CRANFIELD UNIVERSITY

KATIE LI

EXAMINING THE USE OF VISUALISATION METHODS FOR THE DESIGN OF INTERACTIVE SYSTEMS

SCHOOL OF AEROSPACE, TRANSPORT AND MANUFACTURING

PhD Thesis
Academic Year: 2015 - 2016

Supervisor: Prof. Ashutosh Tiwari & Dr. Jeffrey Alcock
June 2016

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This thesis is submitted in partial fulfilment of the requirements for the degree of Doctor of Philosophy

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ABSTRACT

Human-Computer Interaction (HCI) design has historically involved people from different fields. Designing HCI systems with people of varying background and expertise can bring different perspectives and ideas, but discipline-specific language and design methods can hinder such collaborations. The application of visualisation methods is a way to overcome these challenges, but to date selection tools tend to focus on a facet of HCI design methods and no research has been attempted to assemble a collection of HCI visualisation methods. To fill this gap, this research seeks to establish an inventory of HCI visualisation methods and identify ways of selecting amongst them. Creating the inventory of HCI methods would enable designers to discover and learn about methods that they may not have used before or be familiar with. Categorising the methods provides a structure for new and experienced designers to determine appropriate methods for their design project.

The aim of this research is to support designers in the development of Human-Computer Interaction (HCI) systems through better selection and application of visualisation methods. This is achieved through four phases. In the first phase, three case studies are conducted to investigate the challenges and obstacles that influence the choice of a design approach in the development of HCI systems. The findings from the three case studies helped to form the design requirements for a visualisation methods selection and application guide. In the second phase, the Guide is developed. The third phase aims to evaluate the Guide. The Guide is employed in the development of a serious training game to demonstrate its applicability. In the fourth phase, a user study was designed to evaluate the serious training game. Through the evaluation of the serious training game, the Guide is validated.

This research has contributed to the knowledge surrounding visualisation tools used in the design of interactive systems. The compilation of HCI visualisation methods establishes an inventory of methods for interaction design. The identification of Selection Approaches brings together the ways in which visualisation methods are organised and grouped. By mapping visualisation methods to Selection Approaches, this study has provided a way for practitioners to select a visualisation method to support their design practice. The development of the Selection Guide provided five filters, which helps designers to identify suitable visualisation methods based on the nature of the design challenge. The development of the Application Guide presented the methodology of each visualisation method in a consistent format. This enables the ease of method comparison and to ensure there is comprehensive information for each method. A user study showing the evaluation of a serious training game is presented. Two learning objectives were identified and mapped to Bloom's Taxonomy to advocate an approach for like-to-like comparison with future studies.

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PUBLICATIONS

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González-Franco, M., Cermeron, J., Li, K., Pizarro, R., Thorn, J., Hannah, P., Hutabarat, W., Tiwari, A. and Bermell-Garcia, P. (2016), Immersive Augmented Reality Training for Complex Manufacturing Scenarios, *Cornell University Library*, abs/1602.0, pp.1–6.

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LIST OF ABBREVIATIONS

AFP	Automated Fibre Processing
CAD	Computer Aided Design
CATIA	Computer Aided Three-Dimensional Interactive Application
CTA	Cognitive Task Analysis
HCI	Human-Computer Interaction
HTA	Hierarchical Task Analysis
HTML	Hyper Text Mark-up Language
IxD	Interaction Design
PM	Paper Manual
PPE	Personal Protective Equipment
SD	Service Design
SDK	Software Development Kit
SEREC	Science and Engineering Research Ethics Committee
SG	Serious Game
SSM	Soft System Methodology

TG	Training Game
UCD	User-Centred Design
UX	User Experience
VARK	Visual, Aural, Read/Write, Kinesthetic
VE	Virtual Environment

1 INTRODUCTION

This chapter provides the introduction to the research. The aim, objectives, and methodology are presented.

1.1 Background

Human-Computer Interaction (HCI) is the study of the relationship between human and computers that takes place through the man-machine interface (Lili and Yanli, 2010). Historically, HCI tended to involved people from different fields. Designing HCI with people of varying background and expertise can bring different perspectives and ideas, but at the same time discipline-specific language and design approaches can hinder such collaborations. The application of visualisation methods is a way to overcome these challenges, but to date selection tools tend to focus on a facet of HCI methods and no research has been attempted to assemble a collection of HCI visualisation methods. There is a need to provide better support for designers in the selection and application of HCI visualisation methods. This research examines the use of visualisation methods for the design of interactive systems and seeks to establish an inventory of HCI visualisation methods and identify ways of selecting amongst them.

1.2 Research Motivation

1.2.1 Parent Innovate UK Project

This thesis is part of an Innovate UK (previously known as Technology Strategy Board) funded parent project (Using Gaming Technology to Digitise Complex Manufacturing Process Knowledge, project reference: 101251, 2012-2015), which is being carried out by Airbus Group, Cranfield University, and Aertec Solutions Limited. The aim of the parent project is to leverage commercial gaming technology to capture and re-use human knowledge in the context of complex manufacturing.

In this project, the author worked with a team of programmers, visual designers, project manager, and subject matter expert, and contributed in the planning, design, and evaluation of four industrial case studies (Chapter 4 and 7).

1.2.2 Problem Statement

Hundreds of HCI design methods exists, but there is little guidance to select amongst them. Current selection tools tend to focus on a facet of HCI design methods and no research has been attempted to assemble a collection of HCI visualisation methods. Furthermore, there is little information on when and how designers would make use of the selection tools.

This research seeks to develop a selection and application guide for visualisation methods that supports design and development of HCI systems. Establishing an inventory of HCI visualisation methods would enable designers to discover and learn about methods that they may not have used before or be familiar with. Categorising the methods provides a structure for new and experienced designers to determine appropriate methods for their design project.

1.3 Research Aim

The aim of this research is to develop a selection and application guide for visualisation methods that supports design and development of HCI systems.

1.4 Research Objectives

The objectives of this research are:

1. To identify the visualisation methods and categorisation approaches used in HCI.
2. To undertake case studies to develop better understanding of how visualisation methods are selected and utilised in the development of HCI systems.
3. To propose a guide for the selection and application of visualisation methods.
4. To apply and validate the proposed guide.

1.5 Thesis Structure

The section presents the structure of the thesis.

Chapter 1

Chapter 1 provides the introduction to the research. The aim, objectives, and methodology are presented.

Chapter 2

Chapter 2 is the literature review of HCI visualisation methods and selection approaches. Visualisation methods and their selection approaches were identified. Based on their description, the visualisation methods are categorised in each approach. The benefits and limits of each selection approach is discussed.

Chapter 3

Chapter 3 details the research methodology.

Chapter 4

Chapter 4 presents three case studies. Case Study I and II investigate the requirements capture activities in the early phases of interaction systems development. Case study III investigates the interaction design of a geocollaborative system. The challenges and design approaches for all three case studies are reported and discussed. The design challenged identified in this chapter are evaluated in Chapter 5, and contributed to the Guide development (Chapter 5 and 6).

Chapter 5

Chapter 5 describes the Selection Guide development, which forms the first part of the proposed Guide. The Selection Guide is created in an HTML-format. The Selection Guide is evaluated using design challenges identified in Chapter 4.

Chapter 6

Chapter 6 describes the Application Guide development, which forms the second part of the proposed approach. The methodology for each visualisation method is compiled based on seven key procedural steps.

Chapter 7

Chapter 7 presents a case study to demonstrate the application of the Selection and Application Guide (developed in Chapter 5 and 6). Design challenges are identified, and visualisation methods are selected and employed using the proposed Guide. The resulting artefacts are presented and discussed. A user study is conducted to evaluate the serious training game to validate the Guide. The learning effectiveness of the game is assessed.

Chapter 8

Chapter 8 presents the findings of this research, highlighting the contribution to knowledge. It discusses the limitations and strengths of the research methodology and recommendations for future work. The final conclusions are provided in this chapter.

2 LITERATURE REVIEW

This chapter is the literature review of HCI visualisation methods and selection approaches. A set of visualisation methods and selection approaches were identified. Based on their description, the visualisation methods are categorised in each approach. The benefits and limits of each selection approach is discussed.

2.1 Introduction

As a discipline, Human-Computer Interaction (HCI) has historically involved people from different fields (Lazar et al., 2010; Wania et al., 2007; Seffah et al., 2005; Carroll, 2003; Adamczyk and Twidale, 2007). Even though designing with people of varying background and expertise can help bring different perspectives together to generate new ideas (Rogers et al., 2011), it can also hinder the collaboration if the team members are restricted by discipline language and design approaches (Haesen et al., 2010; Mendel, 2012). The application of visualisation methods is widely discussed as a way to overcome the challenges of collaborative design (Bryan-Kinns and Hamilton, 2002; Pierce, 2014; Zimmerman et al., 2007).

This thesis adopts the definition of Lengler and Eppler (2007, p.1) and defines a visualisation method as "…a systematic, rule-based, external, permanent, and graphic representation that depicts information in a way that is conducive to acquiring insights, developing an elaborate understanding, or communicating experiences."

The adoption of visualisation methods in design has a number of advantages, including:

- *Visualising something externalises your understanding*
  Externalising internal understanding aids the sharing of knowledge. This is important in two ways. Firstly, the adaptation of physical prototypes and sharable tools within a design team can lead to more successful methods in design (Jang and Schunn, 2012). Secondly, the creation of visual

artefacts acts to elicit information from users, which may otherwise be difficult to capture (Sanders and William, 2003).

- *Visual artefacts help to store mental representations physically*
  Creating a visual artefact helps to relieve a person's working memory (Tversky and Suwa, 2009), therefore improving thinking capacity. Furthermore, the act of visualisation could provoke the creation of new ideas (Fallman, 2003) or refinement of a design (Römer et al., 2001).

- *Visual artefacts can group together relevant information*
  Grouping together relevant information can clarify how ideas and concepts are related (Tversky and Suwa, 2009). This reduces the effort, which would otherwise be required to search for elements to make problem-solving inference (Larkin and Herbert 1987).

The purpose of employing a visualisation method is not simply to create an image or object; the challenge is to provide relevant information that furthers the design process (Houde and Hill, 1997). In fact, creating an artefact which does not assist a designer to communicate or develop their ideas in a useful way is "useless, incomprehensible, confusing, worse than no image at all" (Arnheim 1969). Whether or not relevant information is provided can be affected by the expertise of the designer (Haesen et al., 2009; Self et al., 2014) as well as their awareness and understanding of available design methods (Weevers and van Kuijk, 2012).

As HCI matures, there is an increasing demand to support selection amongst the growing number of design methods (Bryan-Kinns and Hamilton, 2002; Houde and Hill, 1997; Tidball et al., 2010). Current selection tools tend to focus on a facet of HCI methods, such as usability (Usability Net, 2006), UCD (Royal College of Art, n.d.; Weevers and van Kuijk, 2012; Maguire, 2001), and Service Design (Mendel, 2012; Tassi, 2009; Segelström and Holmlid, 2011; Stickdorn and Schneider, 2010; Alves and Nunes, 2013). To date, no research has attempted to assemble a collection of HCI visualisation methods. A rare example of a visual-based selection tool is the periodic table of visualisation method created by Lengler and

Eppler (2007). They compiled over 100 visualisation methods and organised them into a periodic table format. Designers can make a selection based on a number of aspects, such as the complexity of the method and how similar they are to each other. These methods, however, are for management purposes and not HCI design.

To fill this gap, this chapter reviews the categorisation of visualisation methods used in HCI. The author seek to establish an inventory of HCI visualisation methods and identify ways of selecting amongst them. Creating the inventory of HCI methods would enable designers to discover and learn about methods that they may have not used before or be familiar with. Categorising the methods provides a structure for new and experienced designers to determine appropriate methods for their design project.

This chapter is organised as follows. Section 2.2 details the research methodology of how HCI visualisation methods and selection approaches are derived and categorised. Section 2.3 presents the resulting methods and selection approaches identified and the categorisation of the methods in each approach. Section 2.4 discusses the results and future work. Section 2.5 provides the gaps statement.

2.2 Methodology for Literature Review

The goal of this methodology is to 1) establish existing HCI visualisation methods, 2) establish selection approaches, 3) categorise the visualisation methods identified. Figure 1 presents a two-phase research methodology. Phase 1 is a keyword search of literature consisting of HCI design methods and selection approaches. Phase 2 is the categorisation of visualisation methods.

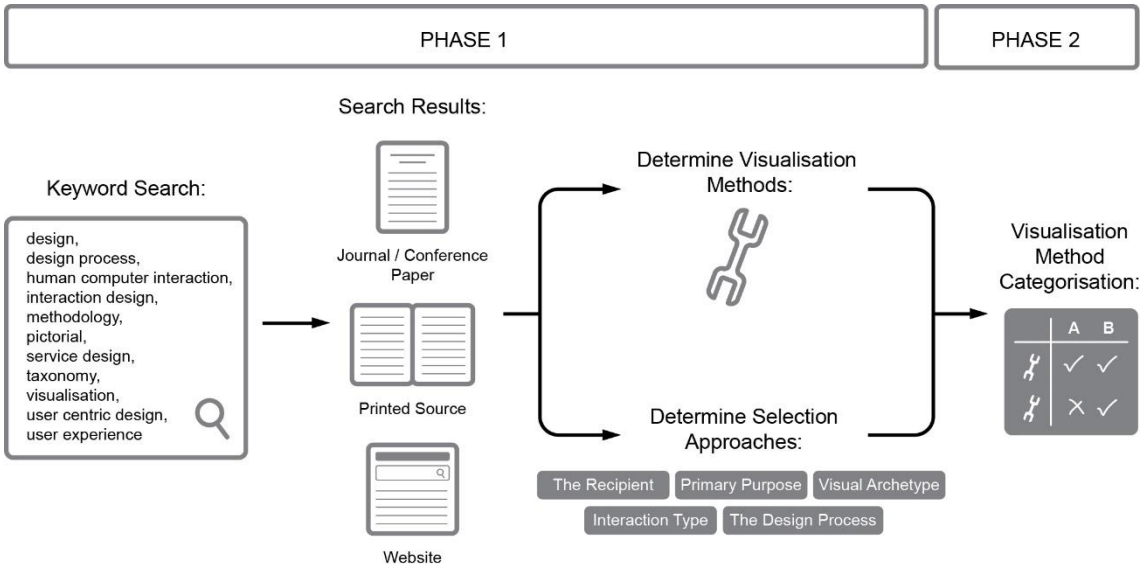


Figure 1 - Research methodology for literature review

2.2.1 Phase 1: Keyword Search

This methodology (Figure 1) began with keyword searches to identify books, websites, and journal and conference papers (using Google Scholar and Elsevier Scopus) that consisted of an inventory of HCI design methods and approaches to categorise these methods. A combination of HCI-related search terms were used: design, design process, Human-Computer Interaction (HCI), Interaction Design (IxD), methodology, pictorial, Service Design (SD), taxonomy, visualisation, user centric design, User Experience (UX). The resulted list of sources was reduced based on two criteria. Firstly, a source with 5 or less methods was not considered. Secondly, each source must provide either 1) detailed description of each design method or 2) a selection approach and show how a design method is categorised.

2.2.1.1 Determining a Visualisation Method

Design methods identified from the keyword search were first examined to group together duplicated methods. This included grouping together methods that are essentially the same but are named differently. For example, *Card Sort* is sometimes named as *Card Sorting*. As they are essentially the same method – involving the sorting of cards to elicit information from a target user – they were grouped together under *Card Sort*. Next, they were filtered to establish a list of

methods that are identified in at least two sources. In some cases, a method was not considered even though they were identified in at least two sources. Methods with only two sources that are referenced from Design Council (n.d.a) and Design Council (n.d.b) were also omitted because the description provided were very similar in both websites. The methods omitted because of this were: *Choosing a Sample*, *Cluster and Vote*, *Comparing Notes*, *Drivers and Hurdles*, *Hopes and Fears*, *Project Space*, *Scribble-Say-Slap Brainstorming*, and *Workshop Toolkit*.

Based on the definition of a visualisation method clarified in Section 2.1, design methods that involved the formation of a 'graphical representation' were classified as a visualisation method. For example, *Card Sort* is considered as a visualisation method because it involves the organisation and grouping of cards to reveal information (Maguire, 2001). The 'graphical representation' is the resulting pattern of card sorted into clusters. In contrast, *Heuristic Evaluation* is not considered as a visualisation method. Although *Heuristic Evaluation* is commonly used in HCI, this method only concerns an activity for evaluating an interface. At no point is a visual artefact created.

Figure 2 shows how visualisation methods were derived in this research. In summary, this research started out with a keyword search to identify design methods for HCI. Subsequently, from this pool of design methods, those concerning the creation of a 'graphic representation' are considered as a visualisation method.

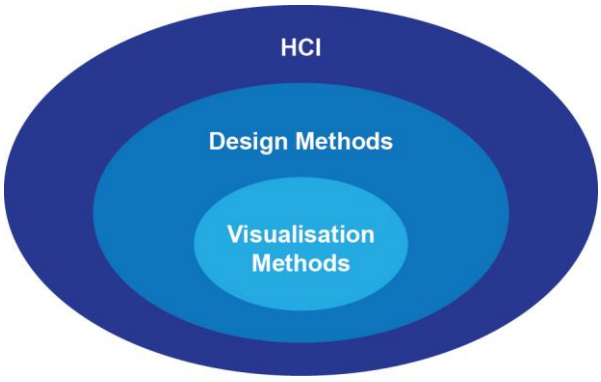


Figure 2 - A number of design methods are available for HCI system design, this literature review investigates the design methods that concern the creation of a 'graphic representation', which this thesis refer to as *visualisation methods*

2.2.1.2 Deriving the Categories within a Selection Approach

Different terminologies were sometimes used to describe the categories of a selection approach. To establish a coherent form of each selection approach, the varying terminologies were collated into a table so the key categories can be derived inductively. Detailed descriptions of each approach and their categories are presented in Section 2.3.2. A category is omitted if it did not fit the approach. For example, the *Visual Archetype* approach omitted *Games* and *Texts*. Similarly, the *Primary Purpose* approach omitted *Analysing Research* and *Running Workshop*.

2.2.2 Phase 2: Categorising Visualisation Methods

The visualisation methods are categorised based on evidence identified in literature. Appendix D presents a table of evidence supporting the categorisation of each method to the five approaches. Each method is categorised based on one or more of three types of evidence, 1) how it is previously categorised, 2) how it is described, and 3) information inferred from its description.

As an example, Table 1 shows how *Card Sort* is categorised. In two approaches (*Primary Purpose* and *The Design Process*) *Card Sort* was placed in categorises where it has previously been categorised. It is categorised as *Designer* in *The Recipient* approach because, as evident in the text, this method is described as a method for designers to elicit information from users. For the *Visual Artefact* approach, this method is categorised in *Maps* based on information inferred from its description – the sorting of design attributes into groups suggests the data is being mapped. In the *Interaction Design* approach, this method is placed in *Learn* and *Ask*. It is placed as *Ask* based on how it has previously been categorised as *Learn* based on inference – after asking users to sort the card the designer evaluates the results to derive meaning from it.

Table 1 - Example of how *Card Sort* is categorised in each Selection Approach

Selection Approach	Category	Evidence
The Recipient	Designer	*Card Sort* is used by designers to evaluate how their target users understand and structure a set of concepts or information (Martin and Hanington, 2012; Maguire, 2001).
Primary Purpose	Explorative / Generative	It has been categorised as *Generative* (Hanington, 2007) and *Exploratory / Generative* (Martin and Hanington, 2012).
Visual Artefact	Maps	Functions, features, and design attributes are presented on individual cards and are categorised into groups (IDEO, 2003; Usability Net, 2006).
Interaction Design	Learn / Ask	It has been categorised as *Ask* (IDEO, 2003). Two steps are associated with *Card Sort*; to categorise the cards and the analysis of data resulted from the card sort (Fincher and Tenenberg, 2005).
The Design Process	Explore	It has been categorised as *Design* (Maguire, 2001), *Exploration / Concept Generation* (Martin and Hanington, 2012), and *Requirements* (Usability Net, 2006).

2.3 Visualisation Methods and the Approaches Used for Their Selection

This section details the outcome of the methodology. Firstly, it presents the HCI visualisation methods identified in the literature. Secondly, it discusses the selection approaches that are being used to categorise these methods. Finally, it presents the categorisation of visualisation methods using each selection approach.

2.3.1 Visualisation Methods

A total of 435 design methods were identified from 13 different sources. The total number of methods identified in each source is shown in Figure 3. This Figure shows the number of methods identified in each source and the type of source in which they were obtained. The design methods were identified from three types of source: websites, printed sources (such as books or printed cards), and journal/conference papers.

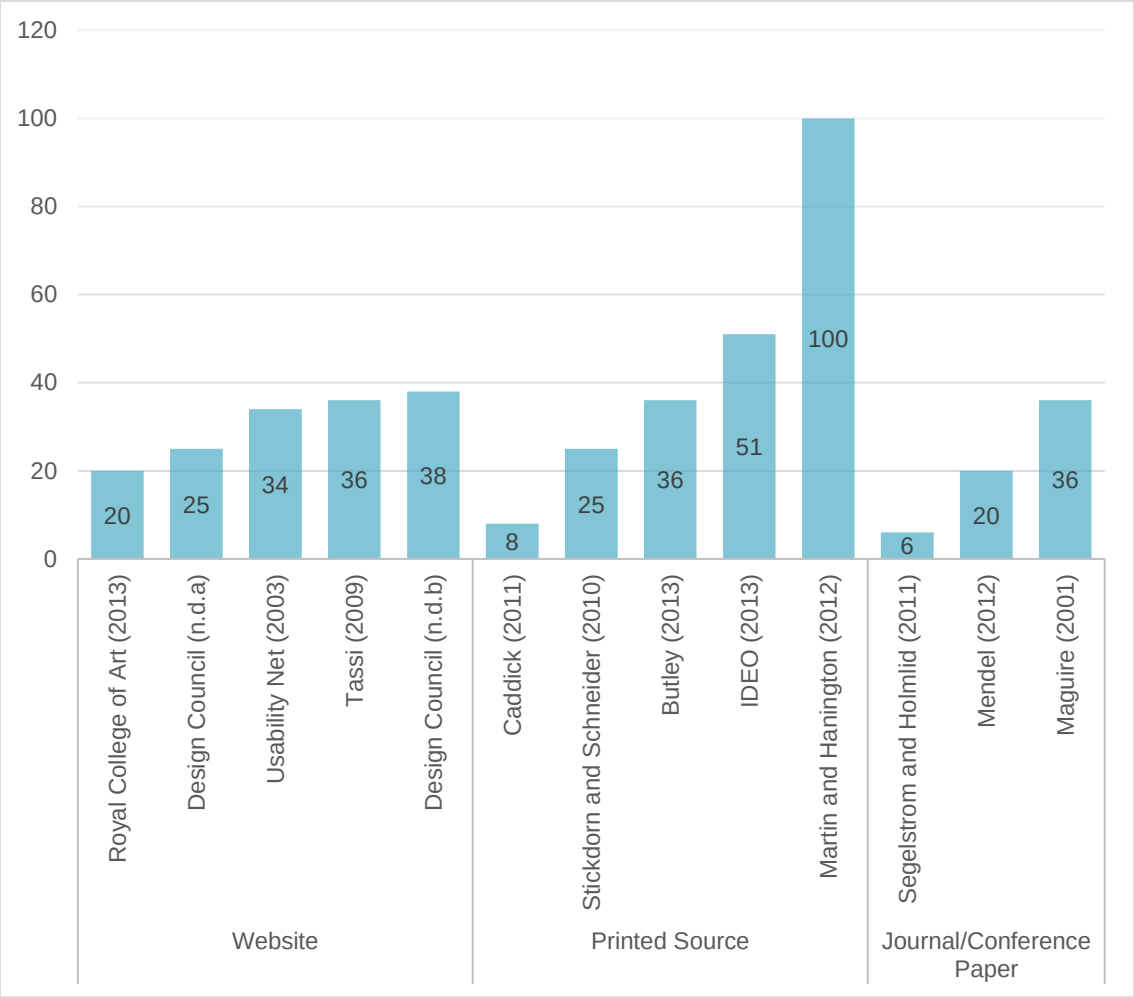


Figure 3 - The number of design methods identified from websites, printed sources (which included books and information cards), and journal/conference papers

After grouping together similar methods (methods with the same purpose but are labelled differently), 245 individual methods were identified. To ensure sufficient information for each method to be put to use, only methods mentioned in two or more sources were retained. This reduced the total number to 57. The full list of HCI design methods are shown in Appendix A, along with the list of eliminated methods in Appendix B. From the 57 HCI methods, 23 were determined to be visualisation methods. The definition of each of the visualisation methods is provided in Appendix C. More information about each method can be obtained using the references provided.

2.3.2 Approaches to Selection

This section presents the approaches to selection identified in literature. The author has chosen to provide illustrations of the different approaches through a catering setting. This is to provide an analogy of the roles and situations we may see in design development to help explain each approach. The chef represents the designer, who designs and creates a new product. The waiter represents the service provider, who makes sure the service runs smoothly and interacts with the customer. The role of the user is universal - a person that purchases and uses a product or service. The stakeholder can be represented by a restaurant owner, who has investment and/or interest in the product or service. Thereby they have a say in the design and perhaps the implementation of the product or service. The following sections present 5 selection approaches. They are illustrated and described in turn.

2.3.2.1 The Recipients

This approach helps designers to choose suitable methods that target a specific type of participant. As each participant has different interest in the product and service, they would need different information about the final design. Table 2 shows the sources from which *The Recipient* approach was derived. Tassi (2009) suggested four categories of recipients: *Stakeholder*, *Professional*, *Service Staff*, and *User*. Royal College of Art (2013) came up with a variation of this approach. It focuses on people's relationships with the final design. They suggested three relationship categories: whether the designing is conducted *For*, *With* or *By* the user. The RCA approach only tells us if the designer involves the users, but not to whom the results are directed towards. 'Conducted for users', does not mean that the recipient is the user.

Table 2 - The variation of categories in *The Recipient*

Source	**The Recipient**			
	Designer	**Service Provider**	**User**	**Stakeholder**
Royal College of Art (n.d.)	With / By	-	For	-
Tassi (2009)	Professional	Service Staff	User	Stakeholder

Tassi (2009) did not provide a definition for the roles of the recipients. The author adapted Tassi's (2009) approach and define the categories for *The Recipient* approach as follow (Figure 4):

1. **Designer:** The person that designs the product or service.
2. **Service Provider:** The person that would interact with the user to provide support for a product or service.
3. **User:** The person that uses the final product or service.
4. **Stakeholder:** The person whose interest would be affected by the outcome of the design.

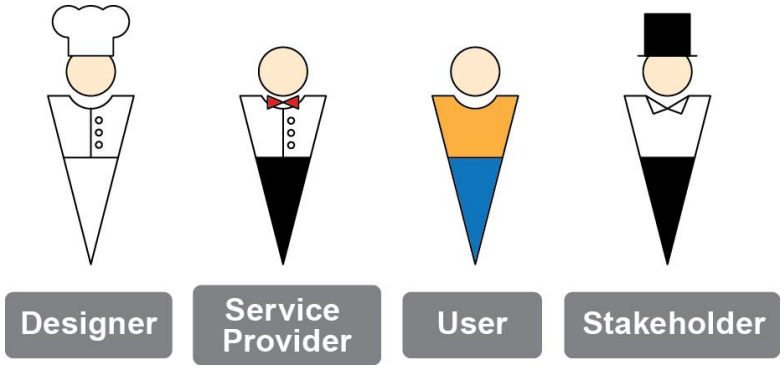


Figure 4 - *The Recipient* approach (adapted from Tassi, 2009) presents the four categories of participants that could be involved in HCI system design

2.3.2.2 Primary Purpose

Primary Purpose was developed by Hanington (2007) in their attempt to integrate human centred research within a design process (Table 3). This approach is adapted by Martin and Hanington (2012) in their book *Universal Methods of Design*. To use this approach, the designer needs to be aware of the information they have at hand and what they want to do with it. If they need to gain understanding or inspiration for an idea, that they are trying to gather more information, or if they are looking for new ways to help them arrange or find new way to understand the information they have.

