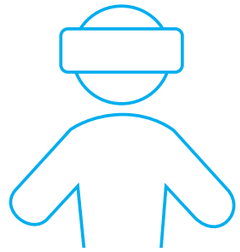
Tools and Apps

VR mobile applications

Cardboard:

Allows you to turn panaromic pictures into VR experiences.

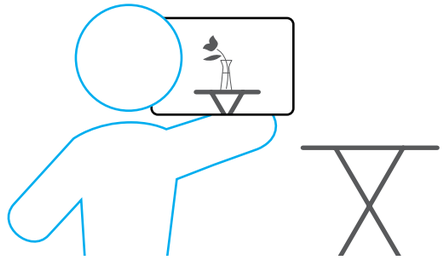
- Take (or upload) a panoramic picture and overlay a voice to describe an experience.
- You can use an already taken panoramic picture and make edits to it in, such as using You Doodle, Sketch, Inkboard, or Let's Draw.
- Idea to paint or draw on the panoramic picture to show the 'prototype experience' 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

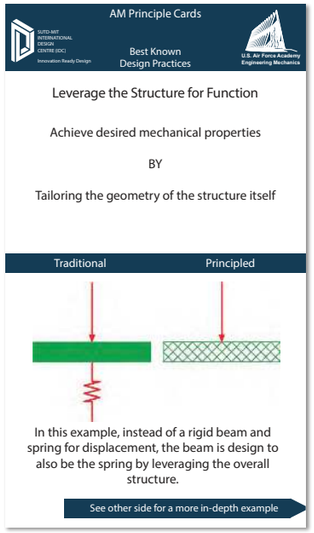
These cards are designed to be used as an education and creativity aid for AM.

Full set of AM Principle Cards can be found here

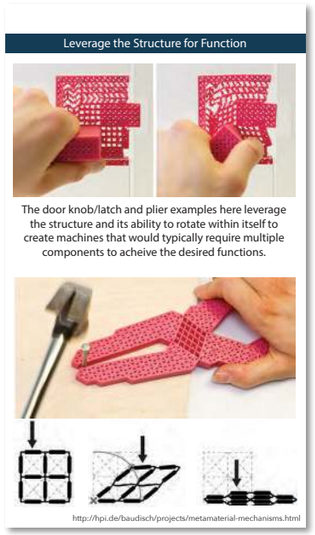
Structure of cards

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

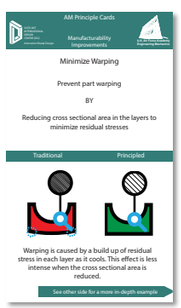
Four categories of AM Principle Cards

Process Capabilities

Red cards

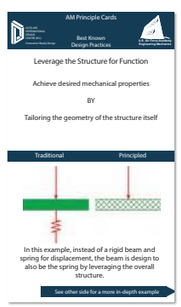
Manufacturability Improvements

Green cards



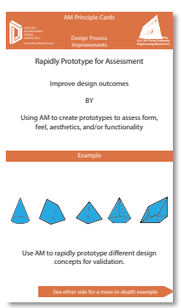
Best Known Design Practices

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

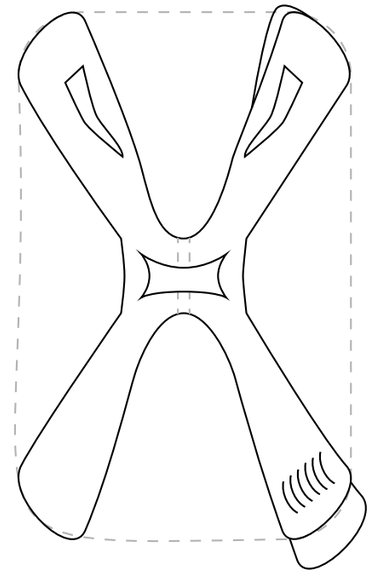
Worked Example with AM Principle Cards

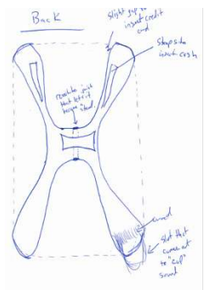
How might we enhance the user-centered capabilities of next generation mobile phones using additive manufacturing, such as charging, viewing, protecting, carrying, listening, talking, and texting?