Table 3 - The variation of categories in *Primary Purpose*

Source	Primary Purpose		
	Exploratory	**Generative**	**Evaluative**
Hanington (2007)	Exploratory	Generative	Evaluative
Martin and Hanington (2012)	Exploratory	Generative	Evaluative

There are three main purposes to design (Figure 5):

1. **Exploratory:** Methods in this category helps the designer to form knowledge based and empathy with people or situations in an unfamiliar territory.

2. **Generative:** Methods in this category are used when the designer needs to form deeper understanding of people or situations. Concept can be generated through participatory design activities.

3. **Evaluative:** Evaluative methods are used to test design concepts against the user expectations.

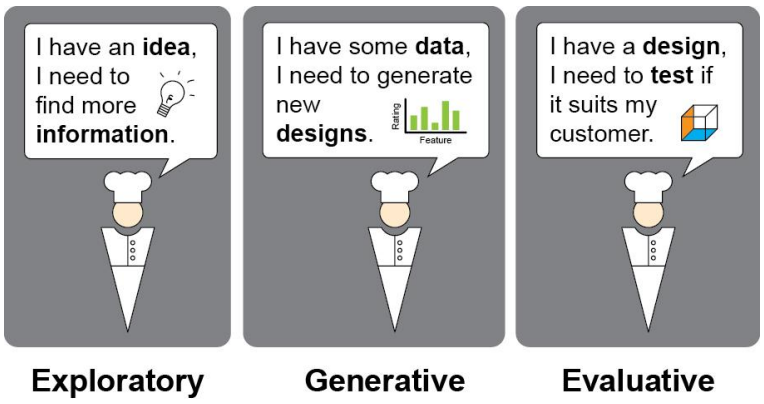


Figure 5 - The *Primary Purpose* approach (adapted from Hannington, 2007) presents the three categories of purposes in the design of HCI systems

This approach, to some extent, bares resemblance to *The Design Process* (Section 2.3.2.5); *Exploratory* is similar to *Explore*, *Generative* to *Create*, and *Evaluative* to *Implement & Evaluate*. However, *The Design Process* helps users to choose suitable methods based on the position or point in a design circle whereas *Primary Purpose* helps user to identify design methods based on their intention.

2.3.2.3 Visual Archetype

This approach is for categorising design methods based on their visual output. Diana et al. (2009) suggested that the main variables concerning visualisation are iconicity (how realistic the representation is) and the time factor (the relation with time). The two extremes of iconicity are abstract and realistic. The two extremes of time are synchronic (how something is at one point in time) and diachronic (how something is develop over time).

Four visual archetypes can be identified when the two axes intersect, which can be used to categorise the visual output of design tools (Figure 6). Each category is detailed as follows:

1. **Maps:** An abstract and synchronic representation. It is used to present an organised and comprehensive view of a design concept.

2. **Flows:** An abstract representation with a pre-defined path that describes the design step-by-step.

3. **Images:** A realistic representation of a design concept. Photographs are usually used to help evoke the emotion of a design.

4. **Narrative:** A realistic representation that conveys the meaning of a design concept through 1) a sequence of images or 2) a person's interaction with the representation.

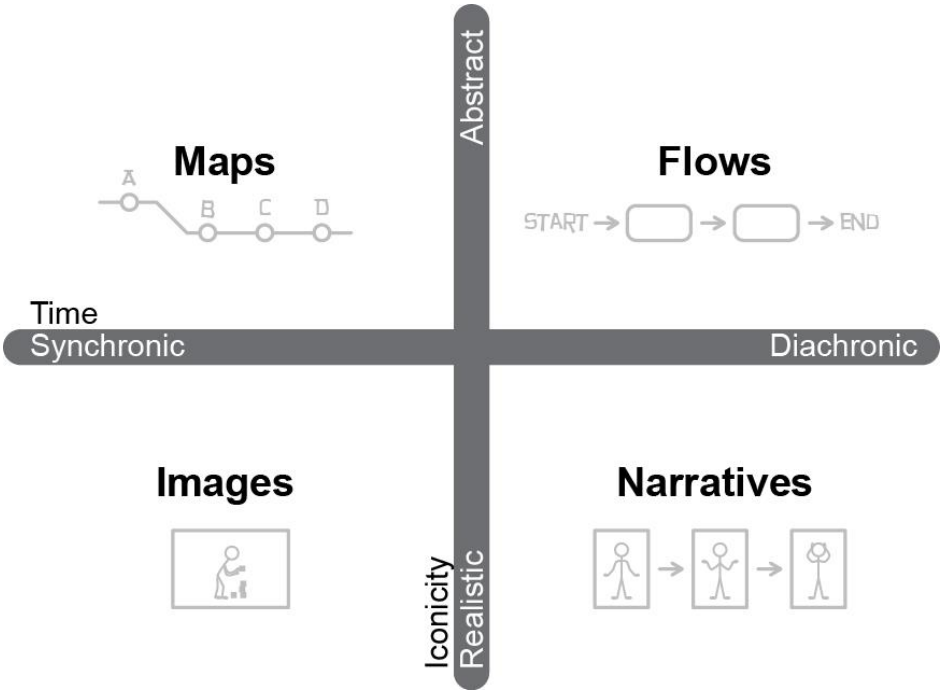


Figure 6 - The *Visual Archetype* approach (adapted from Diana et al., 2009) presents the four categories of visualisation derived from their relation to the iconicity and the time factor

Diana et al. (2009) initially described Narrative as a category for methods that generate realistic representations that exert meaning through a sequence of images. This thesis has extended the meaning of *Narratives* to include methods that require participants to 'perform' or 'act' using the visual artefact created. For example, the *Paper and Interactive Prototype* method could result in the creation of a physical object or digital model. This visual artefact only exerts meaning when a person interacts with it. Hence this method was categorised in *Narratives*.

Table 4 - The variation of categories in *Visual Archetype*

Source	Visual Archetype				Omitted
	Images	**Maps**	**Flows**	**Narratives**	
Diana et al. (2009)	Images	Maps	Flows	Narratives	-
Mayas et al. (2013)	Pictorial or artifactual	Tabular	Diagrammatic	Narrative	-
Tassi (2009)	-	Graphs	-	Narratives / Models	Texts / Games

Mayas et al. (2013) and Tassi (2009) also described similar categories based on the visual output of a method. Table 4 shows how their categories are associated with the categories in the *Visual Archetype* approach.

The category *Games* was omitted because it refers to the activity rather than the visual outcome. The category *Texts* was also omitted because this thesis was looking for approaches to categorise visualisation methods. Methods that purely rely on wording were not considered.

2.3.2.4 Interaction Type

The *Interaction Type* approach describes the categories of activities that designers can undertake to address a design problem. For example, if a designer does have the sufficient information to design a product they can use this selection approach to identify the ways in which they can go about acquiring this information. The definition of each category within this approach is as follows (Figure 7):

1. **Learn:** To collect and analyse a set of information to identify new patterns and insights.

2. **Look:** To observe how users behave to discover what they do rather than what they say they do because some people have difficulties expressing this information (Sanders and William, 2003).

3. **Ask:** To recruit users' participation and obtain information relevant to the design project through inquiry.

4. **Try:** To evaluate a design by creating simulations that enables designers to empathise with the end user.

5. **Imagine:** To explore and gain insight of how users might interaction with a speculative idea.

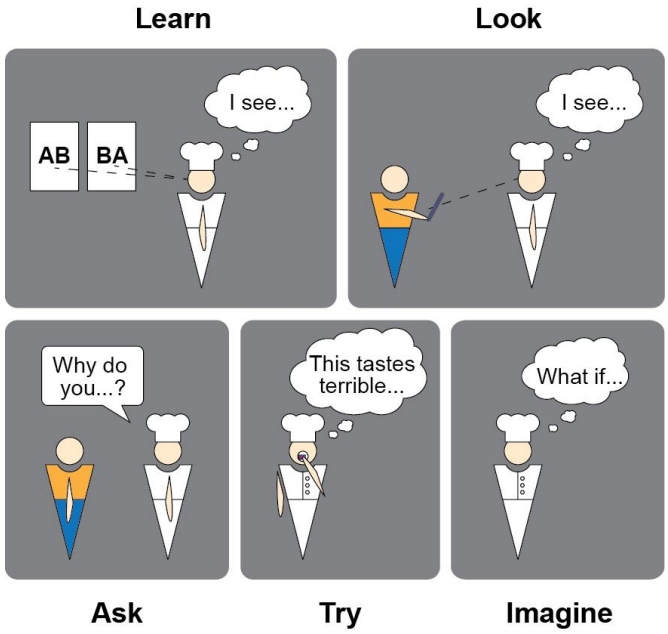


Figure 7 - The *Interaction Type* approach (adapted from IDEO, 2003 and Royal College of Art, n.d.) presents the five categories of activities that designers can undertake to address a design problem

This approach was first developed by IDEO (2003), who identified four category: *Learn*, *Observe*, *Ask*, and *Try*. In their online database, the Royal College of Art (2013) have categorised design methods based on the IDEO approach, but added an additional category; *Imagine*. Saffer (2010) also described four approaches to interaction design. Table 5 shows how they are connected to the categories of the *Interaction Type* approach:

- *Activity Design* is to do with understanding the user's behaviour surrounding a task. This is similar to the *Look* category.

- *User-Centred Design* is to do with involving end users in the design process. This is similar to the *Ask* category.

- In *Genius Design*, design concepts are generated based on the experience of the design practitioner.

- *System Design* is omitted because it describes a holistic design approach, it does not correspond with any of the categories in *Interaction Type*.

Table 5 - The variation of categories in *Interaction Type*

Source	Interaction Type					Omitted
	Learn	**Look**	**Ask**	**Try**	**Imagine**	
IDEO (2003)	Learn	Look	Ask	Try	-	-
Royal College of Art (n.d.)	Learn	Look	Ask	Try	Imagine	-
Saffer (2010)	-	Activity	User-Centred	-	Genius	System

2.3.2.5 The Design Process

The Design Process describes the stages of design. This approach allows designs to consider the method they can use for each stage of the design. This was the most popular approach used to categorise design methods - it was described in nine sources. Table 6 shows how nine different sources have described the stages of *The Design Process*. Most of the sources described the middle three stages. Rarely do they include the first (*Plan*) and last (*Monitor*) phase as part of the process.

Table 6 - The variation of categories in *The Design Process*

Source	The Design Process				
	Plan	**Explore**	**Create**	**Implement & Evaluate**	**Monitor**
Buley (2013)	Planning and discovery	Research	Design	Testing and validation	-
Design Council (n.d.a)	-	Discover / Define	Develop	Deliver	-
Maguire (2001)	Planning	Context of use / Requirements	Design	Evaluation	-
Martin and Hanington (2012)	Planning, scoping and definition	Exploration	Concept generation and early prototype iterations	Evaluation, refinement and production	Launch and monitor
Mendel (2012)	-	Discover / Reframe / Envision	Create	-	-
Royal College of Art (n.d.)	-	Discover / Define	Develop	Deliver	-
Stickdorn and Schneider (2010)	-	Explore	Create and reflect	Implement	-
Tassi (2009)	-	Co-designing / Envisioning	Testing and prototyping	Implementing	-
Usability Net (2006)	Planning and feasibility	Requirements	Design	Implementation / Test and measure	Post release

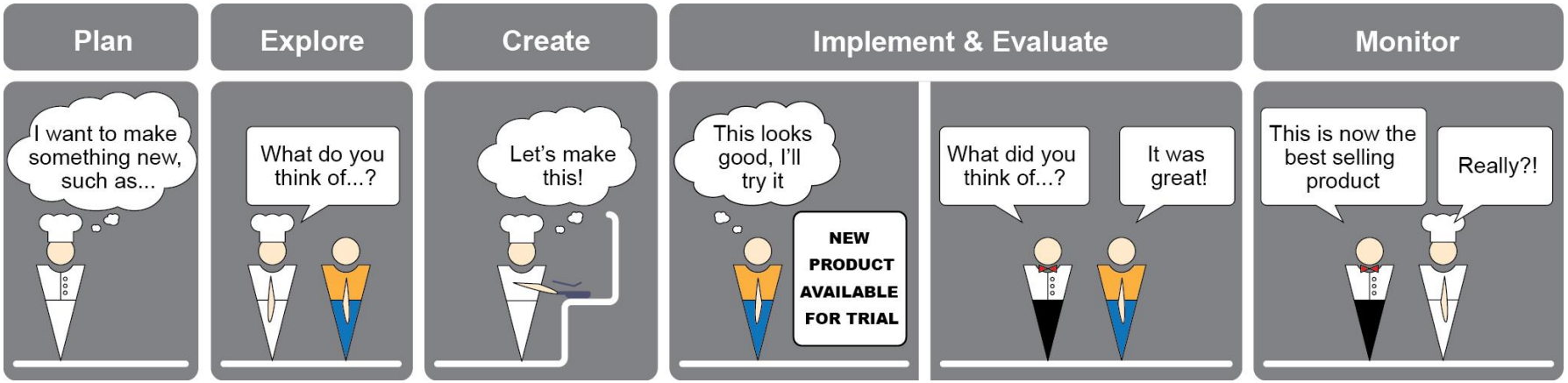


Figure 8 - *The Design Process* approach presents the five categories of design stages in HCI system design

2.3.3 Visualisation Methods Classification

This section presents how the visualisation methods are categorised in each approach and discusses the advantages and disadvantages for using each approach.

2.3.3.1 The Recipient

This approach guides designers to select the visualisation method that is suited for communicating with a certain recipient. This approach helps the designer to think about whom they are designing for or is communicating design concepts with, thereby, tailoring the message to the audience.

From Table 7, it is apparent that most of the visualisation methods are suitable to more than one recipient. In particular, the majority of the methods are suitable for the *Designer* (18/23), or *Stakeholder* (16/23). The vast number of methods in each category would make it difficult to narrow the choice of methods.

2.3.3.2 Primary Purpose

Primary Purpose enables designers to select a visualisation method based on the information they have at hand what it is they would like to with it. It is beneficial in that it helps designers to think about how they would proceed with the information they have. However, as there are only three categories in this approach, it would be difficult for designers to narrow down the choice of visualisation methods from their first selection. For example, if a designer has a concept with some initial data they would like to communicate, they may look for a method in *Generative*.

From Table 8 we can see there are 14 different methods in this category. As it is, designers would need to take the time to find out what each method does to select the most suitable one.

Table 7 - Categorisation of visualisation methods using *The Recipient* approach

Method	The Recipient			
	Designer	**Service Provider**	**User**	**Stakeholder**
A Day in the Life	•			
Affinity Diagram	•			•
Behavioural Mapping	•			
Blueprint	•			•
Card Sort	•			
Collage	•		•	
Customer / User Journey	•		•	
Desktop Walkthrough	•	•	•	•
Mind Map	•			•
Mood Board				•
Paper and Interactive Prototype			•	
Persona	•			•
Photo Studies	•			
Poster				•
Process Model	•	•	•	•
Scenario	•	•	•	•
Service Prototype		•	•	•
Sketching	•	•	•	•
Stakeholders Map	•			•
Storyboard	•	•	•	•
Task Analysis	•	•		•
Task Mapping				•
Wireframe	•		•	•

Table 8 - Categorisation of visualisation methods using the *Primary Purpose* approach

Method	Primary Purpose		
	Exploratory	Generative	Evaluative
A Day in the Life	•		
Affinity Diagram		•	
Behavioural Mapping	•		
Blueprint		•	•
Card Sort	•	•	
Collage		•	
Customer / User Journey	•		•
Desktop Walkthrough	•	•	
Mind Map	•		
Mood Board		•	
Paper and Interactive Prototype		•	•
Persona	•	•	
Photo Studies	•		
Poster		•	
Process Model	•		
Scenario		•	
Service Prototype			•
Sketching	•	•	
Stakeholders Map	•		
Storyboard		•	
Task Analysis	•		
Task Mapping		•	
Wireframe		•	•

2.3.3.3 Visual Archetype

This approach is useful in that it informs the designer about the graphical style of each method. It categorises a visualisation approach based on how information will be structured for communication, and informs them of what the resulting artefact will look like. Nevertheless, methods with the same graphical style could be used to solve very different design problems. Methods categorised in the same category may have a similar format but the way in which the artefact is achieved and how information is derived from them could be very different. For example, *Mood Board* and *Photo Studies* are both placed in the *Image* category (Table 9). A *Mood Board* consists of a combination of images created by a designer to communicate a design concept. In comparison, for *Photo Studies*, the images are typically produced by end-users. These images are studied by designers to gain insights into a certain topic.

2.3.3.4 Interaction Type

This approach supports designers in determining how they would go about solving their design problem. It helps designers to first consider what the problem is (if they require insight of end users or to imagine design concepts), resources they have access to (if they have access to end users or relevant stakeholders to gather information), to derive the design activity they can employ.

Although this approach makes designers aware of the design activity they can perform it does not differentiate the context in which the activities are suited for. Consider the methods *Mind Map* and *Storyboard*. Both methods are categorised in *Imagine* (Table 10) - the category of methods that relies on the experience and imagination of the designer. Whilst *Mind Map* may be more suited for connecting related ideas and problems, *Storyboard* helps to communicate and present the key steps of an idea. To choose between these two particular methods, designers need to be aware of the nature of information they want to communicate.

Table 9 - Categorisation of visualisation methods using the *Visual Archetype* approach

Method	Visual Archetype			
	Images	**Maps**	**Flows**	**Narratives**
A Day in the Life				•
Affinity Diagram		•		
Behavioural Mapping		•		
Blueprint			•	
Card Sort		•		
Collage	•			
Customer / User Journey			•	
Desktop Walkthrough				•
Mind Map		•		
Mood Board	•			
Paper and Interactive Prototype				•
Persona				•
Photo Studies	•			
Poster	•			
Process Model			•	
Scenario				•
Service Prototype				•
Sketching	•			
Stakeholders Map		•		
Storyboard				•
Task Analysis			•	
Task Mapping		•		
Wireframe		•		

Table 10 - Categorisation of visualisation methods using the *Interaction Type* approach

Method	Interaction Type				
	Learn	**Look**	**Ask**	**Try**	**Imagine**
A Day in the Life		•			
Affinity Diagram	•				
Behavioural Mapping		•			
Blueprint	•				•
Card Sort	•		•		
Collage			•		
Customer / User Journey			•		
Desktop Walkthrough				•	•
Mind Map	•				•
Mood Board					•
Paper and Interactive Prototype				•	
Persona	•		•		•
Photo Studies	•		•		•
Poster					•
Process Model	•		•		
Scenario	•				•
Service Prototype				•	
Sketching	•		•		•
Stakeholders Map		•			
Storyboard					•
Task Analysis	•				
Task Mapping	•				
Wireframe				•	•

2.3.3.5 The Design Process

This approach allows designers to plan the type of methods they would like to use at each stage of the design process. To use this approach, users will need to consider which stage they are at. However, in a similar way to the problem found in *Primary Purpose* and *The Recipient*, the majority of methods are categorised in *Explore* (22/23), which makes it difficult for designers to select this category.

Figure **11** shows that *Affinity Diagram* is the most flexible method in that it can be used in four of the five categories (*Explore*, *Create*, *Implement & Evaluate*, and *Monitor*). Most of the methods are suitable for multiple stages of the design development this means that it is possible to use the same method to further develop the design as it evolves in the design development. Usually when a method can be used in more than one category, they span across consecutive stages. For example, *Blueprint* can be used in *Create* and *Implement & Evaluate* (the stage that comes after *Create* in a design process). The only exception is Task Mapping which can be used in *Explore* and *Implement & Evaluate*, missing out *Create*. *Task Mapping* helps to sums up the required functions and tasks identified in the *Explore* stage, providing clear scope for design during *Implementation & Evaluation*.

The majority of the methods were categorised in the *Explore* stage, which is understandable considering that visualisation methods are used to communicate design ideas. There seems to be fewer methods in *Plan*, *Implement & Evaluation*, and *Monitor*. Visualising information is perhaps less useful or does not lend themselves as well to these stages.

Table 11 - Categorisation of visualisation methods using *The Design Process* approach

Method	The Design Process				
	Plan	**Explore**	**Create**	**Implement & Evaluate**	**Monitor**
A Day in the Life		•			
Affinity Diagram		•	•	•	•
Behavioural Mapping		•			
Blueprint			•	•	
Card Sort		•			
Collage		•			
Customer / User Journey		•			
Desktop Walkthrough	•	•	•		
Mind Map		•			
Mood Board		•			
Paper and Interactive Prototype		•	•	•	
Persona		•	•		
Photo Studies		•			
Poster		•			
Process Model		•			
Scenario		•	•	•	
Service Prototype		•	•		
Sketching		•			
Stakeholders Map	•	•	•		
Storyboard		•	•	•	
Task Analysis		•	•		
Task Mapping		•		•	
Wireframe		•			

2.4 Discussion

In this chapter we reviewed visualisation methods that can be used in HCI. A keyword search was performed to identify literature with an inventory of HCI design methods and approaches to categorise these method. The resulted list of sources was reduced based on two criteria. Firstly, a source with 5 or less methods was not considered. Secondly, each source must provide either 1) detailed description of each design method or 2) a selection approach and show how a design method is categorised. From a total of 435 HCI methods, 57 were identified as common HCI methods (methods that were identified in two or more literature sources). From the 57 HCI methods, only those methods concerning the creation of a 'graphic representation' were selected as visualisation methods. Twenty-three visualisation methods were identified.

Five approaches were found to categorise design methods: *The Recipient*, *Primary Purpose*, *Visual Archetype*, *Interaction Type*, and *The Design Process*. *The Recipient* approach categorises design methods based on who we are generating information for. It helps the designers to select methods depending on the level of detail they need to provide to the target audience. The *Primary Purpose* approach categorises methods based on the outcome that the designer is looking for. This approach can help designer to select a suitable method depending on the desired end result. *Visual Archetype* categorises the methods depending on how realistic are the type of representations used in the method and whether they consist of a time element. This is the only approach that categorises design methods based on their outlook. The *Interaction Type* approach categorises design methods based on the type of action that designers could perform to gain further understanding of the design problem. *The Design Process* approach describes the stages of design. It informs the types of methods designers can use at each stage of design.

By categorising visualisation methods according to the selection approaches a number of advantages and disadvantages were identified. Each approach is unique for method selection, but it appears that they are not so effective if there are applied individually. A problem is that there could be a high number of

methods categorised in one category. This is true, for example, in *The Design Process*. From Table 11, it can be seen that visualisation methods tend to be most suited for the *Explore* stage of a design process. This makes *The Design Process* approach ill-suited for categorising visualisation methods because it does not help a designer to narrow down the choice of visualisation methods. Without further intervention, designers would have difficulty in making a selection.

Even in approaches where the visualisation methods were better distributed, such as in *Visual Archetype* and *Interaction Type*, it is still not straight forward for the designers to make a selection. Deciding on the type of visual archetype (Section 2.3.3.3) they want to produce or how they want to approach a design problem (Section 2.3.3.4) is not enough because methods categorised in the same category could be used for very different purposes. Perhaps one way to overcome this issue is to use more than one selection approach. For example, as mentioned in Section 2.3.3.4, *Mind Map* and *Storyboard* are both categorised in *Imagine*. To distinguish between which methods to use, designers can refer to another a second approach such as *Primary Purpose*. If the designer would like a method for generating a design after imagining an idea, then the choice would be *Storyboard*. If the designer would like to imagine and explore possible design ideas, then *Mind Map* would be more suitable.

This chapter has shown that each selection approach has its benefits and limitations. Individually, the selection approaches do not appear to be very effective when a large number of methods are categorised in one category. To choose between the methods, the designers must take time to differentiate between the methods as, currently, there is no mechanism to narrow down the choices. There is a need to investigate the possibility of bringing together multiple approaches which could help to narrow down the choice of visualisation methods and improve the selection process.

One visualisation method on its own may not be enough to address a design problem. Depending on the information they have at hand and what their design intentions are, designers may require other methods to obtain the necessary information. For example, in choosing to use the *Storyboard* method, the designer

will need to first consider if they have a clear picture of who their intended users are (Truong et al., 2006) and the story they are aiming to illustrate (Maguire, 2001). If the designer has little understanding of the end users, and decide that this information is important, then they may first employ another visualisation method such as *Persona*. Hence another factor to consider for further investigation is the procedure of each method. Providing addition information on the method procedure could help designers to quickly decide if it is a suitable method and whether or not they have the necessary resources for its application.

In the search for HCI methods, only those mentioned in at least two of the 13 key sources were considered. Although some useful but lesser known methods may have been omitted, this step was necessary as over 400 methods were initially identified from the literature search. Focusing on methods that came from more than two key sources ensures that there are sufficient information a) for categorising the methods and b) for designers to employ less familiar method. To avoid neglecting methods that, in essence, perform the same tasks but are named differently, the author had grouped together similar methods and provided their alternative names in Appendix A.

This chapter focused on HCI visualisation methods in websites and published literature, which means that the methods identified may not necessarily be the most novel ones used by practising designers. Nevertheless, at the time of writing no inventory of HCI visualisation methods was established. Therefore, the author deemed it important to first clarify what visualisation methods are commonly known in the literature. Only once this is determined then it can be used to enquire for methods missing from this initial study.

2.5 Gaps Statement

This research is significant because no research has studied the categorisation of visualisation methods in HCI. Although some studies have made an attempt in categorising design methods, they either had a broader focus (of methods for design in general), or have been in a specific discipline (such as service design) that is related but does not cover the whole of HCI. This literature review contributes to knowledge by 1) creating an inventory of visualisation methods

used in HCI, 2) providing an analysis of the current approaches being used to categorise them, and 3) categorising the visualisation methods in each approach and discussing the advantages and disadvantages of each approach. As a result, this thesis has produced an inventory of 23 visualisation methods and 5 different ways in which designers can choose to select a suitable method. Two research questions are identified to be address in this thesis, including: 1) further developing the method selection process to help designers narrow down the choice of methods effectively and 2) to investigate the procedure for the application of each visualisation method. These two research questions are the focus for this thesis.

3 METHODOLOGY

From the literature review in Chapter 2, the first research objective was addressed (Table 12) and two research questions were identified: 1) there is no method selection process in literature to help designers narrow down the choice of methods effectively and 2) the procedure for the application of each visualisation method varies in terms of both the level of details and contents. This chapter presents a four-phase methodology (Figure 9) to address the remaining three objectives.

Table 12 - How each research objective is to be addressed in the research phases

Objectives	Research Phase
Objective 1: To identify the visualisation methods and categorisation approaches used in HCI	Research Definition
Objective 2: To undertake case studies to develop better understanding of how visualisation methods are selected and utilised in the development of HCI systems.	Phase 1: Data Collection and Analysis
Objective 3: To propose a guide for the selection and application of visualisation methods.	Phase 2: Guide Development
Objective 4: To apply and validate the proposed guide.	Phase 3: Guide Application Phase 4: Guide Validation.

Phase 1 is the *Data Collection and Analysis* phase that addresses Objective 2. In this phase, three inductive case studies are conducted to examine how visualisation methods are selected and used. The purpose of Phase 1 is to explore the types of design challenges designers face in HCI system development. Phase 2 is the *Guide Development* phase that addresses Objective 3. In this phase, findings from Phase 1 are utilised to address the development of the Guide. Phase 3 is the *Guide Application* phase that addresses Objective 4. In this phase, the Guide developed in Phase 2 is applied in the development of a HCI system. Phase 4 is the *Guide Validation* phase that also addresses Objective 4. In this phase the HCI system developed in Phase 3 is tested. Since the Guide supported the development of the HCI system, the Guide is validated through the evaluation of this system.

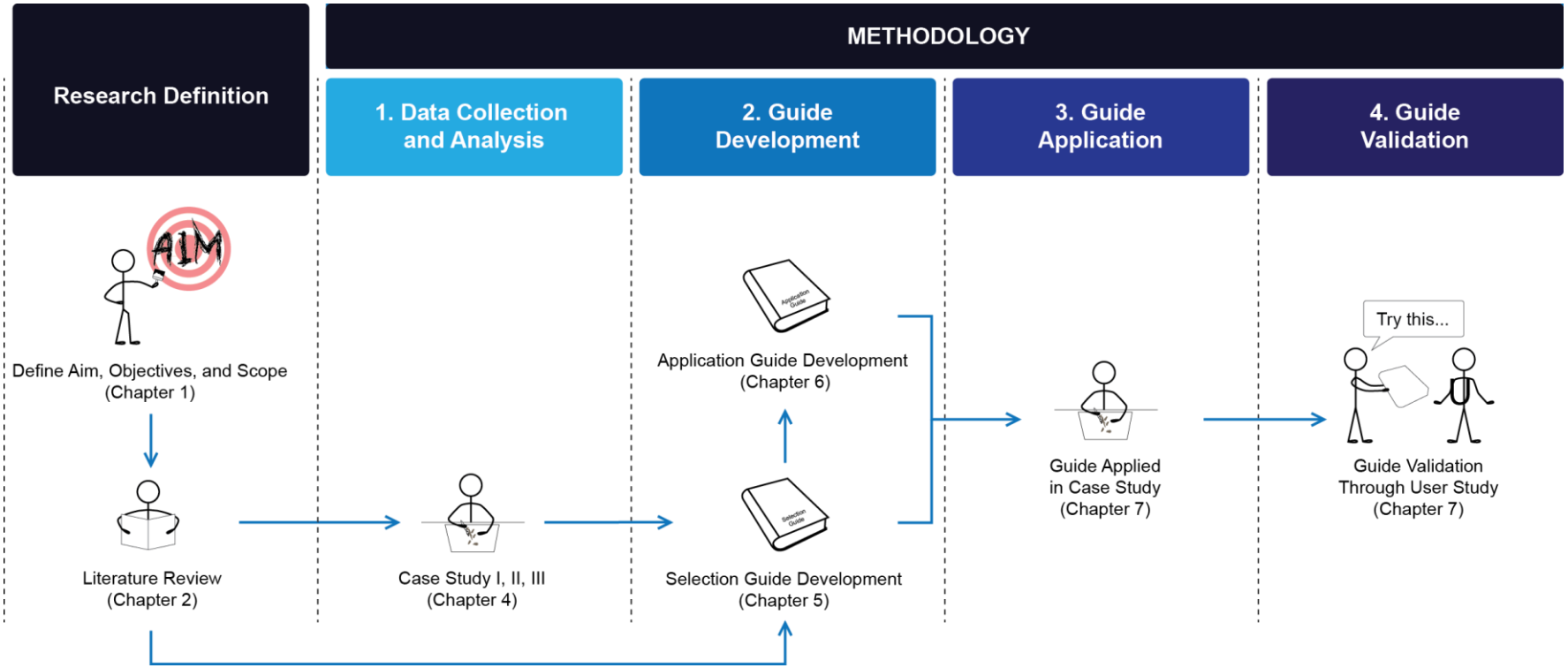


Figure 9 - A depiction of the research methodology showing how the chapters in this thesis are linked to the four phases of research

3.1 Phase 1: Data Collection and Analysis

In this phase, three inductive case studies were conducted to investigate the challenges and obstacles designers may face in the design and development of HCI systems. The three case studies were derived from the parent project (further discussed in Section 1.2.1). The aim of the parent project was to leverage commercial gaming technology to capture and re-use human knowledge in complex manufacturing. One such technology is Microsoft Kinect™, which is depth camera that was launched in 2010. This technology was adapted in all three inductive case studies:

- **Case Study I - Wheel Alignment:** In this case study, Kinect™ was used to capture the position of a car wheel to automate the wheel assembly process. Currently in car productions, the wheels are assembled by workers manually. The high cost of commercial sensors and the complexity of this assembly procedure means that it is presently unviable to automate this procedure.

- **Case Study II - Carbon Fibre Placement:** Robotic arms are used to produce carbon fibre structure based on computer simulated carbon fibre paths. However, short comings with the computer simulated paths may results in flaws for more complex structures. Currently, these flaws can only be eliminated through lengthy trial and error processes. To reduce the time it takes to eliminate these flaws, this project uses Kinect™ to capture how an expert (human expert) applies carbon fibre strands to complex structures. The purpose is to analyse what an expert is doing differently to correct and improve the computer simulation.

- **Case Study III - Kinect Demonstrator:** In this case study, Kinect™ was used to develop a multi-person mapping system. Current multi-person collaborative mapping would only occur around a large paper map. This is not ideal because it requires digitisation after the collaboration, which is time-consuming and error-prone (further discussed in Section 4.1.3).

To ensure consistent information are captured, the following aspects were recorded and presented for each case study:

- **Overview:** The overview provided the background to each case study and the issues that were being investigated.

- **Procedures:** The stages of the design project were detailed to provide the context in which each visualisation method were selected and utilised.

- **Visual Artefacts:** The resulting visual artefacts were presented and explained.

- **Findings:** The findings describe issues that were observed in the choice, formation and employment of the visual artefacts.

3.1.1 Methodology for Case Study I and II

In Case Study I and II, a four-step methodology was followed:

1. **Information Gathering:** This first step was to identify what is currently known of the proposed system and the stakeholders involved.

2. **Requirements Elicitation:** The second phase involved eliciting information from selected actors (this included stakeholders and end users).

3. **Envisioning:** In step 3, the requirements identified in step 2 were transformed into a format that could be validated (Maguire and Bevan, 2002).

4. **Evaluation:** In the last step, the requirements identified were evaluated with the stakeholders involved in this project. The requirements were selected and refined based on the feedback of the stakeholders.

Each step is detailed in the following sub-sections.

3.1.1.1 Step 1: Information Gathering

This step was to identify the available resources and to develop plans for selecting suitable actors for requirements elicitation in Step 2.

Case Study I: Wheel Alignment

Two visual artefacts were developed for the *Wheel Alignment* project:

- Function of Kinect™ (Figure 10).
- Automation of wheel alignment (Figure 11).

Figure 10 was developed to provide a summary of the automated wheel alignment system. There are three stages. First, Kinect™ detects the position of the holes on two wheels. One wheel represents the normal wheel in wheel assembly, and the other represented the axle in which the wheel should be fitted. Once this information is captured, the angle between the two wheels is calculated. Finally, the direction with the smallest angle to turn is identified.

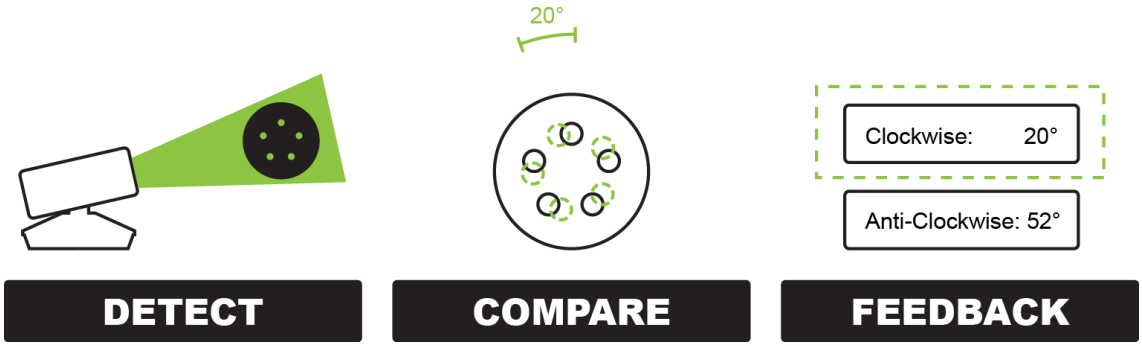


Figure 10 - An overview of automated wheel alignment system, where the position of the wheel is first detected, next the position of the wheel is compared to where it should be, and finally feedback is provided to correct the position of the wheel

Figure 11 shows the traditional method of wheel assembly and two new methods if Kinect™ is used to automate this process. In the tradition method, a manual worker detects the variation in the position of the holes on the wheel to the hub, they would rotate the wheel to match and to secure the wheel onto the hub. To automate this task, Kinect™ could be used to detect the position of the holes on the wheel. Robotics are used to match the axle of the car hub. The wheel can then be applied by the manual worker (*Kinect 1* in Figure 11) or by robotics (*Kinect 2* in Figure 11).

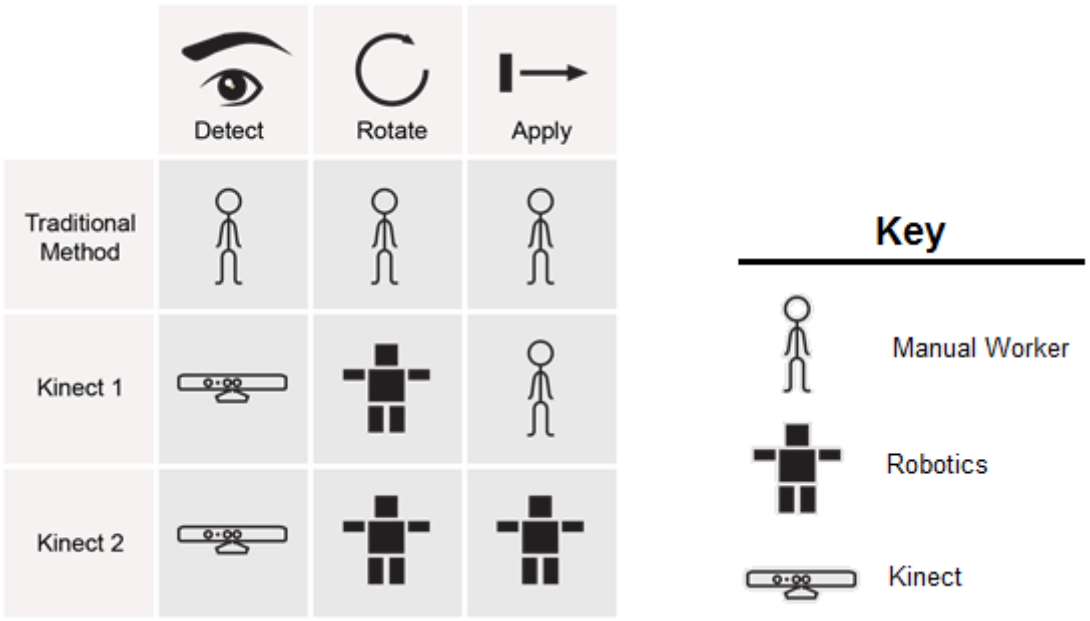


Figure 11 **- Comparing the conventional wheel assembly process to two new scenarios: 1) the conventional way (***Traditional Method***) for wheel assembly requires a manual worker in all three stages (to detect, rotate, and apply the wheel), 2) the first scenario (***Kinect 1***) shows how the assembly process can be semi-automated using a combination of a Kinect, robotics and a manual worker, 3) the second scenario (***Kinect 2***) shows how the assembly process can be fully automated using a combination of a Kinect and robotics**

Case Study II: Carbon Fibre Placement

One diagram was developed for the *Carbon Fibre Placement* project to show the roles of each actor over the duration of the project. In Figure 12, the horizontal dimension presents the stages of the project and the vertical dimensions presents the actors involved in the project. In the first stage the Kinect Programmer and CATIA Simulation Expert work together to design the experiment. Their design will be shown to a Carbon Fibre Placement Expert in stage 2, to acquire feedback before the Kinect-based elements are developed in Stage 3. Once this is developed, the experiment is performed with the Carbon Fibre Placement Expert to capture knowledge in Stage 4. CATIA Simulation Expert use the results from the experiment to develop the CATIA link in Stage 5, in Stage 6 the Knowledge Capture and Management Expert analyses the data captured to and generate the new paths.

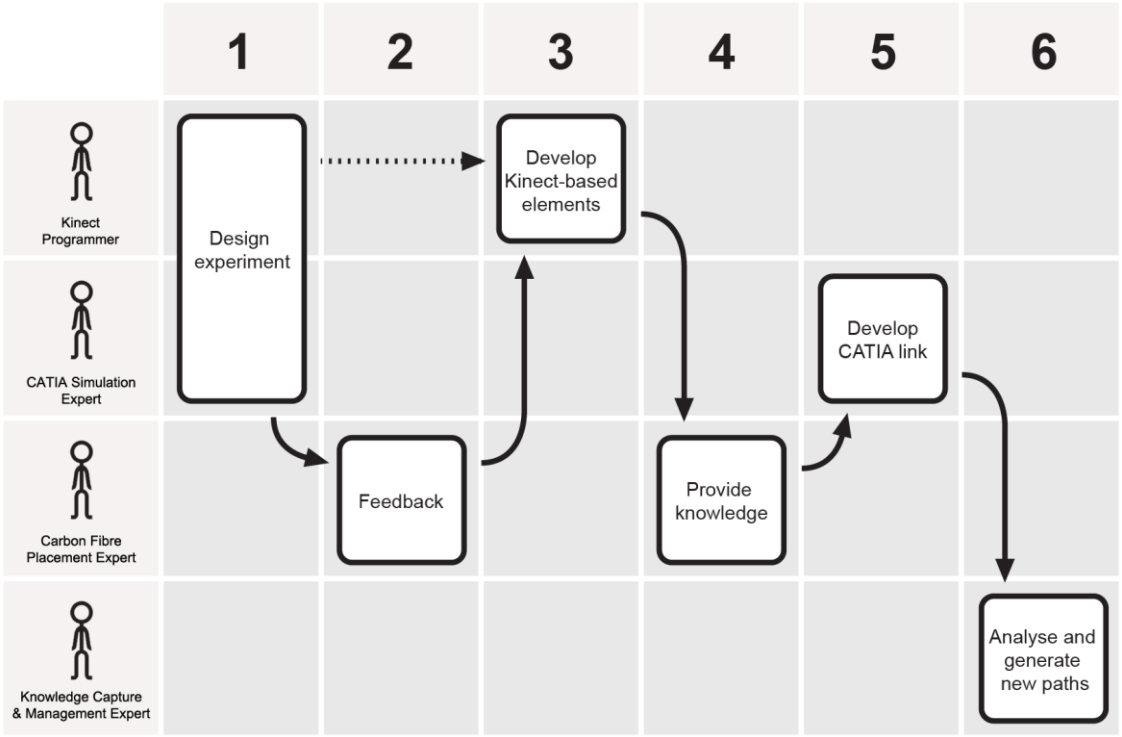


Figure 12 - A diagram of how each actor contributes to the different stages of the system development in *Carbon Fibre Placement* (Case Study II)

3.1.1.2 Step 2: Requirements Elicitation

A semi-structured interview was designed to capture information from stakeholders. A list of questions were prepared prior to the interview but new topics were explored during interview.

Interviewee Selection

In the *Wheel Alignment* project, only one person was involved in the system development. Therefore, the Kinect™ Programmer was interviewed for the requirements elicitation.

In the *Carbon Fibre Placement* project, four people were identified for the system development (as detailed in Figure 12). Two people were interviewed: the Kinect ™ Programmer and the CATIA Simulation Expert. At the time of the interview, the Carbon Fibre Placement Expert and the Knowledge Management and Capture Expert was not available. Nevertheless, all parties were involved in the evaluation phase (Step 4).

Interview Questions

The questions for the interview were specially prepared to fill in the knowledge gap as well as to verify what is already known about the proposed system. Furthermore, to ensure that different aspects of the two case studies are capture, the CATWOE checklist from the Soft System Methodology (SSM) was adapted. SSM was developed during 1960s and 1970s by Peter Checkland. SSM is a methodology for structuring a complex situation (Berg and Pooley, 2013) in order for potential solutions to be identified (Morcos and Henshaw, 2009). The CATWOE check list is a mnemonic of six elements (Checkland and Scholes, 1990): Customers, Actors, Transformation Process, Weltanschauung, Owner, and Environmental Constraints. The purpose of adapting the CATWOE checklist is to ensure that the core purpose and the activity surrounding the conceptual systems are captured.

As an example, Table 13 shows the list of questions prepared for the *Wheel Alignment* project interview. The interview questions consisted of four parts. Questions in the first part were to validate the steps of the conceptual interactive system (shown in Figure 10). Questions in the second part were to check which wheel assemble scenario was the one envisioned by the system developed (Figure 11). The third part related to the CATWOE checklist described in Soft System Methodology. The fourth part are additional questions surrounding the conceptual wheel assembly system.

Table 13 - Interview questions for the *Wheel Alignment* case study

Part 1: Questions related to Figure 10	• Are these the steps of the project? • When and how does Kinect start to detect the wheel? • How will the wheel be held up to Kinect? • Can it detect the difference continuously? • How fast can it calculate the differences • How accurate is the reading from Kinect, how accurate does the industrial robot needs it to be? • Is it possible to check if the correct turn had been made? • How will the data be feed into industrial robots/settings? • Is there such robot available that will provide this function? • Who will input the data into the robot?
Part 2: Question related to Figure 11	• Which setup are envisioning, Kinect 1 or Kinect 2?
Part 3: CATWOE	*Customers* • Who benefits from this system? • Who does it help? *Actors* • Who facilitates the transformation to these customers? *Transformation Process* • What does the system does in converting the input to the output? • How do we measure how successful the project is? • What are we trying to learn? • What is the next step? *Weltanschauung* • What gives the transformation some meaning? *Owners* • Who has authority to stop the transformation process? *Environmental Constraints* • What elements can influence the system? *Root Definition* • What does the system do? • How is it being done? • Why is it being done?
Part 4: Other questions	• What was the problem or the reason behind this project? How did manual workers do this to start off with? • How difficult is it to turn the wheel manually? • What problem arose during this project, how did you solve it? Anything you could not solve? For example, at the workshop you mentioned that at a close range two images of the wheel appeared. Did it affect the end result of this project, would this be affected in the long run? • What is the next step? What else can this application be used for? How can it be applied?

3.1.1.3 Step 3: Envisioning

Information captured in the previous step was transformed into visual formats that could be communicated with stakeholders and team members.

Storyboard to Show Requirements Captured

For both case studies, *a* storyboard was designed to convey understanding between the team members and to tell other people about their project. It acts as an artefact for discussion rather than just something to learn from. Hence the style of the visualisation needed to be simple and clear so non-experts can informed effectively and understand the idea behind each visualisation. As Buxton (2007) suggested, creating simpler representations of the reality could amplify their meaning. A sketch is not simply about eliminating details but focusing on specific details.

In the storyboards, background images provided the context of the case studies. Simple illustration of the machines and apparatus were used to show how they are utilised. To show intangible features (such as the transfer of data), arrows and data tables were used to represent how and where data were transferred.

The actors were differentiated by a letter (taken either from their name of their role in the project). This helps to indicating the actors that are involved. In addition, interactions the figures representing the actors and their actions (speech and thought bubbles) were highlighted from the background images to help readers focus on their interactions.

Colours were used sparingly. It was used to highlight important features, such as to show how Kinect™ is detecting an object, or to add clarity to drawings. For example, in the background stage of the *Carbon Fibre Placement Storyboard* (Figure 13), a red arrow was used to suggest that the Carbon Fibre Placement Expert and the CATIA Simulation Expert was discussing the direction of a carbon fibre path. Even though both actors were discussing carbon fibre path of the same direction, it is the shape in which they were thinking about that is different. This helps to explain why miscommunication between the two actors may occur.

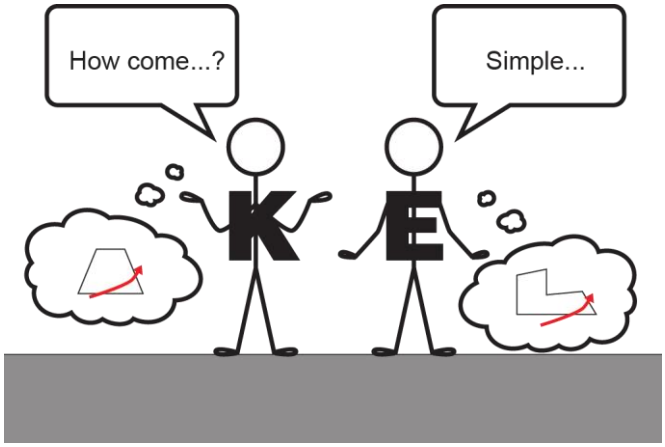


Figure 13 - An example of the Storyboard showing: 1) the figures (stickmen) were characterised with letters to provide clarity as to who they represent, and 2) colours were used sparingly to highlight important features

Animation to Show Requirements Captured

A short animation was created for the *Wheel Alignment* case study. This animation was intended to show the interactive features of the wheel alignment process. To compliment the *Storyboard* showing the background and consultation process, a similar style were used in the graphic design.

The animation was created using Adobe Photoshop. Seventeen images were used to create a short 15 second clip. An animation was created to represent the automation of the wheel alignment process to explain how a number of moving equipment must synchronise to enable automation. A number of interactions could be seen taking place, including:

- The car move steadily along the conveyor belt.
- Kinect™ captures several measurement of the hub position.
- Data is transmitted to the robotic arm as the car approaches it.
- The robot arm adjusts the wheel position to match the hub.
- The wheel is attached to the car.

Although animation is powerful for showing dynamic aspects of the system design, it was very time consuming to produce. Hence the use of animation was limited to show the final concept.

3.1.1.4 Step 4: Evaluation

To validate the requirements captured, the *Storyboards* and animation clip created for both case studies were shown and discussed with the relevant team members. The storyboards and clip were revised based on their feedback and the final visualisations are shown in Section 4.2.

3.1.2 Methodology for Case Study III

Table 14 details a use case that was provided by the client. The *Kinect Demonstrator* is used by two types of users; Airspace Manager and Mission Planner. Both types of users are able to open and save files and to navigate around a map.

Table 14 - A use case detailing two user types, both users can open, save and conduct map navigation, only the mission planner can perform and amend missioning planning features, and only the airspace manager can perform and edit airspace management features

Task	Type of User	
	Mission Planner	Airspace Manager
Open	Open an existing file	
Save	Save all or individual layers	
Map Navigation	Zoom, Pan	
Edit Mission Planning Layer		Interest, Waypoint, Avoid area, Path
Edit Airspace Management Layer	No fly zone, Air corridor	

Based on their role, each user is required to perform different tasks. Therefore, two editable layers are needed on the map – a Mission Planning Layer and an Airspace Management Layer. The types of feature they can add and edit on their layer are also specific to their role. The Mission Planner is in charge of planning the route of flight. Only they can edit the Mission Planning Layer. They are permitted to add interest points, waypoints, possible areas to avoid, and the path of flight. The Airspace Manager plans for the activities of the airspace. Only the Airspace Manager can edit the mission planning layer. They are in charge of mapping the no fly zones and air corridors.

There were three steps in this methodology: 1) Gesture Design, 2) Interface Design, and 3) Communication of the Finished Design. The first two steps (Gesture Design and Interface Design) took the information provided in the client's use case to generate a design concept. The last phase (Communicating the Finished Design) occurred after the *Kinect Demonstrator* software was developed. Visual artefacts were generated in each step to help with the design of the *Kinect Demonstrator* and to aid the communication between the stakeholders (the designer, software engineer, project manager, and the client), who had different backgrounds.

3.1.2.1 Step 1: Gesture Design

The purpose of Step 1 was to identify the type of gestures that Kinect™ can recognise and to design how they would be applied in the *Kinect Demonstrator*. The *Storyboard* method was used to detail how the gestures are performed.

3.1.2.2 Step 2: Interface Design

This step made use of three visualisation methods to develop the interface of the *Kinect Demonstrator*:

- **Static *Wireframe*:** This method was used to generate initial designs of the interface.

- ***Paper and Interactive Prototype*:** A paper prototype was produced to test the layout design. Problematic areas were identified to help refine the design.

- **Interactive *Wireframe*:** This method was used to generate visuals of the system interface to communicate the interactive elements.

3.1.2.3 Step 3: Communicating the Finished Design

The last step was the communication of the finished design. The purpose of this phase was to inform users of the purpose the *Kinect Demonstrator* and how to use it. It made use of the *Wireframe* method in combination with images of the gesture design. This method was used to show the type of gesture the system recognises and how they are implemented.

3.2 Phase 2: Guide Development

The Guide consists of two parts: the Selection Guide (this helps the designers to select an appropriate method) and the Application Guide (this consist of the methodology for the visualisation method).

3.2.1 Methodology for Selection Guide Development

The Selection Guide was developed in three steps:

1. **Evaluation of Selection Approaches:** The Selection Approaches were evaluated based on the design challenges identified in Case Study I, II, and III. The findings in this evaluation contributed to the Selection Guide development in Step 2.

2. **Selection Guide Development:** The Selection Guide was developed in an HTML-based interactive format.

3. **Evaluation of Selection Guide:** The Selection Guide is applied to six design challenges. Visualisation methods derived for each challenge were evaluated based on their suitability for that challenge.

Each step is detailed in the following sub-sections:

3.2.1.1 Step 1: Evaluation of Selection Approaches

The five Selection Approaches, identified in the literature review (Section 2.3.2), were evaluated based on the design challenges identified from Chapter 4. Each

challenge is mapped retrospectively to the Selection Approaches to evaluate the relevance of the Selection Approaches for selecting visualisation methods. The benefits and limitations are discussed. The following sub-sections summarises the design challenges identified in each case study.

Design Challenges in Requirements Capture (Case Study I and II)

Case Study I and II investigated the design challenges in capturing the user requirements in early phase of two HCI system developments. Both projects involved the collaboration of team members from different disciplines. Since each team member has a unique role in the project, it was important to bring together their views to create a coherent picture of the design solution and how the team propose to realise it. Three design challenges were identified:

- **Fragmented Knowledge:** The design team consisted of people from different backgrounds. It was unclear how each team member would contribute in the project. There was a need to clarify their roles and how they would contribute in the design project.

- **Ambiguous Scenario:** At the start of the project the design team had identified two areas for manufacturing automation. It was important to bring together the knowledge of different partners (client, programmer, subject-matter experts) to establish a clear scenario of how the automation would be achieved.

- **Communicate With Non-Experts**: In order to communicate the design solution with sponsors and potential clients, the design team was required to consider how to depict the scenario in a way that people without technical experience can understand.

Design Challenges in Interaction Design (Case Study III)

In Case Study III, the design team was presented with the challenge to create a Natural User Interface (NUI) for a geocollaboration system. The team was presented with a use case consisting of a number of functional requirements. The following design challenges were identified:

- **Screen Area Design:** Ensuring the functional requirements are met in the design and that the user interface compliments with the gesture design.

- **Gesture Design:** In this challenge, the design team first had to identify Kinect™ -recognisable gestures and map them to relevant functions. The design team were required to consider the gestures most suitable for each function.

- **Communicate With Stakeholders:** In order to communicate and receive feedback from clients, it was necessary for the design team to identify ways in which the interaction design can be represented.

3.2.1.2 Step 2: Selection Guide Development

The Selection Guide was developed based on the design requirements captured in Step 1. The findings from this first step lead to the development of an HTML-based Selection Guide.

3.2.1.3 Step 3: Evaluation of Selection Guide

To evaluate the Selection Guide, it was applied to each of the six design challenges (detailed in Section 3.2.1.1). The categories for each filter were already identified in Stage 1. The resulting visualisation methods were analysed for their suitability for each design challenge.

3.2.2 Methodology for Application Guide Development

The Application Guide was developed in three steps:

1. **Determine Methodology:** Compile the techniques for each visualisation method based on references identified in the literature (detailed in Appendix C).

2. **Identify Key Steps:** Analyse the methodologies for each visualisation method to derive the key steps.

3. **Diagram Creation:** Based on the methodology and examples identified from the references (detailed in Appendix C), create a diagram for each method showing their key features.

Each step is detailed in the following sub-sections:

3.2.2.1 Step 1: Determine Methodology

The techniques for each visualisation method was compiled using the reference available in Appendix C. Common steps were identified to derive the methodology for each visualisation method.

3.2.2.2 Step 2: Identify Key Steps

The visualisation methods were compared with each other to identify common steps. For example, this involve identifying at which point the visual artefact is created, what type of information is required, how that information is acquired, from whom it is acquired, and who is involved in creating the visual artefacts.