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

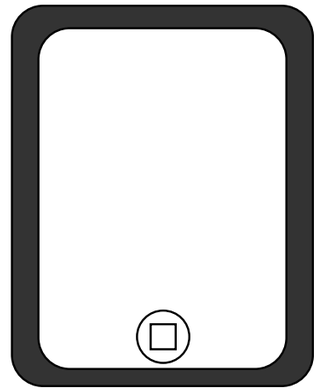


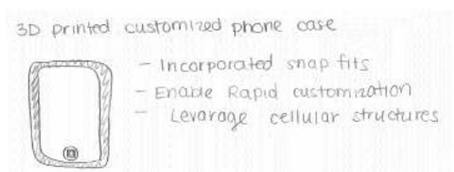


Original sketch

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.

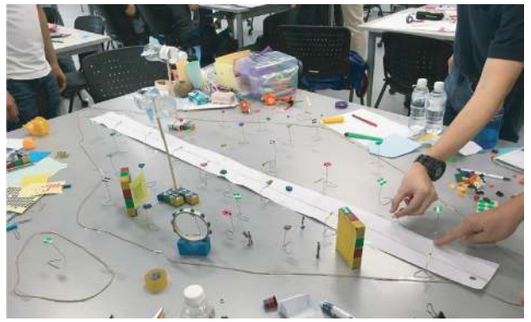
Assign a scribe

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

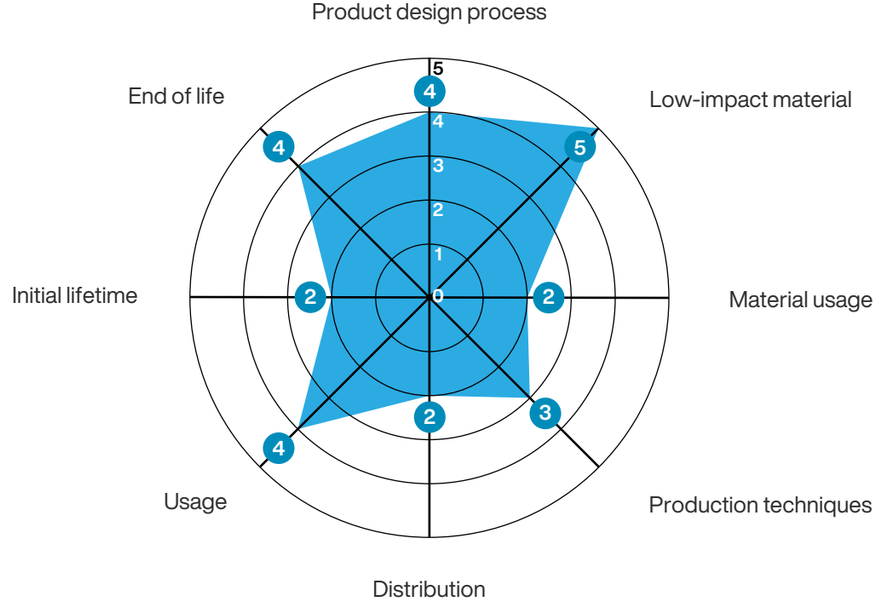
Just because a material or assembly is recyclable doesn't mean it is easy to recycle, or that users will recycle.

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

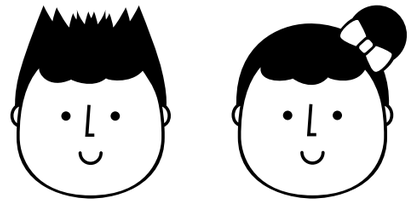
- ANOVA assumptions on distribution
- If your test is experience based, practice your test in advance to not conflate improvement from learning with higher or lower performance of the design

Worked Example 1

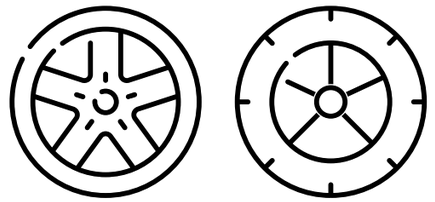
Four different aspects (factors) of a game are represented by the images below: the character, the vehicle, tire, and parachute type. With two options for each aspect, there are 16 different combinations possible, meaning 16 different prototypes are needed to test all combinations. One time playing the 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.

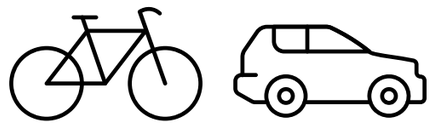
Character



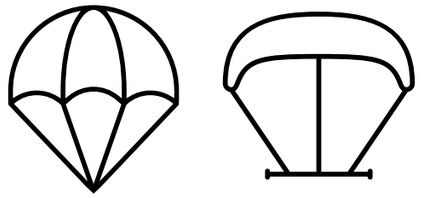
Tire



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.