3.2.2.3 Step 3: Diagram Creation

For methods with more than one representation technique, the author has attempted to provide the diagrams for each of the representation technique identified. For example, *A Day in the Life* could be represented using two different representation techniques: using a diagram or a video format. For this method, an outline for each technique was presented. For methods with more than two representation techniques, only one representative technique was chosen and presented. Nonetheless, users will be able to find more information for the other techniques using the references provided. A representative technique was chosen for the following methods:

- **Paper and Interactive Prototype:** The *Low-Fidelity Prototyping* technique was provided for this method. Other prototyping techniques includes: *High-Fidelity Prototyping* and *Wizard-of-Oz* (Bailey et al., 2007).

- **Process Model:** The *Flow Chart* technique was chosen for this method. *Flow Chart* is one of the simpler and flexible techniques for depicting processes. A number of process modelling techniques are available, including *FMEA*, *IDEF0*, and *Gantt Chart* (Aguilar-Savén, 2004).

- **Task Analysis:** The *Hierarchical Task Analysis (HTA)* technique was provided for this method as it is one of the most widely used (Rogers et al., 2011). Other *Task Analysis* techniques include: *GOMS*, *Cognitive Task Analysis* (*CTA)*, and *Activity Theory* (Crystal and Ellington, 2004).

3.3 Phase 3: Guide Application

In this phase, the Guide was employed in a case study to demonstrate its application. The following aspects were recorded and presented:

- **Overview:** The overview provided the background and the issues that were being investigated.

- **Design Challenge and method selection:** The design challenges were detailed. The Guide is utilised to select an appropriate method for each challenge.

- **Application of Visualisation Method:** The methodology for each visualisation method is followed. The resulting visual artefact is presented.

3.3.1 Methodology for Validation Case Study

This case study followed a two-step methodology:

1. **Design Challenge Identification:** Design challenges were identified during the serious training game development.

2. **Visualisation Method Selection and Application:** The Guide was utilised to aid the selection of a suitable visualisation method for each design challenge.

3.3.1.1 Step 1: Design Challenge Identification

To design the game, the design team (further detailed in Section 7.1.1) began by studying the available information to understand what the training manual entails. Four design challenges were encountered in the design project. They were:

- **Composing Design Ideas:** After forming an initial understanding of the instruction manuals, the next step was to consider how it can be converted

into a game format. For example, at this stage, the design team knew that users must collect a number of tools, materials and equipment and then assemble them together using the jig. The team needed to come up with ideas of how a user was to perform these tasks on a computer screen.

- **Composing the User Interface Design:** In the second design challenge, the design team already have an initial interface design. This challenge is about revising and finalising the interface design and making sure that the games is suitable to be played on a tablet and on a desktop computer. The team needed to consider a) how the instruction would appear, b) how user would move through the game, and c) how to select different materials and tools for each operation.

- **Transforming the Instructions into a Game:** At this stage, the design team had designed the initial features and scenes. The next challenge is to provide how the game is played. The team needed to consider a) how a user would proceed within the game, b) what features of the jig do user need to interact with and how to they navigate these features, and c) how do a user signals that a task have been completed to move onto the next one.

- **Designing Feedback System:** To provide feedback of how well the users are doing in the game, a health system was designed. The design team began to develop how this feedback system would function. This depended on how severe the mistake is, whether or not the users can re-work to amend the mistake made, and to consider at what point the feedback is given.

3.3.1.2 Step 2: Visualisation Method Selection and Application

The Guide was utilised to identify suitable visualisation methods for each design challenge. Based on the design challenge, categories were selected for each filter. The design team made a selection from the resulting visualisation methods.

Visual artefacts were created for each design challenge by following the methodology of each visualisation method.

3.4 Phase 4: Guide Validation

In this phase a user study was designed to evaluate the effectiveness of the HCI system developed in Phase 3. As the design of this HCI system was supported by the application of the Guide, the effectiveness of this system validates the Guide. The following steps were carried out to evaluate the system:

1. **User Study Design:** The user study was designed to evaluate the learning effectiveness of the serious training game developed in Phase 3. Two aspects of the learning were evaluated: factual and procedural knowledge.

2. **Recruit Participants:** Employees from Cranfield University and Airbus Group were invited to participate in the user study. Participants had no prior knowledge of the training material. They were randomly placed in one of two study groups.

3. **Conduct User Study:** Participants were first asked to study a training procedure. This material they were provided depended on the study group they were placed in. This is followed by a two-part evaluation. Participants were first asked to complete a multi-chose questionnaire. This is to test their factual knowledge. Next, participants were asked to perform tasks on a model of an assembly jig. This is to test their procedural knowledge. At the end of the experiment, participants were asked to complete an attitudinal survey.

3.4.1 Methodology for Serious Training Game Evaluation

The methodology of each step is detailed in the following sub-sections:

3.4.1.1 Step 1: User Study Design

The serious Training Game (TG) being evaluated was developed to support complex manufacturing training. The TG proposed was developed from a manufacturing manual of an aircraft maintenance door. Manufacturing of civil aircrafts is subject to strict procedures due to the legal and safety implications of

non-conformities. These include the design and the costs associated to the auditing and certification of the product. Through interacting with the TG, new operators are expected to achieve a reasonable level of knowledge of the assembly procedure before they are exposed to an instructor or physical manufacturing equipment. In this context the ultimate goal of the TG is to reduce the cost of non-conformance via a more interactive and cost-effective approach to minimise product defects or deviations from the design during production.

As a first evaluation of the Training Game, this study assesses the learning effectiveness of the TG. This randomised controlled trail employed a post-test only control group design. The treatment group were trained on the TG, whereas the controlled group was trained on the PM. This study was designed to evaluate if the TG is successful in training the assembly procedure under the condition that no instructor or physical equipment is present. Both learning materials contained the same written manufacturing instructions. The differences between the two instructional approaches are detailed in the following subsections.

Paper Manual

The PM used for this experiment was an original aircraft door assembly manual that is currently in use. Due to confidentiality, the PM will not be presented. It contains two main parts: 1) manufacturing instructions, and 2) supporting documents. For the first part, the manufacturing instructions are provided as a series of tasks combined with images to show how the tasks are performed. For example, one task involved removing pin bolts from the assembly jig. An image was provided to show the location of the pin bolts. For the second part, a number of support documents are presented. They provide addition information that is not detailed in the manufacturing instruction. This included the material and tool lists, and lists of documents (such as regulations) that workers will need to refer to within the manufacturing process.

Training Game

The TG solution was designed and developed by a team of 8 (further discussed in Section 7.1.1) on Unity3D, which is a gaming platform chosen by the

stakeholders in the parent project (Section 1.2.1). The implementation did not include the players' body representation, i.e. the whole TG was based on a point and click navigation within a desktop computer. To increase the fidelity of the TG, the maintenance door and assembly jig models were low-poly definitions of the original CATIA (Computer Aided Three-Dimensional Interactive Application) models; where participants could interact with all moving elements. For example, participants could rotate the jig, adjust drilling templates, or take in and out pin bolts. In essence, the TG model consists of the same functionality as a real factory jig. An overview of the TG is detail in Section 7.2.3.

3.4.1.2 Step 2: Recruit Participants

Due to the confidential nature of the manufacturing content, this study was conducted with employees from Airbus Group Innovations and Cranfield University in the United Kingdom. Twenty employees participated in the user study (20% female, mean age of 29.95 ± 12.87 SD years). Participants did not have extensive manufacturing knowledge prior to their participation, scoring a mean of 1.01 ± 1.2 SD in a scale from 0 to 3 (0-no experience, 1-minimal experience of less than one year, 2-moderate experience between one to three years, 3-extensive experience of over three years), and none previously trained on the assembly procedure studied in this chapter.

Learning through playing the TG and learning by studying the PM are two very different methods of learning. To monitor if an individual's preferred learning style affected how they performed in this study, each participant was asked to complete the VARK questionnaire (version 7.8) before participating. This questionnaire was designed by Fleming (2015) for the assessment of an individual's learning preference. According to VARK the main categories of learning preference are Visual, Aural, Read/Write, and Kinaesthetic but a user may be a multi-modal learner – when they have more than one main preference. In this study, participants were found to be in all of the main preference categories (Visual 20%, Aural 10%, Read/Write 10%, Kinaesthetic 45%), and two multi-model categories (Visual-Kinaesthetic 10%, and Visual-Read/Write 5%). To minimise the influence of an individual's learning preference in the experiment,

participants of the different learning types were counterbalanced and randomly distributed through the two experimental conditions.

This study was approved by the Science and Engineering Research Ethics Committee (SEREC) of Cranfield University. Written consent was obtained from all participants.

3.4.1.3 Step 3: Conduct User Study

In the user study, participants were asked to complete a demographic questionnaire (Appendix G) before undergoing two sequential experimental phases (Figure 14). They first undergo a Study Phase in a between-subjects experimental design before proceeding to the knowledge tests in the Evaluation Phase.

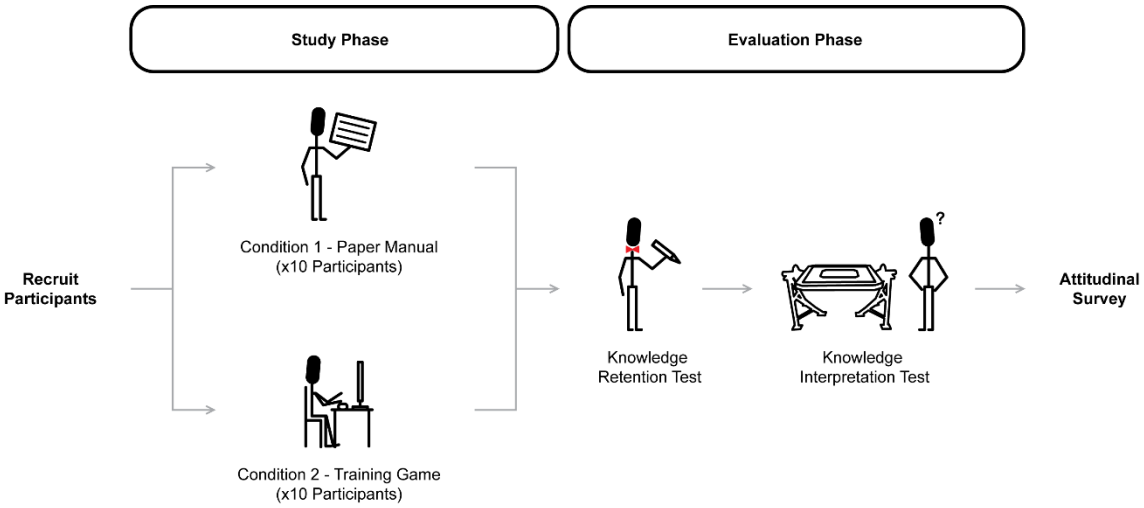


Figure 14 - Participants were recruited for the experiment which consisted of two phases: 1) in the Study Phase half of the participants were asked to study the Paper Manual and the other half studied the Training Game, 2) in the Evaluation Phase all the participants took part in the Knowledge Retention Test and a Knowledge Interpretation Test, at the end of the experiment participants were asked to complete an attitudinal survey

Study Phase

In the Study Phase participants were given 30 minutes to study the manufacturing procedure. They were permitted to take notes during this time, but the notes could

not be used in the evaluation phase. Participants were randomly assigned to one of two test groups:

- **Condition 1:** Participants were given a PM to read (detailed in Section 3.4.1.1).

- **Condition 2:** Participants were trained using the TG (detailed in Section 3.4.1.1). The TG was played on a desktop computer.

Evaluation Phase

The Study Phase was followed by an Evaluation Phase where participants were asked to complete two different knowledge tests to evaluate the learning effectiveness of the two instructional approaches. To ensure that the tests provide an accurate assessment of the desired learning outcome, the questions were designed with the help of a Subject Matter Expert in complex manufacturing. Participants were evaluated on two learning objectives:

1. **Knowledge Retention Test:** This was a written test in which participants completed a multiple choice test (Appendix H). It was designed to evaluate how much factual knowledge was retained from the Study Phase (Objective 1).

2. **Knowledge Interpretation Test:** This was a practical test that evaluated how participants applied the knowledge they had learnt in a real world environment (Objective 2). Participants were asked to perform two operations that included interacting with multiple moving parts on a scaled model (Figure 15). This test was designed to 1) reflect real-life situations where parts could be missing or misplaced on equipment, and for 2) detecting whether a participant was applying acquired knowledge or simply relying on inference.

Attitudinal Survey

At the end of the experiment participants were asked to complete an Attitudinal Survey. This survey was devised to evaluate the participants' subjective experience during three phases of the study (Study Phase, Evaluation Phase –

Knowledge Retention Test, Evaluation Phase – Knowledge Interpretation Test). Table 15 presents the questions in the Attitudinal Survey. Participants answered a survey of 21 items, with 7 items referring to each phase of the experiment. Answers were provided in a seven-point Likert scale (1-Strongly disagree, 2-Disagree, 3-Somewhat disagree, 4-Neither agree nor disagree, 5-Somewhat agree, 6-Agree, 7-Strongly agree).

Figure 15 - A moveable cardboard model of the jig was created for the Knowledge Interpretation Test, the image on the left (Normal View) shows the jig in the standard position, the image on the right (Rotated View) shows the underside of the jig

The Attitudinal Survey investigates two elements: confidence level and engagement. The part of the survey that measures confidence level consisted of 50% positive and 50% negative statements. The statements representing a positive experience were scored positively (1 to 7), and the statements that represented a negative experience were scored negatively (-1 to -7). The average score indicated the participant's overall confidence level. Regarding engagement, participants were asked to what extent they agreed with the following statement: *I enjoyed this part of the study*.

3.5 Summary

This chapter presented the methodology of this research. Four phases were described: 1) Data Collection and Analyses, 2) Guide Development, 3) Guide Application, and 4) Guide Validation.

Table 15 - Attitudinal Survey questions

	Study Phase	Evaluation Phase: Knowledge Retention Test	Evaluation Phase: Knowledge Interpretation Test
Confidence	• *I had enough time to study the assembly process.* • *There are technical terms that I did not understand.* • *At the end of the study phase I can fully recall the assembly process* . • *The work instructions were easy to understand.* • *The assembly process was not well explained.* • *I did not have time to go through the whole assembly process.*	• *I did well in the knowledge retention test.* • *The questions were relevant to the work instructions I studied.* • *The questions were difficult.* • *The work manual/video game provided enough information for me to answer the questions.* • *I guessed most of the answers.* • *The wording of the questions is too technical.*	• *I made a guess on how the tasks are performed.* • *I did well in the knowledge interpretation test.* • *The questions were difficult.* • *The work manual/video game provided enough information for me to perform the tasks.* • *The wording of the questions is too technical.* • *The questions were relevant to the work instructions I studied.*
Engagement	• *I enjoyed this part of the study.*	• *I enjoyed this part of the study.*	• *I enjoyed this part of the study.*

4 INDUCTIVE CASE STUDIES FOR EXPLORING THE DESIGN CHALLENGES IN HCI SYSTEM DEVELOPMENT

This chapter presents case studies that investigate the requirements capture and design activities surrounding three interaction systems development. The case studies described in this chapter was provided as part of the parent project (detailed in Section 1.2.1). Two different aspects of HCI system development are studied. The first two case studies are concerned with the user requirements capture activities in the early phase of HCI system development. The third case study is concerned with a later phase where the user requirements were provided at the start of the study.

The purpose of the case studies is to form deeper understanding of the challenges designers face in HCI system development. Understanding the type of challenges designers face will assist the author to assess whether the Selection Approaches identified in Chapter 2 are appropriate for method selection. Therefore, the results in this chapter will inform the development of the Guide development in Chapter 5 and 6.

4.1 Introduction

Case Studies I and II investigates the requirements capture process in HCI system development. User Requirements are the user's needs and requirements for a product or a system (Maguire and Bevan, 2002; British Standard Institution, 2010). The first case study looks at automating an assembly process in car manufacture. This case study will be subsequently referred to as the Wheel Alignment project (detailed in Section 4.1.1). The second case study looks at capturing tacit knowledge of carbon fibre experts to ultimate automate carbon fibre placement (detailed in Section 4.1.2). The second case study will subsequently be referred to as the Carbon Fibre Placement project.

Case Study III investigates the challenges in the design of a geocollaborative system. This system employs a gaming technology – Microsoft Kinect™ – to enable same-time, same-place, multi-user mapping and navigation.

4.1.1 Case Study I: *Wheel Alignment*

This project was initiated by a partner in the parent project. The partner identified that parts of a vehicle assembly process are completed manually due to complication in its automation. One such process is the application of the vehicle wheel. Currently in this procedure, the assembly line is slowed down for manual workers to physically align and attach the wheel before it could move onto the next procedure. Although workers have equipment to help them (the gantry), they are found to be difficult to manipulate. As a result, workers are inclined to use them and would, instead, lift the wheels by hands.

A four-step methodology was followed for this case study (the methodology is described in more detail in Section 3.1.1):

1. **Information Gathering:** This first step was to identify what is currently known of the proposed system and the stakeholders involved.

2. **Requirements Elicitation:** The second phase involved eliciting information from selected actors. One stakeholder (the Kinect ™ Programmer) was interviewed.

3. **Envisioning:** In step 3, the requirements identified in step 2 were transformed into a format that could be validated.

4. **Evaluation:** In the last step, the requirements identified were evaluated with suitable actors. The requirements were selected and refined based on the feedback of the actors.

4.1.2 Case Study II: *Carbon Fibre Placement*

This project was initiated to adopt new gaming technology in the manufacturing environment. The project aimed to use Microsoft Kinect™ to capture tacit knowledge of skilled workers in the application of carbon fibre. This knowledge can aid the generation suitable carbon fibre paths that can be produced by AFP without defects. As a result, the carbon fibre placement process is automated.

A four-step methodology was followed for this case study (the methodology is described in more detail in Section 3.1.1):

1. **Information Gathering:** This first step was to identify what is currently known of the proposed system and the stakeholders involved.

2. **Requirements Elicitation:** The second phase involved eliciting information from selected actors. Two stakeholders were interview (the Kinect ™ Programmer and the CATIA Simulation Expert).

3. **Envisioning:** In step 3, the requirements identified in step 2 were transformed into a format that could be validated.

4. **Evaluation:** In the last step, the requirements identified were evaluated with suitable actors. The requirements were selected and refined based on the feedback of the actors.

4.1.3 Case Study III: *Kinect Demonstrator*

Geocollaboration is a field of study examining how communication technologies can support a group of people working to solve a geospatial problem (Schafer et al., 2005). Current geocollaborative systems that utilise touch displays restrict map navigation to one user at a time.

The geocollaboration system being developed will be referred to as the *Kinect Demonstrator* in the rest of the chapter. This design project was initiated by a client who wanted to make better use of space and time in group geospatial collaboration. At the moment, the client could only work collaboratively around a large paper map and they are required to digitise their work afterwards. There are a number of issues associated with the current method of planning, including:

1. A paper map is not resizable and additional information of the surrounding area cannot be accessed easily.

2. Marking features may accidently fall from the paper map, thereby disrupting the flow of the team collaboration.

3. Once the initial planning is completed, the work on the paper version must be digitised manually.

4. Information from the initial discussion could be missed or misinterpreted whilst being digitised.

5. Any errors in the digital version cannot be easily amended, prolonging the overall planning time.

The development of touch displays for geospatial planning could help to solve part of the problem. They allow users to work in a digital format, thereby permitting users to save their data as they work. However, it is not possible for more than one user to input data and manipulate the map on a touch screen at one instance. Paelke et al. (2012) designed a drafting table format that allows interactions using pen, multi-touch, and a tangible puck. The tangible puck is a physical object that is placed on the touch screen. Moving and rotating the puck will translate and zoom in and out of the map. Nevertheless, there is only one puck so only one user can control the map at a time. Similar to the work of Paelke et al. (2012), Döweling et al. (2013) developed a light table system for crisis management. They made used of a Bluetooth tracking system that permits individual users and their orientation to be recognised. This system enables multiple users to add information to the map at the same time but, again, it does not allow multiple users to manipulate the map simultaneously.

This case study describes a project that made use of a gaming technology – Microsoft Kinect™. Microsoft Kinect™ is a depth camera that was launched in 2010 that allows users to use gesture and speech to command inputs. By enabling the users themselves to become a controller (Rydén, 2012), it allows users to interact with computers with natural movements. Microsoft Kinect™ can track and recognise gestures of up to two users simultaneously. This can enable better use of time and space as well as facilitating a more natural way for people to interact with technology. The audio feature was not considered in the design of the *Kinect Demonstrator* based on the decision of the client.

There were three steps in this methodology: 1) Gesture Design, 2) Interface Design, and 3) Communication of the Finished Design (the methodology is described in more detail in Section 3.1.2). The first two steps (Gesture Design

and Interface Design) took the information provided in the client's use case to generate a design concept. The last phase (Communicating the Finished Design) occurred after the *Kinect Demonstrator* software was developed.

4.2 Results and Discussion

This section presents the visuals created as a result of the requirements capture for the three case studies.

4.2.1 Case Study I: *Wheel Alignment*

As a solution to the wheel alignment problem, a researcher from Cranfield University had developed a programme that uses Kinect™ to detect the wheel position and the angle that it needs to turn for it to align with axle in the car hub. To elicit the design requirements, a one-to-one interview was conducted with the Kinect™ Programmer (detailed in Appendix E). The requirements were transformed into a *Storyboard* and an animation clip, which was then validated with the Kinect Programmer. This section presents the validated visuals created as a result of the requirements capture.

4.2.1.1 Actors

From the interview, three key actors were identified for this project (Figure 16):

- Kinect™ Programmer.
- Car Manufacturer.
- Automotive Assembly Operator.

Figure 16 - Actors in *Wheel Alignment Storyboard*, distinguished actors involved with the development of the HCI system were represented by their initials

The Automotive Assembly Operator is identified by a simple stick figure. The Kinect™ Programmer and Car Manufacturer were involved in the design of the system. They are distinguished by their initials.

4.2.1.2 Background and the Consultation Stage

The *Storyboard* is composed of a background stage and a consultation stage (Figure 17). The background describes the problem and why Kinect™ was required. This part of the *Storyboard* is to inform the current state of the manufacturing procedure (the problem).

The second part of the *Storyboard* is the consultation stage. It describes the next stages to apply this system in the real world. The actual system designed by the Kinect™ Programmer is summarised in a single image (detailed in Figure 10 of Section 3.1.1.1). As the system has already been designed by the Kinect™ Programmer, there is a live example of how it functions. It was not necessary to explain what was already available.

4.2.1.3 Animation of Functions

A short clip was also developed to show the end product of how Kinect™ would function in the real environment. It was intended provide knowledge of how the Kinect™ would work in sync with the robotic arm that is difficult to just describe on a still image. Snap shots of the clip can be seen in the last row of Figure 17.

The animation clip shows the car moving along the conveyor belt (grey coloured band) from above. The plan view was used because it can clearly show the positions of the equipment. A yellow beam was used to represent the Kinect™ scanning the position of the wheel hub and the holes on a wheel. Just before the car reaches the robotic arm, Kinect™ sends data to the robotic arm which adjusts the wheel accordingly. The robotic arm places the wheel on the car hub once it reaches the correct point. Kinect™ then begins to scan the back wheel.

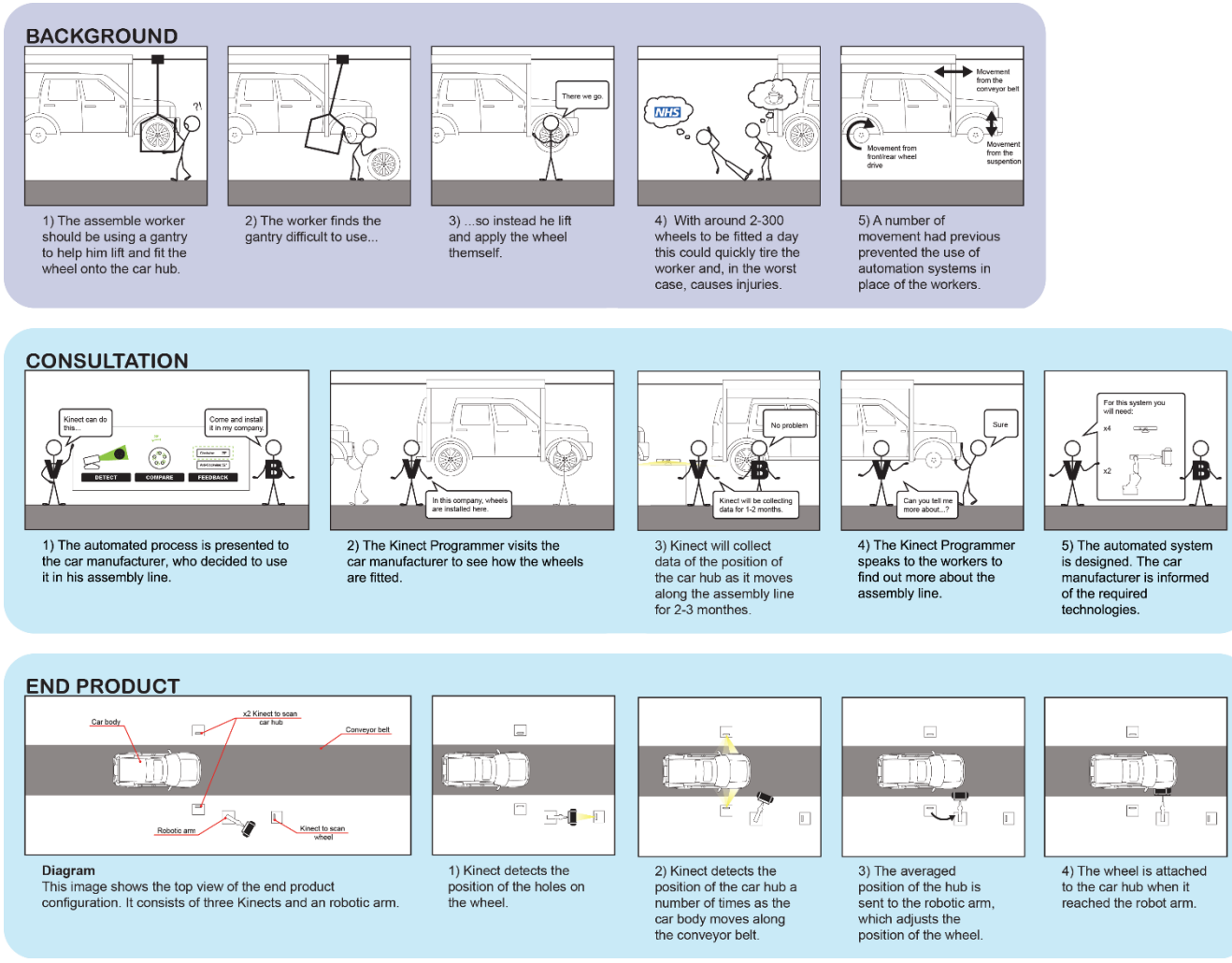


Figure 17 - *Storyboard* of *Wheel Alignment*

4.2.2 Case Study II: *Carbon Fibre Placement*

To elicit the design requirements for this project, a group interview was conducted with CATIA Simulation Expert and Kinect Programmer. The requirements are transformed into a *Storyboard* format before being shown to the concerning actors and the stakeholder. This section presents the validated *Storyboard* (hereby referred to as *Carbon Fibre Placement Storyboard*).

4.2.2.1 Actors

The *Carbon Fibre Placement Storyboard* consists of four key actors. Figure 18 shows the design of the characters in the *Storyboard*.

Figure 18 - Actors in *Carbon Fibre Placement Storyboard*, distinguished actors involved with the development of the HCI system were represented by their initials

Each actor is represented with a simple stickman figure and distinguished by a letter. The Carbon Fibre Placement Expert is identified with an ‘E’ (for expert). The other three actors were part of the design team in the parent project. To provide clarity to each of their role they are identified with the initial of their names. Their roles are as follow:

- **Carbon Fibre Placement Expert:** The Carbon Fibre Placement Expert is not part of the design team, but his knowledge contribution is vital in this system. It is his knowledge that will be captured and used for machine learning.

- **CATIA Simulation Expert:** The CATIA Simulation Expert is part of the design team. His role is to 1) provide the default carbon fibre path generated on a CAD software (CATIA) for analysis and 2) to correct the default setting on CATIA.

- **Kinect™ Programmer:** The Kinect™ Programmer is part of the design team. His role is to programme Kinect™ to capture the knowledge of the carbon fibre placement expert.

- **Knowledge Capture and Management Expert:** The Knowledge Capture and Management Expert is part of the design team. His role is to form rules that could correct the default setting on CATIA so that correct carbon fibre path could be generated each time.

4.2.2.2 Overview of Storyboard

The background explains the need for the *Storyboard*. The remainder of the *Storyboard* is made up of four stages (detailed in Figure 19).

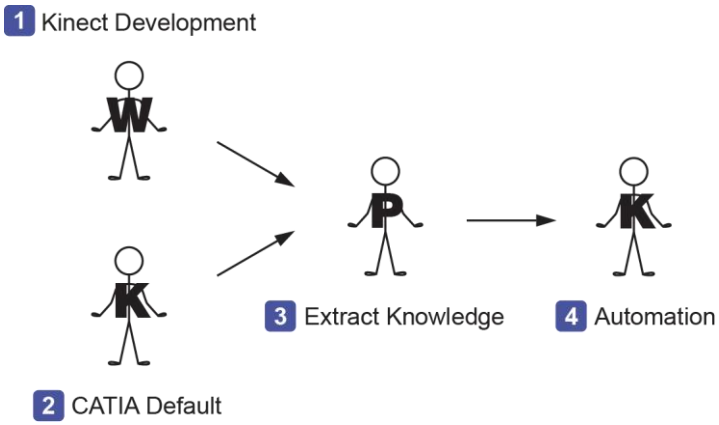


Figure 19 - Keys Stages in *Carbon Fibre Placement*

The first stage is the Kinect™ development. This is led by the Kinect™ Programmer. Stage 1 and 2 take place at the same time. Stage 2 is led by the CATIA Simulation Expert, who generates the default carbon fibre path on CATIA. Data generated from the first two stages are used for Stage 3, which is led by the Knowledge Capture and Management Expert. The Knowledge Capture and Management Expert analyses the two sets of data from Stage 1 and 2 to extract knowledge. Results from this stage are used in Stage 4, where the CATIA Simulation Expert uses it to correct the default setting on CATIA.

4.2.2.3 Stages of the *Carbon Fibre Placement Storyboard*

Figure 20 and Figure 21 show the stages of the *Carbon Fibre Placement Storyboard*.

Background

The background explains the problem with the current system. To compete with competitions and keep up with the increasing demand for commercial aircrafts there is a need to save time and cost in the manufacturing process. At the moment, existing AFP (Automated Fibre Processing) machines could be used for some areas of carbon fibre application, but it is limited due to process induced defects (Kim et al., 2012). Although the carbon fibre path trajectories could be calculated and created on CAD applications (such as CATIA), once that data is feed to the robotic arm the carbon fibre may winkle or detour away from the direction it is supposed to be applied.

To correct this, it is possible to interview manual workers who have explicit knowledge of its capabilities of how carbon fibre should be managed at different parts of the manufacturing process. However, this process is time-consuming and often unsuccessful. Although the manual workers are able to apply their skills in a given situation, it is difficult for them to explain this in words. Furthermore, manual workers may not always be available to answer the programming engineer's queries. This could be due to a conflict of schedule or that they are simply unwilling to expose their trade skill.

Stage 1

The *Carbon Fibre Placement* project proposes to use Microsoft Kinect™ as a tool that will allow the manual workers, the people that understand the most about carbon fibre application, to teach the machines how to do it. The worker could demonstrate to the machines how to lay carbon fibre, and point out the defects. This method provides a rapid and unobtrusive way to capture knowledge and pinpoint the problem when and where it occurs. To do so, Stage 1 involves the programming of Kinect™ to capture hand movements and audio commands. Three types of data are collected as Kinect™ watches the carbon fibre placement

expert: the carbon fibre path created by the Carbon Fibre Placement Expert, audio information, and the time stamp to show the pace of events.

Stage 2

Stage 2 involves the generation of the carbon fibre path on CATIA. It is known as the ‘default’ path because it is the path that CATIA create on default at the moment. This is the path that will need to be corrected as defects are known to occur.

Stage 3

Data from Stage 1 and 2 are fed into this stage. By comparing the two sets of data, new rules can be generated to correct the default carbon fibre path generated on CATIA. The data can also be organised into a format to help solve new problems that may arise in the future.

Stage 4a and 4b

Stage 4 is made up of two parts. In Stage 4a the default carbon fibre path would have been corrected by findings in Stage 3. However, in case defects can still be found, the data set generated in Stage 3 can be reviewed and new rules can be added to correct the default carbon fibre path. Eventually once all defects have been removed (Stage 4b), Kinect™ would be able to identify the geometrical shape of any object. Using the (corrected) default settings on CATIA, carbon fibre paths would be generated and fed to the AFP machine. The AFP would apply the carbon fibre without defects.

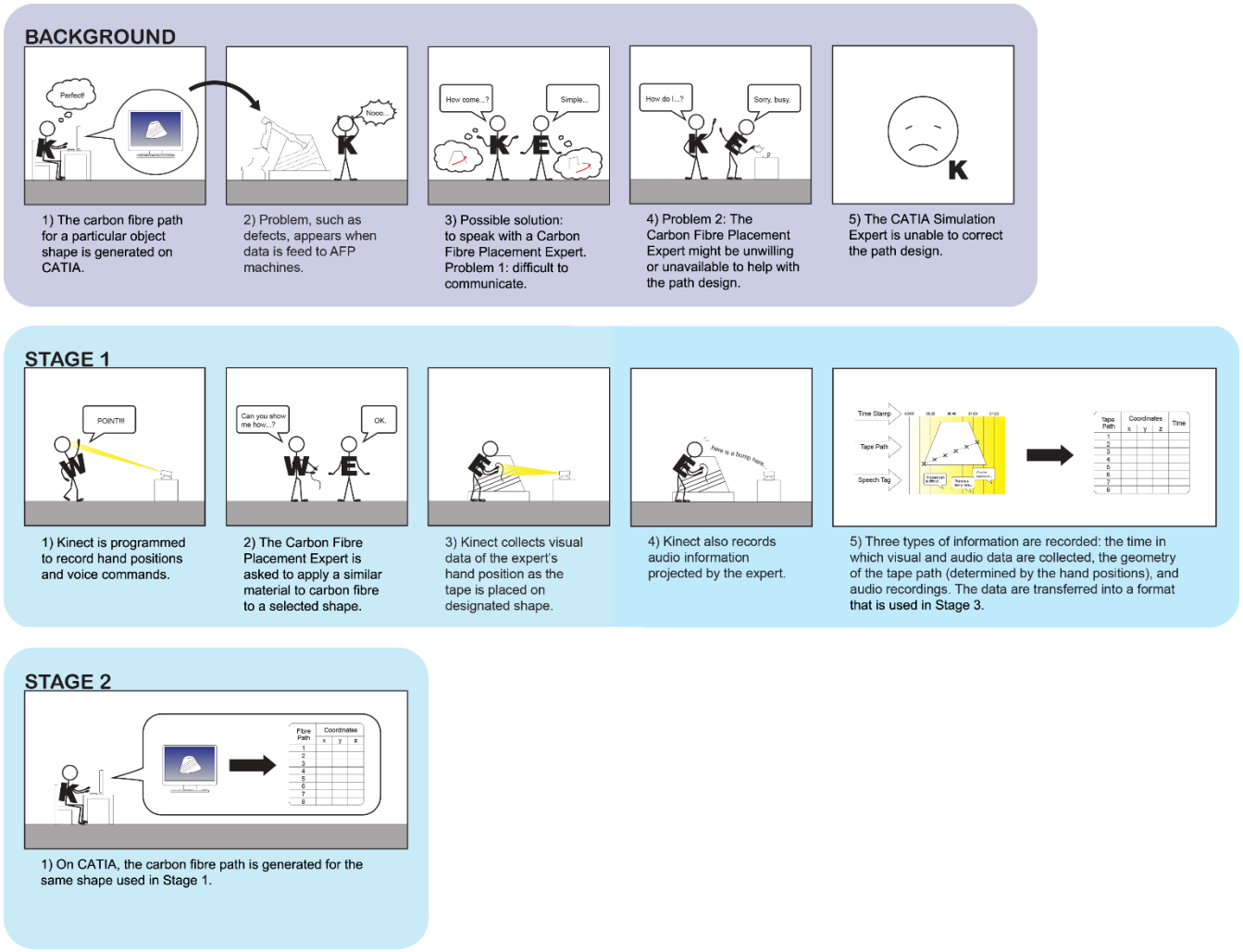


Figure 20 - Storyboard of Carbon Fibre Placement: Background, Stage 1, and Stage 2

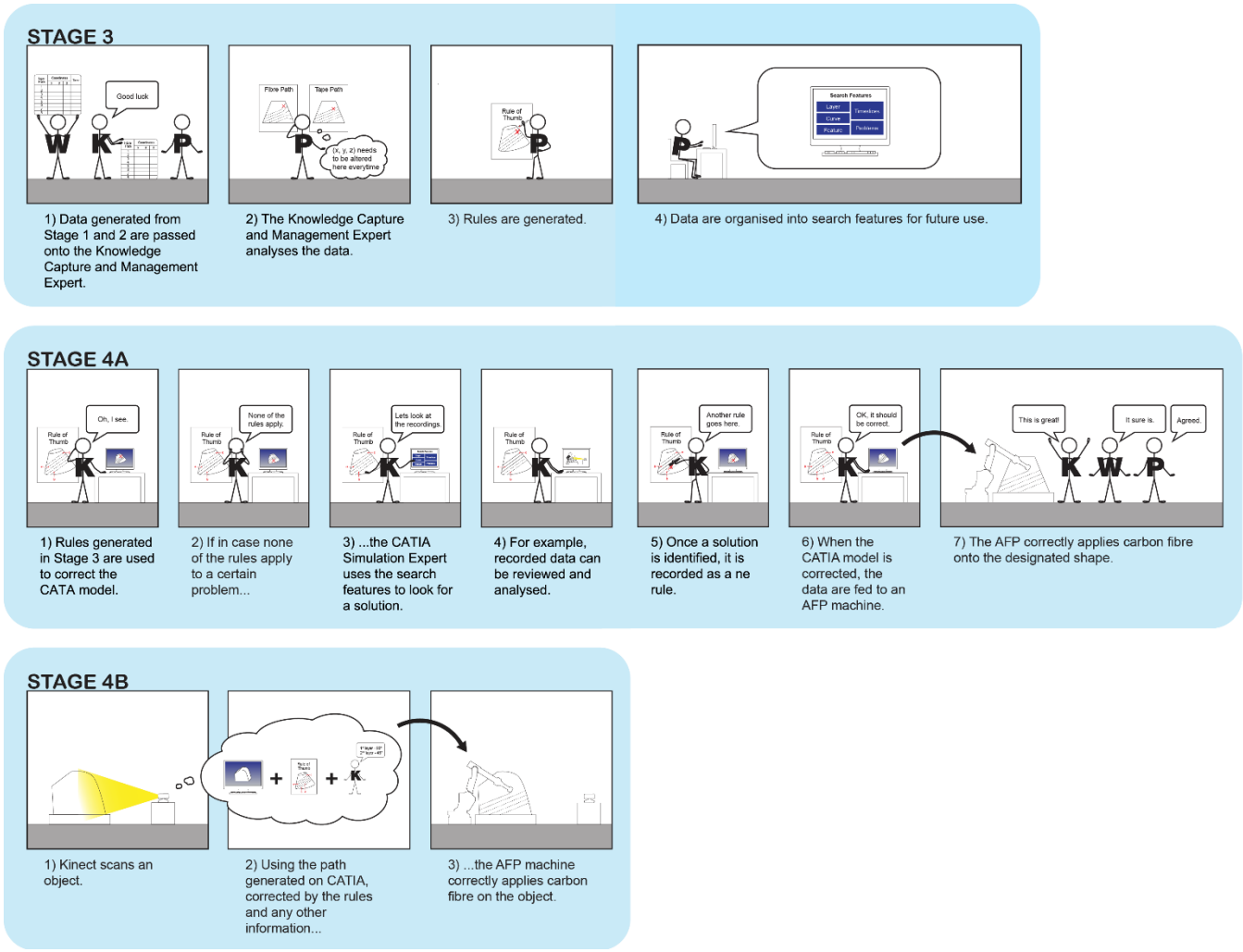


Figure 21 - Storyboard of Carbon Fibre Placement: Stage 3, Stage 4A, and Stage 4B

4.2.3 Case Study III: *Kinect Demonstrator*

The *Kinect Demonstrator* for multi-person mission planning was developed in three parts. The first part was the gesture design, this was where suitable natural gestures were identified for map navigation and composition. The second part was the interface design whereby the interface was developed. The last part involved communicating the final design to end users.

4.2.3.1 Gesture Design

Previous research have looked at using gestures for navigating both 2D maps (Stellmach et al., 2012) and 3D virtual globes (Boulos et al., 2011) using Microsoft Kinect™. However, no research has looked at the use of natural gestures to draw and edit features on a map (which does not involve a touch screen).

As the *Kinect Demonstrator* was to be developed on a gaming platform (Unity3D), it was important to make sure the gestures being designed were applicable to this platform and could be incorporated within the project time frame. To identify suitable gestures, a number of sources were studied, including gestures available on Kinect™ SDK (Software Development Kit), the design of natural gestures in games, and academic research. As a result, four applicable gestures were determined (Figure 22):

- **Zoom:** The hands move close together and apart again.
- **Select:** One hand is clutched into a fist and released again.
- **Add Point:** One hand is first held in a waving position and is then extended forward.
- **Pan:** The left hand is clutched into a fist and the right hand moves around (up, down, left, and right).

Once the application gestures were determined, the next stage was to design how the gestures would be used to manifest corresponding commands. To do so, the *Storyboard* method was used.

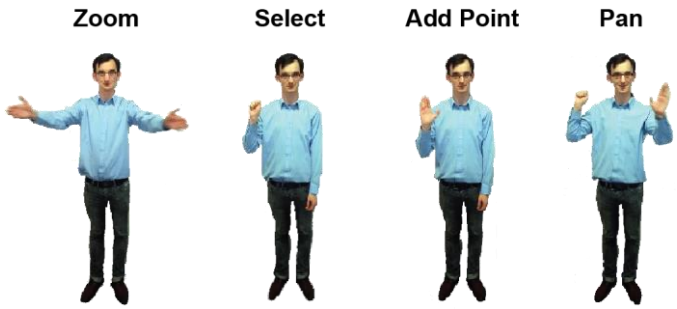


Figure 22 - Four applicable natural gestures were identified for navigating and editing the geocollaborative system

Storyboards are made up of a series of drawings to present a sequence of events (Segelström and Holmlid, 2011; Stickdorn and Schneider, 2010). It is used to project the context in which an experience is formed as well as the key steps that makes up the experience (Martin and Hanington, 2012; Tassi, 2009).

Table 16 - The sequence of natural gestures to perform four different commands for editing points and paths

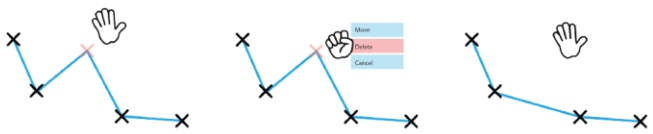
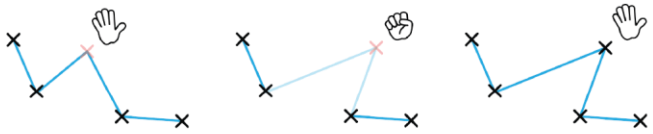
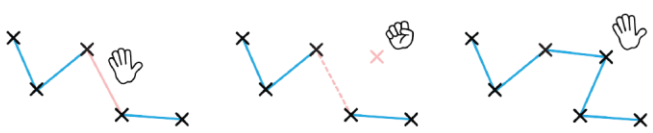
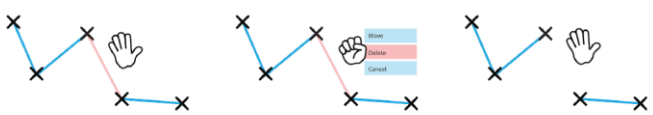
	Gesture Sequence
Delete Point	
Move Point	
Add Point	
Delete Path	

Table 16 shows some examples of how the commands with their corresponding gestures were presented to the stakeholders. A sequence of images was produced for each mapping feature so that it provided the detail necessary to comprehend each action. Feedback was collected from the stakeholders which found that although some gestures did provide a natural interaction (grabbing the points to change their position) other gestures were too much like *mouse clicks* (selecting from a menu list). This enabled some of the gestures to be re-designed for better performance.

4.2.3.2 Interface Design

The *Wireframe* method was used for the screen interface design. This method is for structuring the data of the interface design to allow the design team to come to an agreement of what functions are to be developed and how the page will be laid out (Caddick, 2011). Figure 23 shows examples of how the *Wireframe* method was employed in this research. A simple outline of the interface was sketched and the location of the map position was indicated with text.

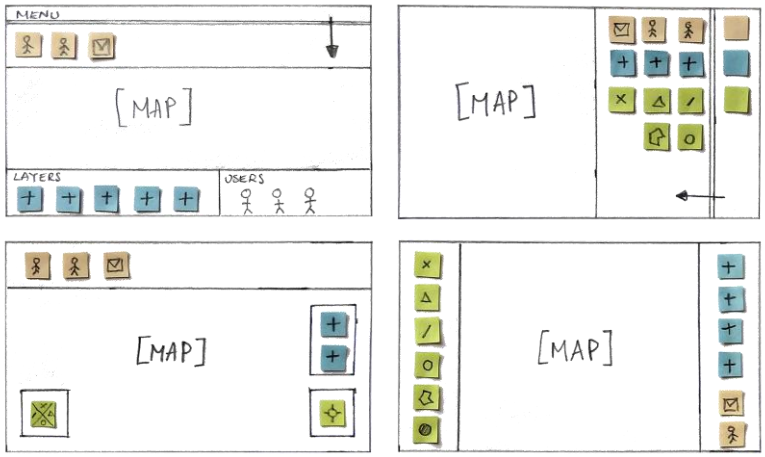


Figure 23 - Examples of interface designs using the *Wireframe* method, four different interface layouts are shown

Three types of interactions were identified from the use case provided by the client, including: mapping and editing (adding waypoints, air corridor etc.), map navigation (zoom and pan), and general administration purposes (logging in, opening and saving file). To help organise the positions of the different types of

interaction, three different colours were used; orange for the general administration purposes, blue for the map navigation, and green for mapping and editing.

In arranging how the functions would appear on the screen, it was found that including all the functions on the screen would vastly limit the map space. Hence a decision was made to keep some of the functions hidden until called upon. This way, all of the functions are accessible but would be out of the way when not in used.

The simplistic nature of this visualisation method enabled a number of ideas to be quickly explored. One disadvantage of this method is that it is static and cannot convey interactive elements easily. The arrows in the top two images of Figure 23 represent the menu can be extended to show additional features.

Figure 24 - A movable paper prototype was created to demonstrate and refine the interface design

To evaluate the initial interface design and explore interactive elements, a paper prototype was created (Figure 24). *Paper and Interactive Prototype* is the creation of a working model that transfer concepts into a tangible object, or experience in to the context of use (Martin and Hanington, 2012). This allows designers and users to refine the design (Mendel, 2012) and helps to reduce the risk of costly mistakes (Royal College of Art, n.d.). According to Lidwell et al. (2003), a common

problem with conceptual prototyping is the artificial reality problem because the prototype is essentially an implausible working model that is being used to convey a plausible concept. Therefore, it is important that the prototype appear as though it would work.

To make the prototype appear as realistic as possible, it was constructed to scale of a typical TV screen (16:9 aspect ratios) – on which the *Kinect Demonstrator* would eventually be used. The prototype was made out of cardstock, which enabled different design features (menus, mapping features, cursors) to be tested physically. This artefact helped to uncover several design issues:

- Whilst trying out different scenarios on this prototype, the position and arrangement of the menus were found to be problematic. If both the side and top menus were fully extended they would overlap and limit accessibility. This prompted the redesign of the top menu, so that even when the side menus are extended none of the functions are covered up.

- A second challenge was found in the scale of the mapping features. One required mapping feature was to draw and edit a circle (the avoid area feature) around a point of interest with diameters of 10m, 100m, and 1000m. When paper versions of the circles were created it was found that the size of the circles varied too greatly for users to comfortably edit them on screen. This feature was revised and the scales of the circle diameter were changed.

- Another problem identified was how Kinect™ was going to recognise the different users that were present. If a user move in and out of the range of view of Kinect™, would they need to sign-in to their roles? To meet this challenge, a side menu was developed to show the role of the users present. This allows the user to switch back to their relevant role should they need to.

An interactive *Wireframe* was created using Microsoft PowerPoint. The composition of the interactive *Wireframe* is presented in Figure 25.

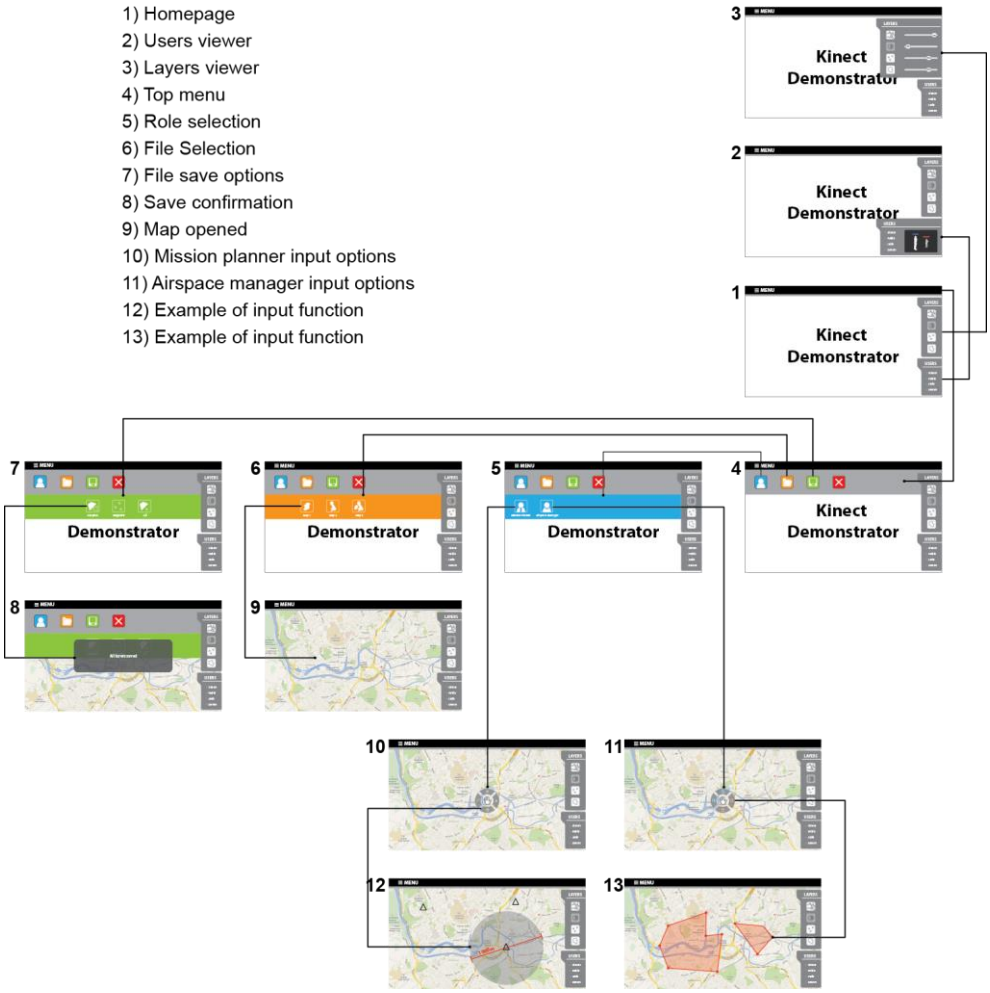


Figure 25 - The composition of the interactive *Wireframe*, 13 screen shots of the to illustrate the functions of the *Kinect Demonstrator*

A total of 13 screen pages were created. An advantage of this artefact is that it can be evaluated independent of the designer. However, in this artefact, the screen pages are linked by a mouse click whereas the system is intended to be operated by gestures.

4.2.3.3 Communicating the Finished Design

As a new vocabulary of natural gestures was developed for the *Kinect Demonstrator*, it was necessary to clearly show the gestures that the system recognises and the commands that they correspond to. To do so, the *Wireframe* method was used along with gesture *Storyboards* (Figure 26).

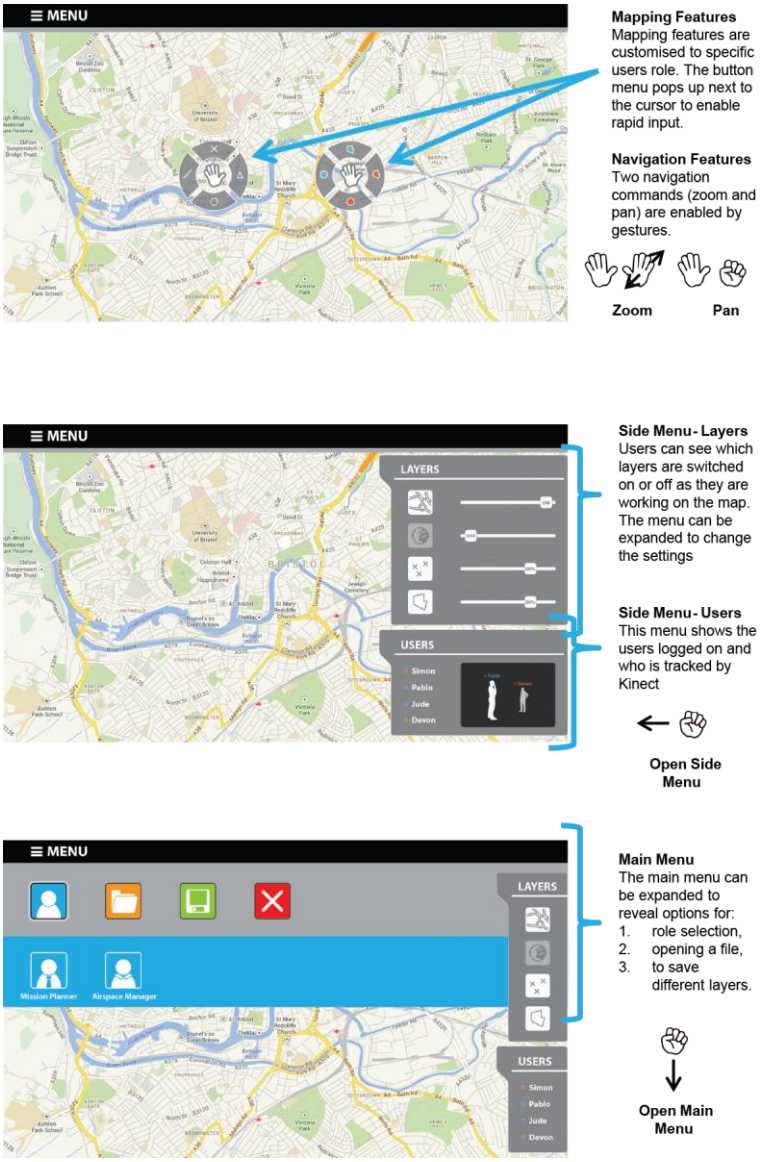


Figure 26 - The *Wireframe* method was employed in combination with gesture images to present the natural gestures design for the *Kinect Demonstrator*, the top figure shows how the mapping and navigation features are accessed, the middle figure shows the functions of the side menus, and the bottom figure shows how the main menu is accessed

4.3 Summary

This chapter presented three case studies that examined how visualisation methods are selected and applied in HCI system development. Case Study I and II investigate the requirements capture activities in the early phases of interaction systems development. Case study III investigates the interaction design of a

geocollaborative system. The challenges and design approaches for all three case studies are reported and discussed. The design challenged identified in this chapter are evaluated in Chapter 5, and contributes to the Guide development (Chapter 5 and 6).

5 VISUALISATION METHOD SELECTION GUIDE

This chapter describes Selection Guide development, which forms the first part of the proposed Guide. The Selection Guide was developed in three steps (detailed in Section 3.2.1): 1) the Selection Approaches identified in the literature review is evaluated, 2) the format of the Selection Guide is designed and developed, and 3) the Selection Guide is evaluated to see if suitable visualisation methods can be identified.

5.1 Introduction

The literature review in Chapter 2 has identified visualisation methods and categorised to five Selection Approaches. However, it was found that individually the Selection Approaches were ineffective when a large number of methods are categorised in one category. To choose between the methods, the designers must take time to differentiate between the methods as, currently, there is no mechanism to narrow down the choices. This chapter seeks to investigate the possibility of bringing together multiple approaches which could help to narrow down the choice of visualisation methods and improve the selection process. To do so, a three-step methodology was followed (this is further detailed in Section 3.2.1):

1. **Evaluation of Selection Approaches:** The Selection Approaches were evaluated based on the design challenges identified in Case Study I, II, and III. The findings in this evaluation contributed to the Selection Guide development in Step 2.

2. **Selection Guide Development:** The Selection Guide was developed in an HTML-based interactive format.

3. **Evaluation of Selection Guide:** The Selection Guide is applied to design challenges. Visualisation methods derived for each challenge were evaluated based on their suitability for that challenge.

5.2 Results and Discussion

In this section, the results of each stage of the methodology are presented followed by the discussion.

5.2.1 Analysis of Selection Approaches

To evaluate the five Selection Approaches, six design challenges (detailed in Section 3.2.1.1) that were identified from the case studies undertaken in Chapter 4 were mapped to suitable categories in each Selection Approach. Table 17 show how the design challenges were mapped to each Selection Approach.

The following sub-sections describe how the categories were selected for each design challenge.

5.2.1.1 Design Challenge I: Fragmented Knowledge

For Design Challenge I, three Selection Approaches were employed. In *The Recipient* approach, the *Designers* category was selected because the roles of the team members were unclear. A visualisation method was needed to clarify the roles within the team. For the *Interaction Type* approach, the categories *Ask* and *Look* were selected. The roles of each team member can be identified through asking them individually or observing their contribution. In *The Design Process* approach, *Plan* was selected because, for this challenge, the design team is determining the scope of the project.

Two Approaches (*Primary Purpose* and *Visual Artefact*) were not employed because they were not appropriate for this design challenge. *Primary Purpose* was not employed because this design challenge is to do with establishing the overall picture of the design team rather than acquiring insights for or evaluating a design. *Visual Archetype* was not employed because no visual preference can be identified from the design challenge description.

Table 17 - The six design challenges identified from case studies undertaken in Chapter 4 are mapped to each Selection Approach

Selection Approach	Design Challenges Identified in Chapter 4					
	I. Fragmented Knowledge	**II. Ambiguous Scenario**	**III. Communicate With Non-Experts**	**IV. Screen Area Design**	**V. Gestures Design**	**VI. Communicate With Stakeholders**
The Recipient	Designers	Designers	User / Stakeholder	Designer	Designer / Stakeholder	Stakeholders
Primary Purpose	-	Generative	Evaluative	Generative	Generative	Evaluative
Visual Archetype	-	-	-	-	Narratives	-
Interaction Type	Ask / Look	Ask / Imagine	-	Imagine	Learn / Imagine	-
The Design Process	Plan	Plan / Explore	Explore	Explore / Create	Explore / Create	Create

5.2.1.2 Design Challenge II: Ambiguous Scenario

For Design Challenge II, four Selection Approaches were employed. For *The Recipient* approach, the *Designers* category was selected because a visualisation method was needed to clarify the design scenario within the team. For the *Primary Purpose* approach, *Generating* was selected to create an overall view of the design scenario. For the *Interaction Type* approach, the categories *Ask* and *Imagine* were selected. The scenario can be developed through asking the team members and then piecing together this information through imagination. In *The Design Process* approach, *Plan* and *Explore* were selected. This challenge was identified in the early stage of the design project when the design team is determining the scope and collating initial ideas.

The *Visual Archetype* approach was not employed because no visual preference can be identified from the design challenge description.

5.2.1.3 Design Challenge III: Communicate With Non-Experts

For Design Challenge III, only three Selection Approaches were employed. For *The Recipient* approach, the *User* and *Stakeholder* categories were selected. A visualisation method is required to communicate the design with end users and stakeholders. For the *Primary Purpose* approach, *Evaluative* was selected to present the design scenario and acquire feedback. In *The Design Process* approach, *Explore* was selected. The design scenario is being evaluated with stakeholders to explore its potential at an early phase of the design project.

The Visual Archetype approach was not employed because no visual preference can be identified from the design challenge description. The *Interaction Type* approach was not employed because this design challenge is to do with presenting a design scenario rather than furthering its development.

5.2.1.4 Design Challenge IV: Screen Area Design

For Design Challenge IV, four Selection Approaches were employed. For *The Recipient* approach, the *Designers* category is selected. A visualisation method is required to communicate the screen are design within the design team. For the *Primary Purpose* approach, *Generative* was selected to identify visualisation

methods to support the creation of the screen area design. For the *Interaction Type* approach, the *Imagine* was selected. The design team is required to come up with interface design based on the client's user case. In *The Design Process* approach, *Explore* and *Create* was selected. This design challenge is identified at the stage of the project where initial ideas are being generated and refined.

The *Visual Archetype* approach was not employed because no visual preference can be identified from the design challenge description.

5.2.1.5 Design Challenge V: Gesture Design

For Design Challenge V, all five Selection Approaches were employed. For *The Recipient* approach, the *Designers* and Stakeholders categories were selected. A visualisation method is required to communicate within the design team and with the client. For the *Primary Purpose* approach, *Generative* was selected for identifying visualisation methods to support the creation of the gesture design. For the *Visual Archetype* approach, *Narratives* was selected. A method is required to represent the step-by-step procedure of each gesture design. For the *Interaction Type* approach, the categories *Learn and Imagine* were selected. The gesture design can be developed through identifying device-recognisable gestures and mapping them to the functions required in the client's use case. In *The Design Process* approach, *Explore* and *Create* was selected. Similar to Design Challenge IV, this design challenge is identified at the stage of the project where initial gesture designs are being generated and refined.

5.2.1.6 Design Challenge VI: Communicate with Stakeholders

For Design Challenge VI, three Selection Approaches were employed. For *The Recipient* approach, the *Stakeholder* category was selected. A visualisation method is required to communicate the client to acquire feedback. For the *Primary Purpose* approach, *Evaluative* was selected to present the screen area and gesture design. In *The Design Process* approach, *Create* was selected. A design solution has been created and is being evaluated with stakeholders for refinement.

The *Interaction Type* approach was not employed because this design challenge is to do with presenting a design solution rather than to further its development. The Visual Archetype approach was not employed because no visual preference can be identified from the design challenge description.

5.2.2 Findings from Selection Approach Evaluation

In the evaluation of the Selection Approaches, it was observed that not all of the approaches were applicable in each design challenges. Out of the six design challenges, the *Visual Archetype* approach was not adopted in five. It was difficult to derive a category because this approach is to do with how the visual artefact will look rather than understanding the nature of the design challenge. *Primary Purpose* is to do with furthering a design through three different human-centred techniques. Design Challenge I did not employed this approach because this challenge is not to do with furthering the design solution, but it is about gaining understanding of the people involved in the project. Design Challenges III and VI both omitted the *Interaction Type* approach. Both design challenge is to do with presenting the design solution outside the design team, whereas the *Interaction Type* approach is about activities the designer can undertake to address the design problem. It is not appropriate in this case because both design challenges is to do with communicating a design solution rather that furthering the design itself.

A second observations is that more than one category may apply to a given design challenge. For example, in Design Challenge II, for the *Interaction Type* approach, both *Ask* and *Imagine* was selected. This challenge required a method for amassing knowledge of the design team (through asking each member) and to piece this information together in a cohesive format (through imagining the outcome).

5.2.3 Developed Selection Guide Overview

Based on the findings described in the previous sections of this chapter, the Select Guide was created. It takes the form an HTML-based interactive format. Each of the five selection approaches identified in the literature review (Chapter

2) acts as a filter for down selecting the visualisation methods. They will be refer to as a *Selection Filter* from this point. On the start screen (Figure **27**), the Selection Filters are presented towards the top of the screen. Under the Selection Filters are the visualisation methods.

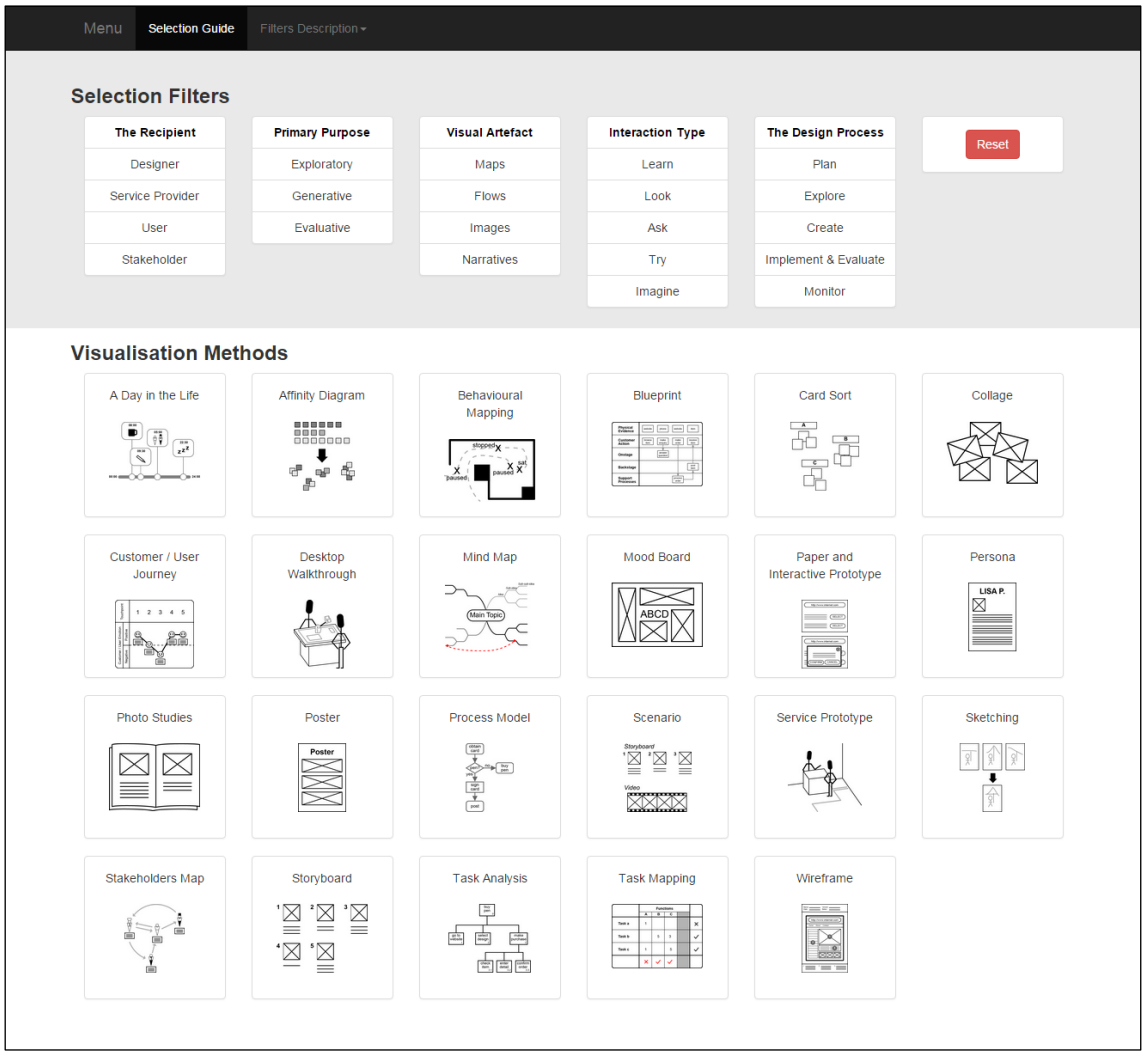


Figure 27 **- A screen short of the developed Selection Guide, at the top are the five Selection Filters, below are the 23 visualisation methods; further details for each visualisation methods are provided in Appendix F**

5.2.3.1 Selection Filters

To use the Selection Guide, the user selects the appropriate category or categories in each filter. The selection can be made in any particular order. After each selection, visualisation methods that do not match the category or

categories selected are filtered out. When more than one category are selected in one filter, the results would show the visualisation method categorised in either category. If categories are selected from different filter, only the visualisation methods categorised in the categories selected for both filters would remain.

Work Example

This section provides an example of how the visualisation methods are down selected when different combinations of Selection Filter categories are chosen. If we consider a situation where the user chooses the following categories:

- In *The Recipient* filter they chose *Designer* and *User.*
- In *The Design Process* filter they chose *Implement & Evaluate*.

When the user selects *Designer* in *The Recipient* filter, all the visualisation methods not categorised in the Designer category are removed (Table 18). From the initial 23 visualisation methods, 18 remains (Figure 28). If the user then select a second category – *Implement & Evaluat*e in *The Design Process* filter, the visualisation methods that are not categorised both these categorises are removed (Table 19). From the 18 visualisation methods (shown in Figure 28), only 4 remains (Figure 29). If the user then select a third category – *User* in *The Recipient* filter, all the visualisation methods that are not categorised in *Designer* or *User* in *The Recipient* filter and *Implement & Evaluation* in *The Design Process* filter is removed (Table 20). This results in 5 visualisation methods (Figure 30), which is one more than the previous step (Figure 29).

When more than one category are selected in one filter, the results would show the visualisation method in either category. If categories are selected from different filter, only the visualisation methods categorised in the categories selected for both filters would remain. The *Scenario* and *Storyboard* methods remain because it was categorised in all three categorises. The *Affinity Diagram*, *Blueprint*, and *Paper and Interactive Prototype* methods also remained because it appeared in *Implement & Evaluation* category in *The Design Process* filter, and either one of *Designer* or *User* category in *The Recipient* filter.

Table 18 - Eighteen visualisation methods are derived when one category (the *Designer* category in *The Recipient* filter) is selected

Method	Selection Filter 1: The Recipient				Selection Filter 2: The Design Process					Resulting Method
	Designer	**Service Provider**	**User**	**Stakeholder**	**Plan**	**Explore**	**Create**	**Implement & Evaluate**	**Monitor**	
A Day in the Life	•					•				✓
Affinity Diagram	•			•		•	•	•	•	✓
Behavioural Mapping	•					•				✓
Blueprint	•			•			•	•		✓
Card Sort	•					•				✓
Collage	•		•			•				✓
Customer / User Journey	•		•			•				✓
Desktop Walkthrough	•	•	•	•	•	•	•			✓
Mind Map	•			•		•				✓
Mood Board				•		•				
Paper and Interactive Prototype			•			•	•	•		
Persona	•			•		•	•			✓
Photo Studies	•					•				✓
Poster				•		•				
Process Model	•	•	•	•		•				✓
Scenario	•	•	•	•		•	•	•		✓
Service Prototype		•	•	•		•	•			
Sketching	•	•	•	•		•				✓
Stakeholders Map	•			•	•	•	•			✓
Storyboard	•	•	•	•		•	•	•		✓
Task Analysis	•	•		•		•	•			✓
Task Mapping				•		•		•		
Wireframe	•		•	•		•				✓

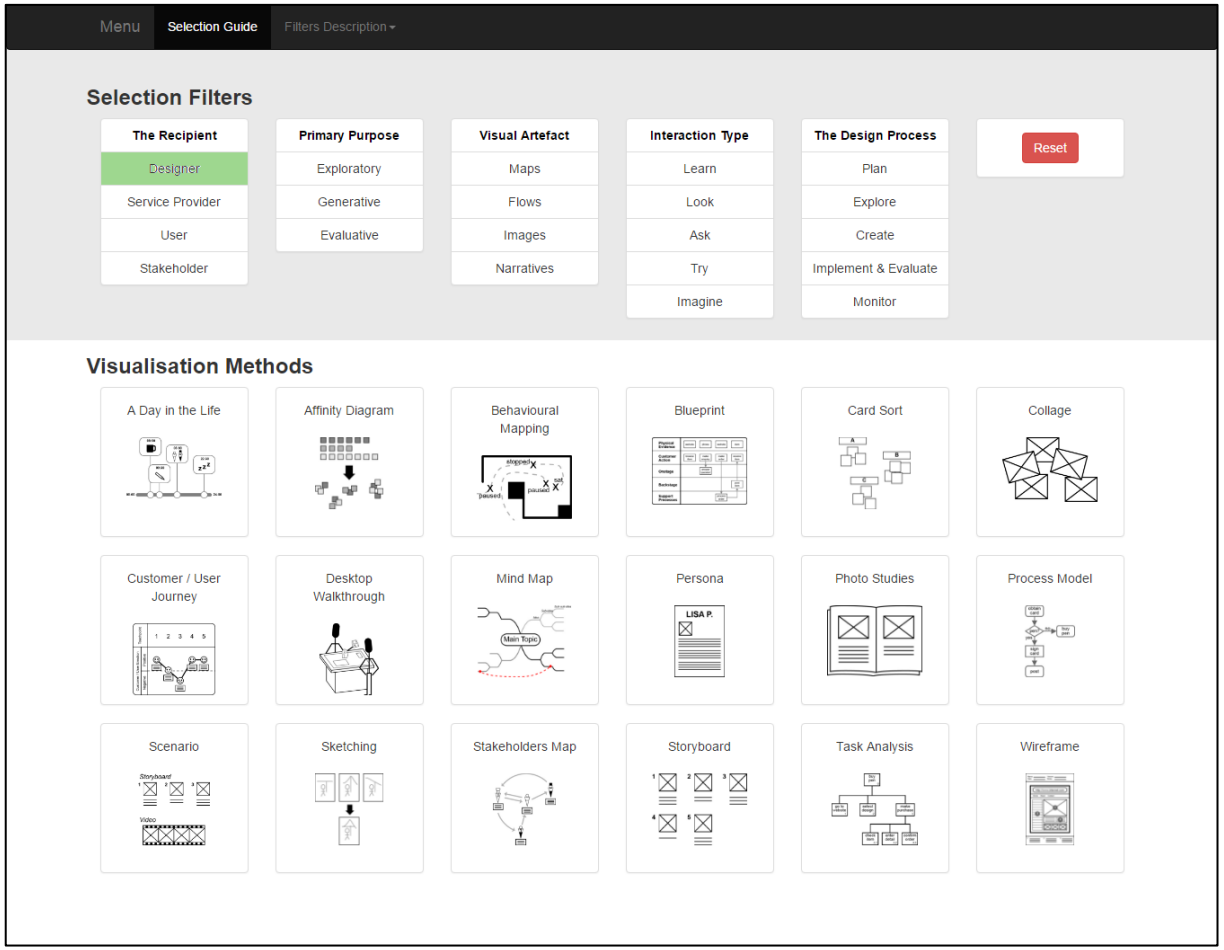


Figure 28 - A screen capture of the Selection Guide when one category (the *Designer* category in *The Recipient* filter) is selected

Table 19 - Four visualisation methods are derived when two categories (the *Designer* category in *The Recipient* filter and the *Implement & Evaluate* category in *The Design Process* filter) are selected

Method	Selection Filter 1: The Recipient				Selection Filter 2: The Design Process					Resulting Method
	Designer	**Service Provider**	**User**	**Stakeholder**	**Plan**	**Explore**	**Create**	**Implement & Evaluate**	**Monitor**	
A Day in the Life	•					•				
Affinity Diagram	•			•		•	•	•	•	✓
Behavioural Mapping	•					•				
Blueprint	•			•			•	•		✓
Card Sort	•					•				
Collage	•		•			•				
Customer / User Journey	•		•			•				
Desktop Walkthrough	•	•	•	•	•	•	•			
Mind Map	•			•		•				
Mood Board				•		•				
Paper and Interactive Prototype			•			•	•	•		
Persona	•			•		•	•			
Photo Studies	•					•				
Poster				•		•				
Process Model	•	•	•	•		•				
Scenario	•	•	•	•		•	•	•		✓
Service Prototype		•	•	•		•	•			
Sketching	•	•	•	•		•				
Stakeholders Map	•			•	•	•	•			
Storyboard	•	•	•	•		•	•	•		✓
Task Analysis	•	•		•		•	•			
Task Mapping				•		•		•		
Wireframe	•		•	•		•				

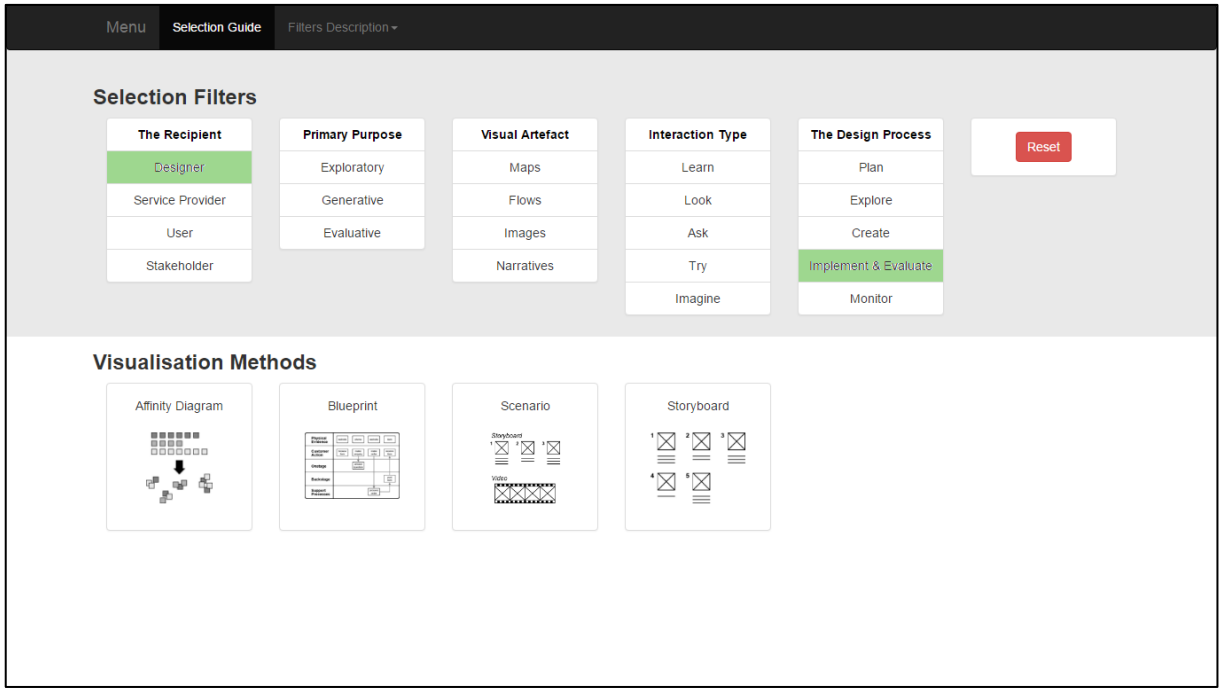


Figure 29 - A screen capture of the Selection Guide when two categories (the *Designer* category in *The Recipient* filter and the *Implement & Evaluate* category in *The Design Process* filter) are selected

Table 20 – Five visualisation methods are derived when three categories (the *Designer* and *User* categories in *The Recipient* filter and the *Implement & Evaluate* category in *The Design Process* filter) are selected

Method	Selection Filter 1: The Recipient				Selection Filter 2: The Design Process					Resulting Method
	Designer	**Service Provider**	**User**	**Stakeholder**	**Plan**	**Explore**	**Create**	**Implement & Evaluate**	**Monitor**	
A Day in the Life	•					•				
Affinity Diagram	•			•		•	•	•	•	✓
Behavioural Mapping	•					•				
Blueprint	•			•			•	•		✓
Card Sort	•					•				
Collage	•		•			•				
Customer / User Journey	•		•			•				
Desktop Walkthrough	•	•	•	•	•	•	•			
Mind Map	•			•		•				
Mood Board				•		•				
Paper and Interactive Prototype			•			•	•	•		✓
Persona	•			•		•	•			
Photo Studies	•					•				
Poster				•		•				
Process Model	•	•	•	•		•				
Scenario	•	•	•	•		•	•	•		✓
Service Prototype		•	•	•		•	•			
Sketching	•	•	•	•		•				
Stakeholders Map	•			•	•	•	•			
Storyboard	•	•	•	•		•	•	•		✓
Task Analysis	•	•		•		•	•			
Task Mapping				•		•		•		
Wireframe	•		•	•		•				

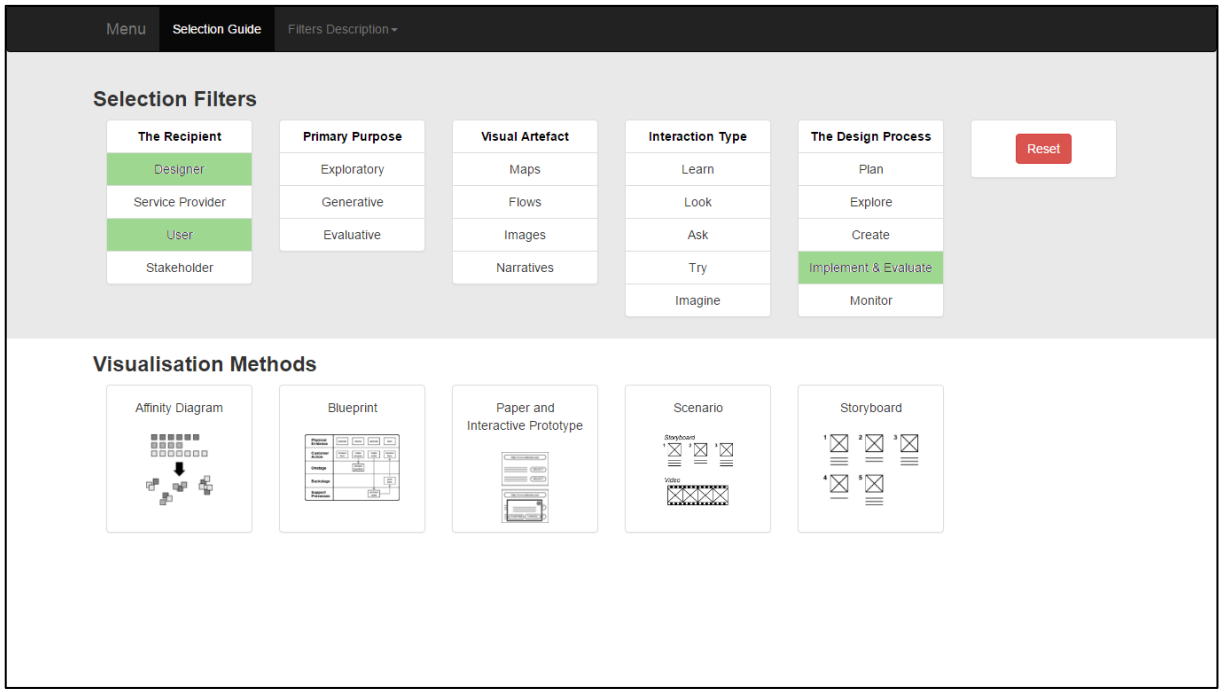


Figure 30 - A screen capture of the Selection Guide when three categories (the *Designer* and *User* categories in *The Recipient* filter and the *Implement & Evaluate* category in *The Design Process* filter) are selected

5.2.3.2 Alert Message

If the filter is not applicable to their challenge, users do not have to use that particular filter. If no suitable visualisation method is identified, an alert would appear (Figure 31). Users can go back to adjust their categories selection, or reset the Selection Guide to make a fresh selection.

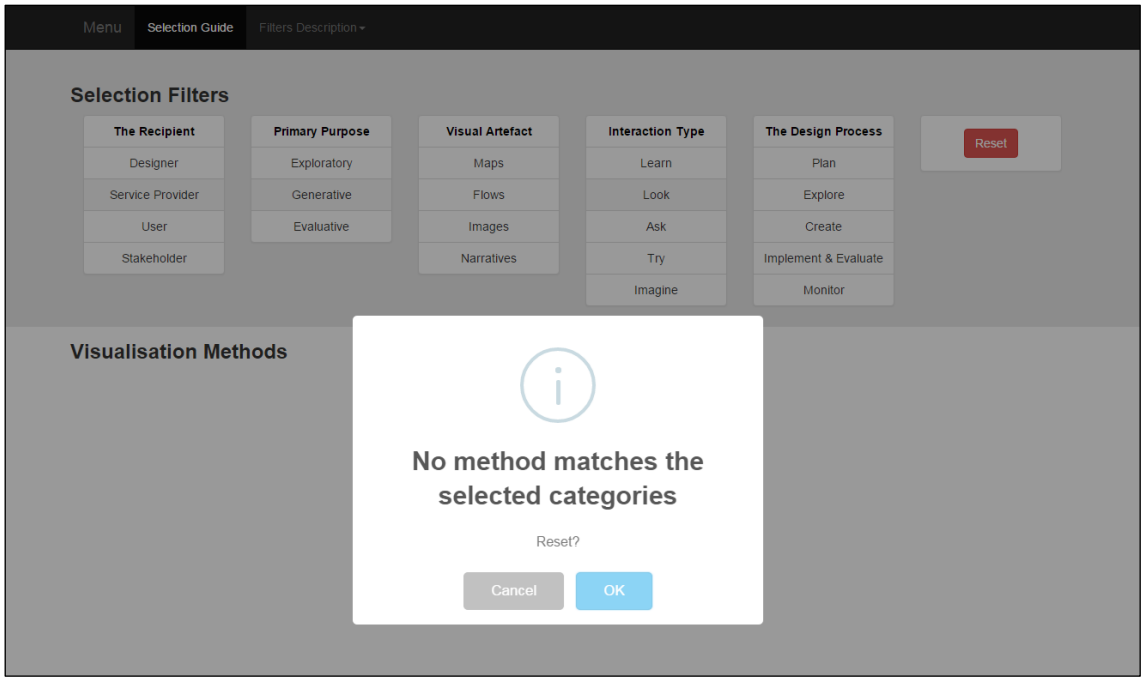


Figure 31 - An alert message is shown if no suitable visualisation method is identified

5.2.3.3 Filters Description

A description for each of the Selection Filters and their categories are provided on separate pages (Figure 32). This is to ensure that users can make the most knowledge selection using this guide, as an incorrect interpretation of the approaches may lead to the selection an inappropriate method (Weevers and van Kuijk, 2012).

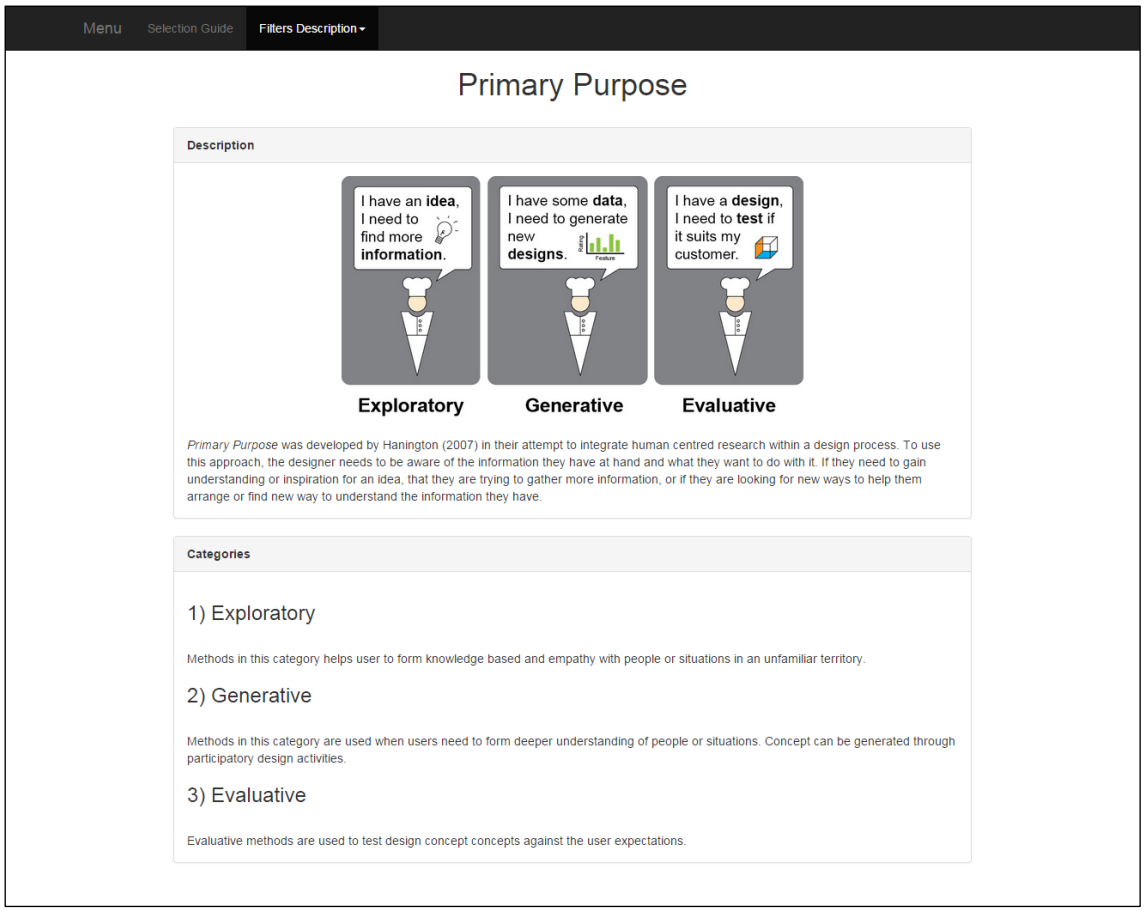


Figure 32 - An example of a Selection Filter description (*Primary Purpose*), an overview of the Selection Approach is given followed by the an explanation of each category

5.2.4 Evaluation of Selection Guide

In this section, the Selection Guide is applied to six design challenges. The resulting visualisation methods are presented and their suitability for that design challenge is discussed.

5.2.4.1 Selection Filters Categories Selection for Design Challenge I: Fragmented Knowledge

For Design Challenge I, the categories chosen for each Selection Filter (detailed in Section 5.2.1: Table 17) is applied to the Selection Guide (Figure 33). This resulted in only one visualisation method, which is *Stakeholders Map.*

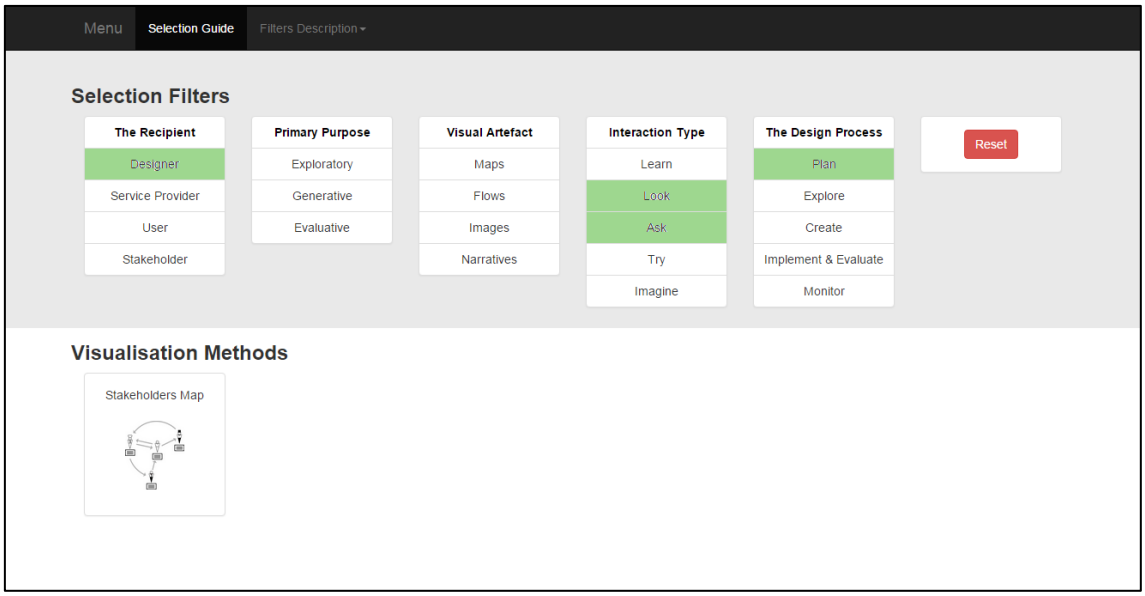


Figure 33 - In the application of the Selection Guide to Design Challenge I four categories were selected (the *Designer* category in *The Recipient* filter, *Look* and *Ask* categories in *Interaction Type* filter, and the *Plan* category in *The Design Process* filter) resulting in one visualisation method

The *Stakeholders Map* method is suitable for Design Challenge I (Table 21). Design Challenge I was to do with the need to clarify team members' role and contribution to the project. The *Stakeholders Map* is a visualisation method for providing an overview of interactions and relationships.

Table 21 - One visualisation method was derived for Design Challenge I

Visualisation Method	Method Suitability	Reason
Stakeholders Map	Yes	This method is for providing an overview of interactions and relationships between stakeholders.

5.2.4.2 Selection Filters Categories Selection for Design Challenge II: Ambiguous Scenario

For Design Challenge II, the categories chosen for each Selection Filter (detailed in Section 5.2.1: Table 17) is applied to the Selection Guide (Figure 34). This resulted in eight visualisation methods (Figure 34), this includes: *Card Sort*, *Collage*, *Desktop Walkthrough*, *Persona*, *Scenario*, *Sketching*, *Storyboard*, and *Wireframe.*

Table 22 - Eight visualisation methods were derived for Design Challenge II

Visualisation Method	Method Suitability	Reason
Card Sort	Yes	This method could be used by the designer to note down known elements of the scenario and ask participants to organise them into relevant groups. Additional elements could be added to generate an overview of the design scenario.
Collage	No	This method makes use of images to help communicate thoughts, feelings, and desire. This design aspect is not required for this design challenge.
Desktop Walkthrough	No	This method involves the creation of a model of the service setting.
Persona	Yes/No	Developing an understanding of the end user is important, but in addition, this design challenge is looking to generate an overview of the design scenario.
Scenario	Yes	This method is specifically for create an explicit account of the design scenario.
Sketching	Yes/No	This method can partially help with the design challenge. Sketching can help the designer to communicate with participants to delve into their understanding of the design scenario.
Storyboard	No	This method is for presenting the key interactions of an interactive system. It is not appropriate for this particular design challenge, in which the goal is to provide an overview of the design scenario.
Wireframe	No	This method supports screen layout design. It is not appropriate for this design challenge.

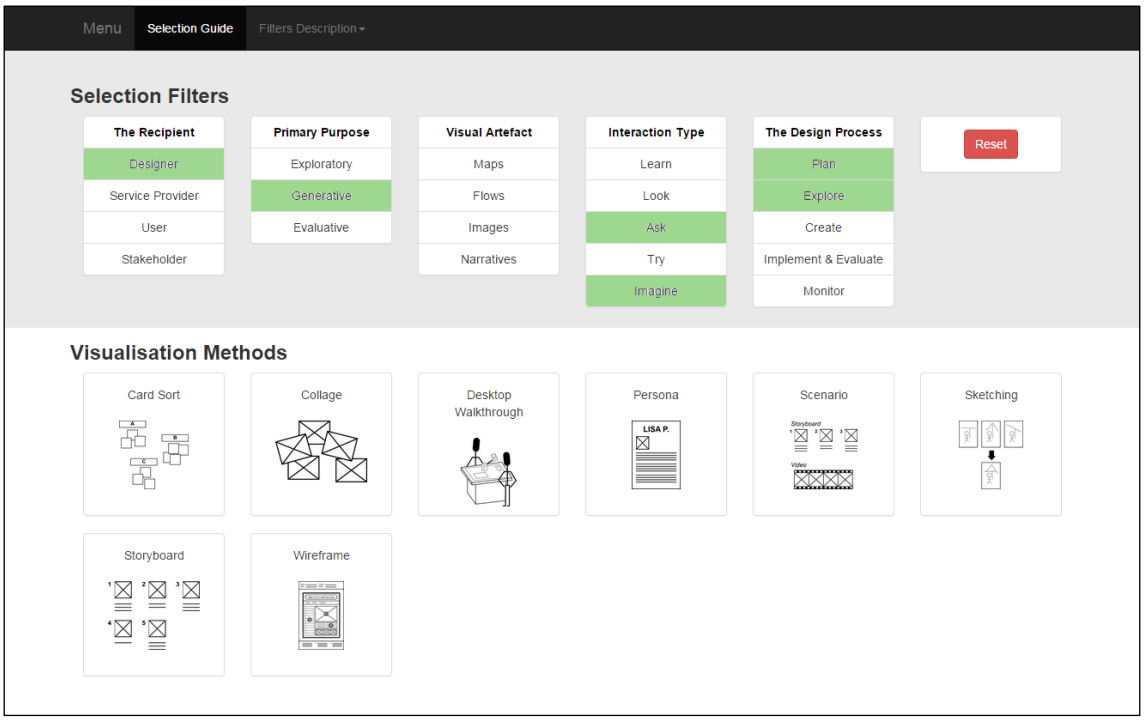


Figure 34 - In the application of the Selection Guide to Design Challenge II six categories were selected (the *Designer* category in *The Recipient* filter, the *Generative* category in *Primary Purpose* filter, *Ask* and *Imagine* categories in *Interaction Type* filter, and *Plan* and *Explore* categories in *The Design Process* filter) resulting in eight visualisation methods

Out of the eight methods identified, four methods (*Collage*, *Desktop Walkthrough*, *Storyboard*, and *Wireframe*) are not suitable, two methods (*Persona* and *Sketching*) are partially suitable and two methods (*Card Sort* and *Scenario*) are suitable for this design challenge (Table 22).

5.2.4.3 Selection Filters Categories Selection for Design *Challenge III:* Communicate With Non-Experts

For Design Challenge III, the categories chosen for each Selection Filter (detailed in Section 5.2.1: Table 17) is applied to the Selection Guide (Figure 35).This resulted in four visualisation methods, this includes: *Customer / User Journey*, *Paper and Interactive Prototype*, *Service Prototype*, and *Wireframe.*

Out of the four visualisation methods identified, three methods are unsuitable (*Customer / User Journey*, *Paper and Interactive Prototype*, and *Wireframe*), and one method (*Service Prototype*) is suitable for this challenge (Table 23).

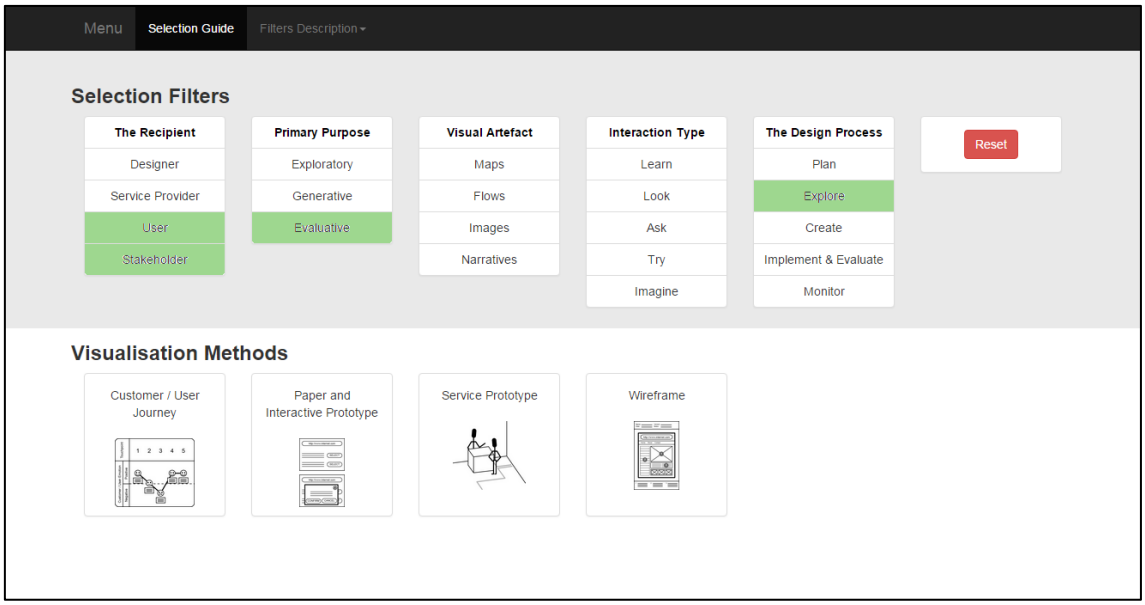


Figure 35 - In the application of the Selection Guide to Design Challenge III, four categories were selected (*User* and *Stakeholder* categories in *The Recipient* filter, the *Evaluative* category in *Primary Purpose* filter, and the *Explore* category in *The Design Process* filter) resulting in four visualisation methods

Table 23 - Four visualisation methods were derived for Design Challenge III

Visualisation Method	Method Suitability	Reason
Customer / User Journey	No	This method presents a user's emotional experience in a service, whereas this design challenge is to communicate a concept of an interaction system.
Paper and Interactive Prototype	No	This method is for representing and testing the screen interface design. It would not have been suitable for this challenge because, at the time, the design team was building up the design scenario. The design project has not reach the point of interface development.
Service Prototype	Yes	As the design scenario involves capturing how a worker performs a task, this method could be adapted to present the setup of the HCI system.
Wireframe	No	As the design challenge is concerned with the communication of the overall design scenario of the HCI system, this method is not appropriate.

5.2.4.4 Selection Filters Categories Selection for Design Challenge IV: Screen Area Design

For Design Challenge IV, the categories chosen for each Selection Filter (detailed in Section 5.2.1: Table 17) is applied to the Selection Guide (Figure 36).This resulted in seven visualisation methods, this includes: *Blueprint*, *Desktop Walkthrough*, *Persona*, *Scenario*, *Sketching*, *Storyboard*, and *Wireframe*.

Of the seven visualisation methods identified, two methods (*Blueprint* and *Desktop Walkthrough*) are unsuitable, two methods (*Persona* and *Scenario*) are partially suitable, and three methods (*Sketching*, *Storyboard*, and *Wireframe*) are suitable for this design challenge (Table 24).

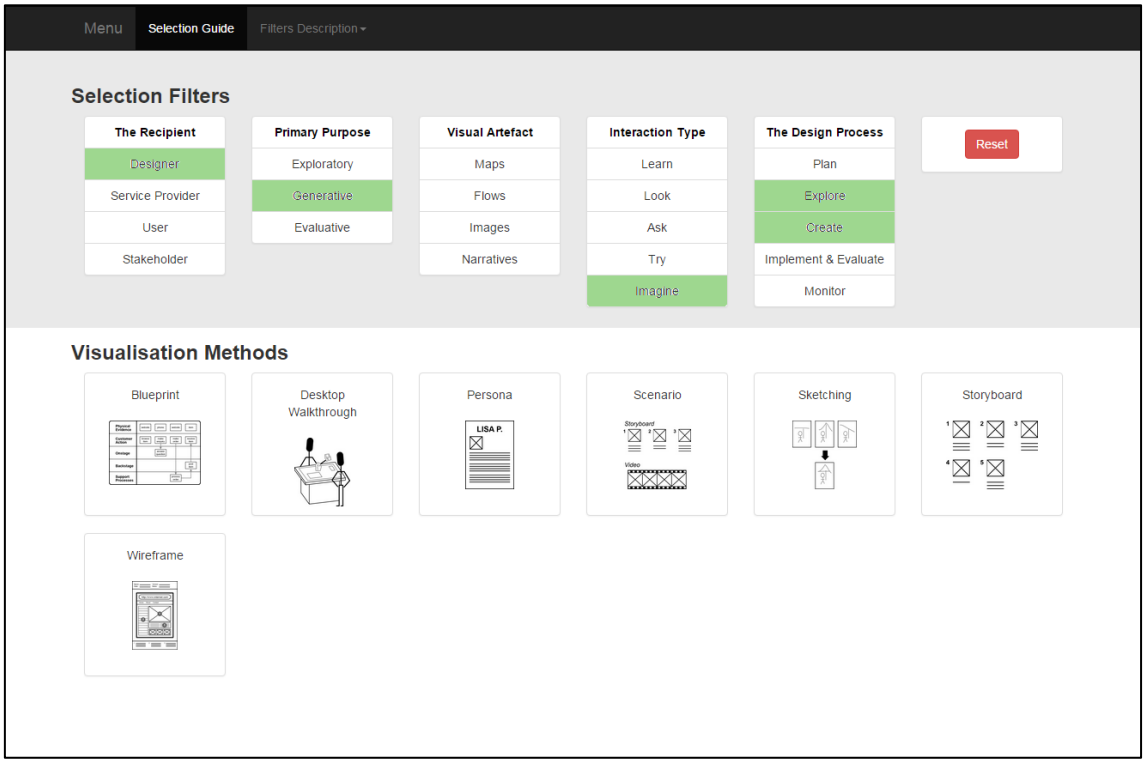


Figure 36 - In the application of the Selection Guide to Design Challenge IV, five categories were selected (the *Designer* category in *The Recipient* filter, the *Generative* category in *Primary Purpose* filter, the *Imagine* category in *Interaction Type* filter, and *Explore* and *Design* categories in *The Design Process* filter) resulting in seven visualisation methods

Table 24 - Seven visualisation methods were derived for Design Challenge IV

Visualisation Method	Method Suitability	Reason
Blueprint	No	This method is tailored for mapping the process of a service design.
Desktop Walkthrough	No	This method involves the creation of the setting of the service interaction. This is not suited for a design challenge that is designing the screen area.
Persona	Yes/No	This method involves gaining understanding of the end user. The artefact created is used to remind the design team of the type of user they are designing for but, by itself, this method does not help to generate screen designs.
Scenario	Yes/No	This method involves the creation of a future scenario from the user's perspective. It helps designers to think of the features the screen design will need to incorporate but, on its own, screen designs are not generated.
Sketching	Yes	This method can be used for designers to communicate and explore ideas within the team.
Storyboard	Yes	This method consists of a series of drawing to show a sequence of events. This could be used to show the variation of the screen as users interact with it.
Wireframe	Yes	This method is specifically for the design of screen layouts.

5.2.4.5 Selection Filters Categories Selection for Design Challenge V: Gesture Design

For Design Challenge V, the categories chosen for each Selection Filter (detailed in Section 5.2.1: Table 17) is applied to the Selection Guide (Figure 37). This resulted in four visualisation methods, this includes: *Desktop Walkthrough*, *Persona*, *Scenario*, and *Storyboard*.

Out of the four visualisation methods, one method (*Desktop Walkthrough*) is found to be unsuitable, two methods (*Persona* and *Scenario*) are partially suitable, and one method (*Storyboard*) is suitable for this design challenge (Table 25).

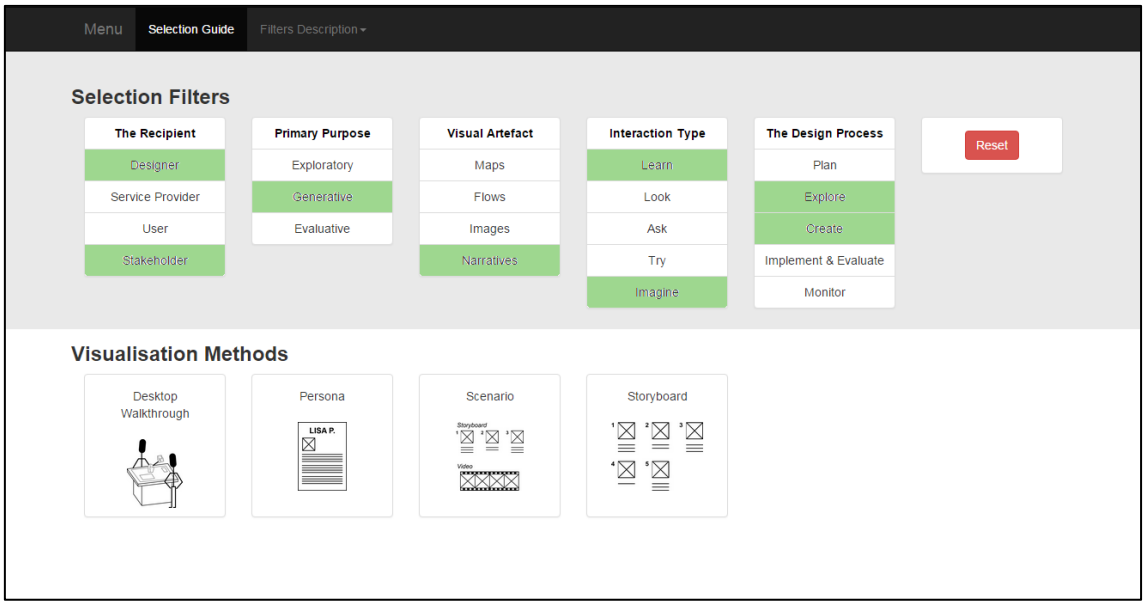


Figure 37 - In the application of the Selection Guide to Design Challenge V, eight categories were selected (*Designer* and *Stakeholder* categories in *The Recipient* filter, the *Generative* category in *Primary Purpose* filter, the *Narrative* category in *Visual Artefact* filter, *Learn* and *Imagine* categories in *Interaction Type* filter, and *Explore* and *Design* categories in *The Design Process* filter) resulting in four visualisation methods

Table 25 - Four Visualisation methods were derived for Design Challenge V

Visualisation Method	Method Suitability	Reason
Desktop Walkthrough	No	This design challenge requires gestures to be designed, but this method is to do with enacting a service setting.
Persona	Yes/No	This method is useful in that it helps the designers to consider who the gestures are being designed for.
Scenario	Yes/No	This method is somewhat useful because it helps the designer to consider possible events in which the gesture design might need to accommodate.
Storyboard	Yes	This method could be used to show the sequence of gestures and the function they constitute.

5.2.4.6 Selection Filters Categories Selection for Design Challenge VI: Communicate With Stakeholders

For Design Challenge VI, the categories chosen for each Selection Filter (detailed in Section 5.2.1: Table 17) is applied to the Selection Guide (Figure 38). This resulted in two visualisation methods, this includes: *Blueprint* and *Service Prototype*.

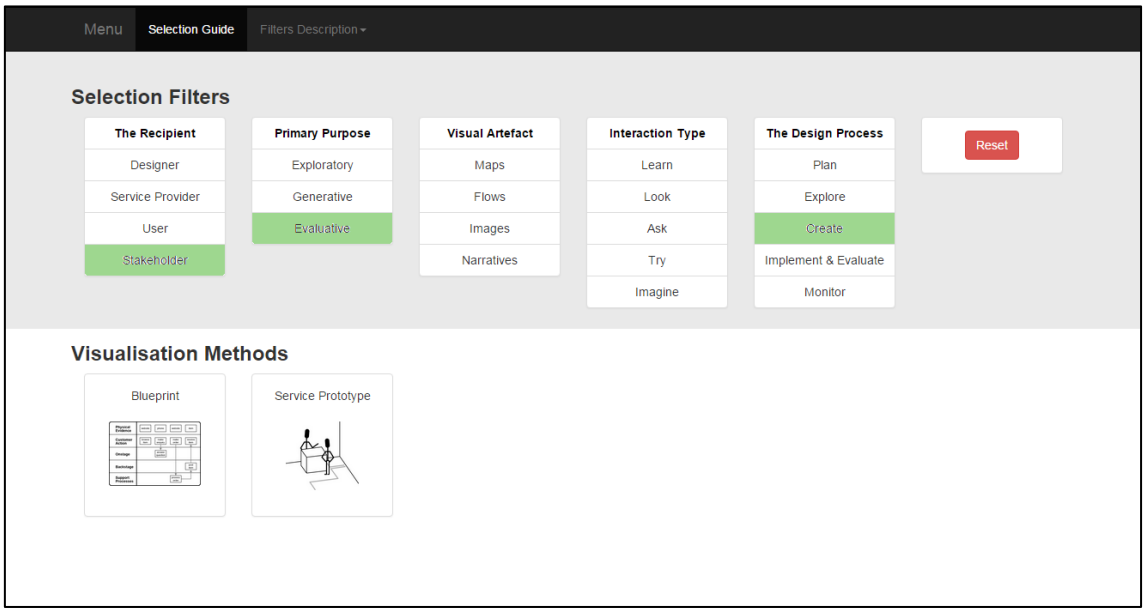


Figure 38 - In the application of the Selection Guide to Design Challenge V, eight categories were selected (the *Stakeholder* category in *The Recipient* filter, the *Evaluative* category in *Primary Purpose* filter, and the *Design* category in *The Design Process* filter) resulting in two visualisation methods

Table 26 - Two visualisation methods were derived for Design Challenge VI

Visualisation Method	Method Suitability	Reason
Blueprint	No	The design challenge requires the gesture and screen design to be communicated with the client. This method is specifically for service design.
Service Prototype	Yes/No	This method is typically used for enacting a service delivery. However, it can be adopted to communicate the arrangement of devices (the position of Kinect™ to the actors and the screen display) and enacting the gestures design.

Of the two visualisation methods identified, one method is found to be unsuitable (*Blueprint*), and the other method (*Service Prototype*) is partially suitable for this challenge (Table 26).

5.3 Summary

This chapter presented the Selection Guide development, which forms the first part of the proposed Guide. An analysis of the Selection Approaches identified that not all the approaches were applicable in each design challenge. Additionally, more than one category may be appropriate for a selection approach. As a result, the Selection Guide was developed in a HTML-based interactive format. The Guide consisted of five Selection Filters. This allows users to down select by selecting suitable categories in each filter. More than one category can be chosen in each filter. The Selection Guide is evaluated using design challenges identified in Chapter 4. This evaluation has shown that it is possible to narrow down and identify suitable visualisation methods from the Selection Guide, which addressed the first research questions identified in the literature review (Section 2.5). The next chapter addresses the second question in the literature review. It details the development of the Application Guide, which is intended to provide a consistent methodology for each visualisation method. This will allow users to compare and choose between the resulting methods from the Selection Guide.

6 VISUALISATION METHOD APPLICATION GUIDE

This chapter describes Application Guide development, which forms the second part of the proposed Guide. The methodology for application of each visualisation method is compiled through three steps (detailed in Section 3.2.2): 1) the techniques for each visualisation method based on references identified in the literature is collated, 2) the methodologies for the visualisation methods are analysed to derive common key steps, and 3) based on the methodology and examples identified from Step 1, a diagram is created for each visualisation method to show their key features.

6.1 Introduction

The previous chapter has presented the development of the first part of the Guide (the Selection Guide). The Selection Guide provides aids designers to down select from a collection of visualisation methods based on their design challenge. This chapter presents the second part of the Guide, which is the development of the Application Guide. It is intended to support the utilisation of the selected visualisation method.

Previous chapters have already identified the description (Appendix C), the categorisation (Section 2.3.3), and examples (Chapter 4) of each visualisation method. Chapter 5 presented the Selection Guide to help designers select a suitable visualisation method for a given design challenge. This chapter seeks to 1) determine the methodology for each visualisation method and 2) to construct the Application Guide.

6.2 Results and Discussion

The methodology for 23 visualisation methods was collated. This section presents the structure of the methodology and the development of the Application Guide.

6.2.1 Key Steps

An analysis was performed on the methodologies collated for each visualisation method. Seven key steps were identified. They are as follows:

1. **Identify Problem:** This step helps the designer to identify: 1) the type of information that is required to create the artefact, or 2) how to obtain the necessary information.

2. **Tool Selection:** This step is to make the designer aware of the types of tools that are available to aid the creation of the visual artefact.

3. **Technique Selection:** This step is to make the designer aware of the techniques available and guide them to use each technique accordingly.

4. **Create Props:** This step informs designers of items required to create the visual artefact. It helps designers to consider if they have the necessary resources to for this visualisation method.

5. **Recruit Participants:** This step informs designers of the type of participant required. It helps designers to consider if they have access to these participants and make clear the roles that participants play in the creation of the artefact.

6. **Create Artefact:** This step indicates the point at which the visual artefact is created. It details the type of information that should be incorporated in the design artefact and how.

7. **Next Step:** Once the artefact is created, this step informs designers what to do with the visual artefact and how it furthers the design process.

6.2.2 Example of Methodology for a Visualisation Method

The methodology for each visualisation method is structured using the key steps identified. The methodology for all 23 visualisation methods is detailed in Appendix F. Using the key steps to structure the methodology can help to familiarise users with the typical methodological steps. Furthermore, it enables the methodological structure to be compared.

Identify Problem

Decide upon the topic you would like to study.

Create Props

Create the following props for the study:

Create Instructions

Set instructions for participants to take photos based on your chosen topic. This could be related to a particular time or event during a day (Sampanes et al., 2011). Create a diary template and ask participants to provide comments or answer set of questions for each photo.

Provide Equipment

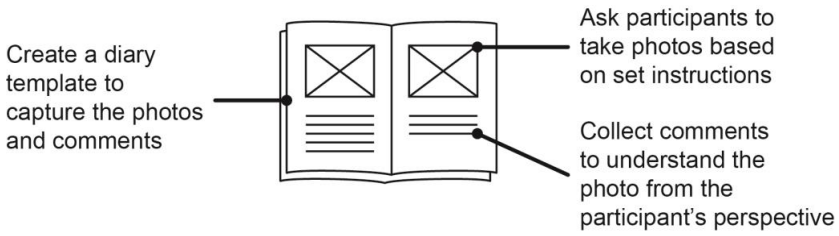
Ensure that you can provide a camera for each participant to undertake this study. Alternatively, provide instructions for participants to use their own camera (Martin and Hanington, 2012).

Recruit Participants

Recruit representative participants of the user group you are designing for.

Create Artefact

Ask participant to follow your set instructions and provide them with a camera. The figure below shows an exemplar format of *Photo Studies*.



Next Step

Once the artefact is created consider to:

Interview Participant

Interview the participants to gain greater understanding of the significance of each photo (Martin and Hanington, 2012).

Sort Photos

Ask the participants to sort the photos in some way (such as positive and negative experiences, or time sequence in which the event in the photo occurs.

Identify Patterns

Analyse the photos for any patterns or themes (Martin and Hanington, 2012).

Figure 39 - *Photo Studies* methodology

As an example, this section presents the methodology of *Photo Studies* (Figure 39). This methodology has 5 steps:

- Step 1: In the first step, the designer is asked to decide on the topic to study. The topic is what you want to learn from the user.

- Step 2: There are a number of props that is necessary for this visualisation method, including a camera and the format in which they are taken and recorded.

- Step 3: The third steps is to recruit suitable participants. For this method the participants required should be representative of the people being designed for.

- Step 4: The actual act of creating the artefact occurs in step 4. For this visualisation method, the artefact is created by the participants. They are provided with cameras and instructions of what photos to take.

- Step 5: Once the study is completed, designers can revisit the photos with the participant or ask them to sort the photos in some way to further understand why they have taken those photos. Furthermore, eliciting pattern from this study inform the design.

6.2.2.1 Main Steps and Sub-Steps

The main steps of the methodology are numbered. For each main step, sub-steps may be included to provide additional information of what to do or offer alternative solutions. For example, in Step 2 (Figure 39), there are two sub-steps. *Create Instructions* and *Provide Equipment*. This clearly shows that two different props are required for this visualisation method, and information for the props creation is provided.

6.2.2.2 Optional Steps

Optional main steps and sub-steps are highlighted using a dotted border. For example, in Step 5 (Figure 39), the sub-steps *Interview Participant* and *Sort Photos* are optional, whereas *Identify Patterns* is mandatory.

6.2.2.3 Diagram

A simple diagram is composed for each method. The diagram serves as a guide for the visual artefact creation. For example, in Step 4 (Figure 39) shows a typical composition of a visual artefact generated from *Photo Studies*. There are three key elements to this artefact: photos, comments, and the diary template.

6.2.3 Development of Application Guide

The Application Guide provides an overview for each visualisation method. To do so, each visualisation method has an individual HTML page containing the following information:

1. **Filters:** This area shows how the visualisation method is categorised in each filter. This information is taken from the literature review (Chapter 2).

2. **Description:** A brief description (taken from Chapter 2) is provided alongside a diagram (developed in this chapter) to show how information is structure using this visualisation method.

3. **How to use:** A methodology is provided for each visualisation method (this was developed in this chapter).

4. **Examples:** The section shows example of visual artefacts developed in Chapter 4.

5. **Reference:** References are provided for further reading.

As an example, Figure 40 shows a screen capture of the HTML page for the *Storyboard* method.

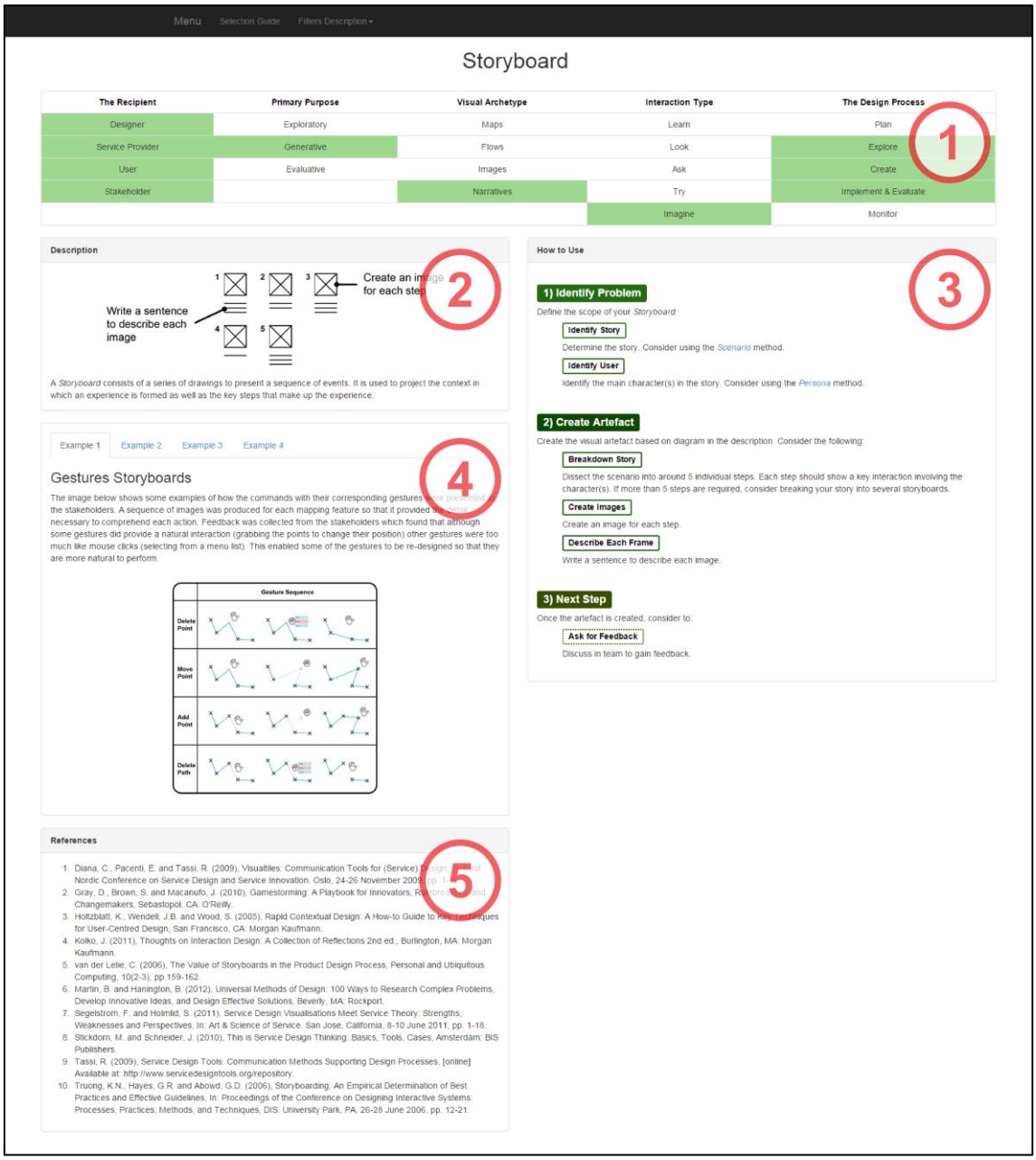


Figure 40 - The composition of the *Storyboard* method in the Application Guide, which consists of: 1) how the method is categorised in each Selection Filter, 2) the description and a diagram of the visualisation method, 3) the methodology of how the method is applied, 4) examples of the visualisation method is provided, and 5) references for users to learn more about the method

6.2.4 Evaluation of Application Guide

6.2.4.1 Methodology Variation

There is variation in the procedure of the methodologies. From Table 27 it can be seen that there are three critical steps in employing a visualisation method: to understand the problem at hand, the act of creating the visual artefact, and to understand how it can be used to further the design process. Factors that could influence the choice of method include the tools and technique selection, props creation, and the participants that may need to be recruited.

Three out of the seven steps are fixed and appears in the methodology of all 23 visualisation method (Table 27). These fixed steps are: *Identify Problem*, *Create Artefact*, and *Next Step*.

6.2.4.2 Associative Methods

The provision of an Application Guide helps designers to see what type of information and resources they require for each method. However, it is clear that some methods require the reinforcement of other techniques (such as Interview, Contextual Inquiry) (Table 28) which are not included in the list of visual methods. As Lengler and Eppler (2007) have suggested, one method on its own may not be enough to meet a design challenge. In some cases it may be beneficial to use combination of visualisation methods (Aldersey-Williams et al., 1999).

Table 27 - The main steps for each visualisation method

	Visualisation Method	Main Steps						
		Identify Problem	Tool Selection	Technique Selection	Create Props	Recruit Participants	Create Artefact	Next Step
1	A Day in the Life	•		•		•	•	•
2	Affinity Diagram	•				•	•	•
3	Behaviour Mapping	•			•	•	•	•
4	Blueprint	•				•	•	•
5	Card Sort	•			•	•	•	•
6	Collage	•			•	•	•	•
7	Customer / User Mapping	•					•	•
8	Desktop Walkthrough	•				•	•	•
9	Mind Map	•	•				•	•
10	Mood Board	•					•	•
11	Paper and Interactive Prototype	•					•	•
12	Persona	•				•	•	•
13	Photo Studies	•			•	•	•	•
14	Poster	•			•	•	•	•
15	Process Model	•					•	•
16	Scenario	•		•			•	•
17	Service Prototype	•					•	•
18	Sketching	•					•	•
19	Stakeholder Map	•					•	•
20	Storyboard	•					•	•
21	Task Analysis	•					•	•
22	Task Mapping	•			•	•	•	•
23	Wireframe	•	•		•		•	•
	Total	23	2	2	7	11	23	23

Table 28 - The associative methods for each visualisation method

Visualisation Method	Associative Research Method					Associative Visualisation Method		
	Contextual Inquiry	Field Studies	Focus Group	Interview	Usability Testing	Persona	Scenario	Storyboard
A Day in the Life		•		•				
Affinity Diagram		•		•				
Behaviour Mapping	•				•			
Customer / User Mapping						•	•	
Desktop Walkthrough						•	•	
Paper and Interactive Prototype								•
Persona		•	•	•				
Scenario	•	•		•		•		•
Storyboard						•	•	

6.3 Summary

In the literature review (Section 2.5), it was found that the procedure for the application of each visualisation method varies in terms of both the level of details and contents. To address this problem a visualisation method Application Guide was developed in this chapter. Methodologies for each visualisation method were collated and analysed. Common key steps identified in the methodologies were derived. This allowed for the methodology of each visualisation method to be structured in the same way for ease of comparison and to ensure comprehensive information is provided.

7 VALIDATION

This chapter presents the validation of the proposed Guide (developed in Chapter 5 and 6). This Guide is validated in two part: the first is to demonstrate the application of the Guide in the design of a serious training game, and the second is to evaluate if the Guide aided the serious training game development.

In demonstrating the application of the Guide, a two-step methodology was followed (further detailed in Section 3.3.1): 1) design challenges were identified during the serious training game development and 2) The Guide was utilised to aid the selection of a suitable visualisation method for each design challenge.

To evaluate if the Guide aided the serious training game development, a user study was carried out to evaluate the effectiveness of the game. A three-step methodology was followed (further detailed in Section 3.4.1): 1) A user study was designed to evaluate learning aspects of the game, 2) participants were recruited to participate in the user study, and 3) the user study was conducted; participants were asked to study the training procedure follow by the completion of two knowledge tests and an attitudinal survey.

7.1 Introduction

Training new workers in complex manufacturing tasks has long been a challenge for high value manufacturing companies (Mital et al., 1999). In particular training that involves hands-on experiences have associated impediments, such as the limited availability of physical equipment (Bal, 2012), health and safety concerns in the operation of dangerous equipment (Sun and Tsai, 2012), and the high training costs involved having to dedicate both the equipment and experienced professionals to instruct new workers. Serious Game (SG) and Virtual Environment (VE) applications have been studied as alternative learning methods for reducing the impact of these hurdles. These applications have many prospective benefits when applied to the context of complex manufacturing training. Firstly, they have the potential to improve the quality of training by providing a standardised work process to train or re-train operators (Vizendo, 2014). Secondly, they enable concurrent learning, thus reducing the training time

and instructor load (Mitchell and Savill-Smith, 2004). Furthermore, SG and VE offer the opportunity for users to train in an environment where they can learn and explore without severe consequences (Ekanayake et al., 2010; Aziz et al., 2014). Not only does this allow users to practice and rehearse situations which may be difficult or dangerous to reproduce in real world scenarios (González-Franco et al., 2014), but it creates the possibility to influence a user's behaviour in real life (Mitgutsch and Alvarado, 2012; Peck et al., 2013).

Inside a VE, players can explore and interact with different scenarios through simulations (Rogers et al., 2011), and experience the effects of their actions (Gredler, 2004; González-Franco et al., 2010; Spanlang et al., 2014). In short, VE are artificial environments that imitate reality (Ma and Zheng, 2011). SG applications, on the other hand, are like video games. They are designed to be competitive and entertaining, but on top of that they contain pedagogic elements that are intended to impart knowledge to the player (Zyda, 2005; Gredler, 2004). To summarise, SG applications are video games with a learning aspect.

SG and VE applications are already being developed for training in a variety of disciplines, including health and safety in the construction industry (Dickinson et al., 2011; Kang and Jain, 2011; Greuter et al., 2012), medical training (Knight et al., 2010; Bartoli et al., 2012; Gonzalez-Franco et al., 2014; Torrente et al., 2014), operations management (Lewis and Maylor, 2007), and fire services (Williams-Bell et al., 2015). However, to date, few examples of their use in complex manufacturing exists. Rare examples include the creation of virtual machines and equipment to allow learners explore at their own pace (Ong and Mannan, 2004) and do so from different localities (Bal, 2012), to provide procedural training for car maintenance (Borsci et al., 2015) and aerospace servicing (Abate et al., 2009), and to ensure safety in the training on injection moulding machines (Sun and Tsai, 2012).

This chapter presents the development and evaluation of a serious training game. It details how the Guide (developed in Chapter 5 and 6) is utilised in the development. Through evaluating the serious training game, the Guide is validated.

7.1.1 Serious Training Game Development

The serious training game (TG) designed in this chapter is intended to act as alternative method for training workers in the manufacturing environment. At the start of the project, the design team were provided with the following documents:

- CAD models of assembly jig and forward door panel,
- Nine instruction manuals for the assembly of a forward door panel.

The goal of the project is to transform the instruction manual into a serious training game. The game was developed by a multidisciplinary team, which consisted on the author and seven other team members. The roles within the team included: the project manager, visual designers, programmers, and subject matter experts (to help decode and interpret the instruction manuals).

In the game development, the author mainly contributed to decoding the instructions manuals and designing the visuals for the game. All of the images in Section 7.2.2 were created by the author.

7.1.2 Serious Training Game Evaluation

The purpose of measuring the effectiveness is to ensure the desired outcomes are achieved. Current literature shows disputes regarding the effectiveness of SG. Even though meta-analytic studies have found gaming to be an effect instructional tool (Sitzmann, 2011; Wouters et al., 2013), it is argued that games included in the analysis lacks of rigorous testing (Bellotti et al., 2013; Connolly et al., 2012; All et al., 2014). There can be a huge variation between one SG to another based on the skills being trained (Girard et al., 2013). In developing a framework for measurement the effectiveness of SG, All et al. (2015) identified three categories of assessment: learning outcome, motivational outcome, and efficiency outcome. This chapter intends to measure the learning effectiveness of the serious training game (detailed in Section 7.1.1).

There have been some attempts in categorising the different learning outcomes of games on: Cognitive Learning, Motor Skill, Affective Learning or Communicative Learning (Wouters et al., 2009), but also on: Cognitive Outcome,

Affective Outcome, Skill Based Learning Outcome (Garris et al., 2002), and on: Content Understanding, Problem Solving, Collaborative/teamwork, Communication, Self-Regulation (O'Neil et al., 2005). Even though, there are several ways of categorising learning outcomes, it seems appropriate to use standardised metrics to really understand the learning effects of a SG. Similar to Buchanan et al. (2011), this study has made use of the revised Bloom's Taxonomy (Anderson and Krathwohl, 2001; Krathwohl, 2002) to describe the type of learning the TG is designed to impart. By clearly documenting the learning objectives the author hope this study can be compared like-for-like with similar work in the future. Two learning objectives are measured in this study. The first is for participants to *recall the necessary tools, equipment, and documentations for a specific manufacturing task* (Objective 1), and the second is to *correctly perform an assembly operation* (Objective 2). Table 29 shows how the two learning objectives are categorised.

Table 29 - Mapping the learning objectives to the knowledge dimension and cognitive process dimension of Bloom's Taxonomy

The Knowledge Dimension	**The Cognitive Process Dimension**					
	1. Remember	2. Understand	3. Apply	4. Analyse	5. Evaluate	6. Create
A. Factual	Objective 1	-	-	-	-	-
B. Conceptual	-	-	-	-	-	-
C. Procedural	-	-	Objective 2	-	-	-
D. Metacognitive	-	-	-	-	-	-

Objective 1 is categorised in A1 (Factual-Remember). This objective requires the learner to be able to remember factual knowledge. *Remember* is at the lower end in the Cognitive Processes Dimension. Objective 2 is categorised in C3 (Procedural-Apply). Objective 2 requires the learner to *apply* the knowledge they have learnt. *Applying* knowledge is a higher order thinking skill compared with *remembering* (as in Objective 1).

7.2 Results and Discussion

This section first presents how the Guide was adopted to identify a suitable visualisation method for each design challenge. This is followed by the application of the visualisation method.

7.2.1 Serious Training Game Development: Visualisation Method Selection

The Selection Guide (Chapter 5) was utilised to identify suitable visualisation methods for each of the design challenges encountered. This section presents: 1) the category or categories chosen for each Selection Filter, 2) the resulting visualisation methods, and 3) which visualisation method is chosen.

7.2.1.1 Design Challenge A: Composing Design Ideas

The choice of categories for each Selection Filter is presented in Table 30. The application of the Selection Guide to Design Challenge A resulted in two visualisation methods (Figure 41), this includes: *Photo Studies* and *Sketching*.

Table 30 - The categories selected in each Selection Filter Design Challenge A

Selection Filter	Category Selection	Reason
The Recipient	Designer	At this early of the game development, initial ideas of the game design is being generated and discussed within the design team.
Primary Purpose	Exploratory	The designer is exploring a number of ideas for the game design.
Visual Archetype	Images	In exploring ideas for the game, images of the interface design are to be created.
Interaction Type	Imagine	Through studying the instruction manuals, the designer have formed initial understand of the manufacturing process. Based on this foundation knowledge, this process needs to be translated into a game setting.
The Design Process	Plan / Explore	This design challenge is to define the scope of the project (identifying the crucial training elements, or steps that can be simplified in the game), and using this information to form initial ideas of the game design.

Of the two visualisation methods identified, one method is suitable (*Sketching*), and the other not suitable (*Photo Studies*) for this design challenge (Table 31). The *Sketching* method was chosen for this design challenge because it is method that could help the design to explore and communicate design ideas. The *Photo Studies* method was not appropriate for this challenge because the design team did not have access to the end user.

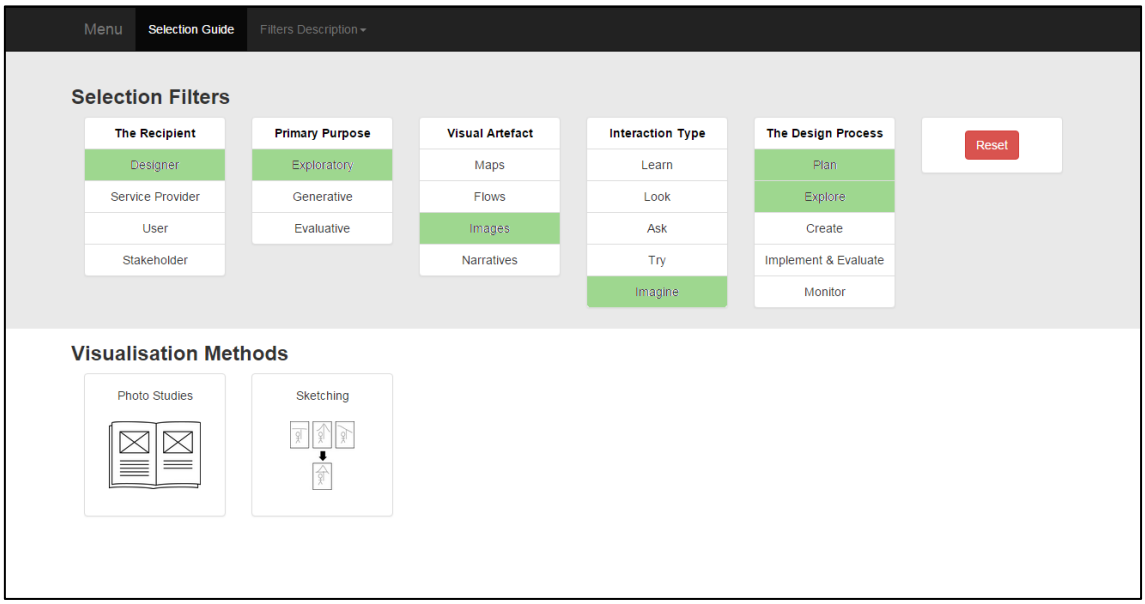


Figure 41 - Two visualisation methods were derived for Design Challenge A

Table 31 - The visualisation methods derived from the Selection Guide and their suitability for Design Challenge A

Visualisation Method	Method Suitability	Reason
Photo Studies	No	This method requires user participation. They are asked to take photos of objects and environments based on a set criteria. As the design team did not have access to the end users, this method was not chosen.
Sketching	Yes	Sketching can help the designer to communicate with participants to delve into their understanding of the design scenario.

7.2.1.2 Design Challenge B: Composing the User Interface Design

The choice of categories for each Selection Filter is presented in Table 32. The application of the Selection Guide to Design Challenge B resulted in one visualisation methods (Figure 42), which was *Wireframe*. The *Wireframe* method is suitable for the design challenge, which was to do with composing the user interface (Table 33). Hence, this method was chosen in Design Challenge B.

Table 32 - The categories selected in each Selection Filter for Design Challenge B

Selection Filter	Category Selection	Reason
The Recipient	Designer / User	The interface design is to be agreed upon. It would be beneficial to gain input from the design team and potential users.
Primary Purpose	Generative / Evaluative	The interface design is being generated and finalised.
Visual Archetype	Maps	The game must contain the required information for the manufacturing training process. The interface design needs to show how this information is structured in the game.
Interaction Type	Try / Imagine	The designer is required to imagine the designer and evaluate the interface design.
The Design Process	Explore	The designer is exploring ideas for the interface design.

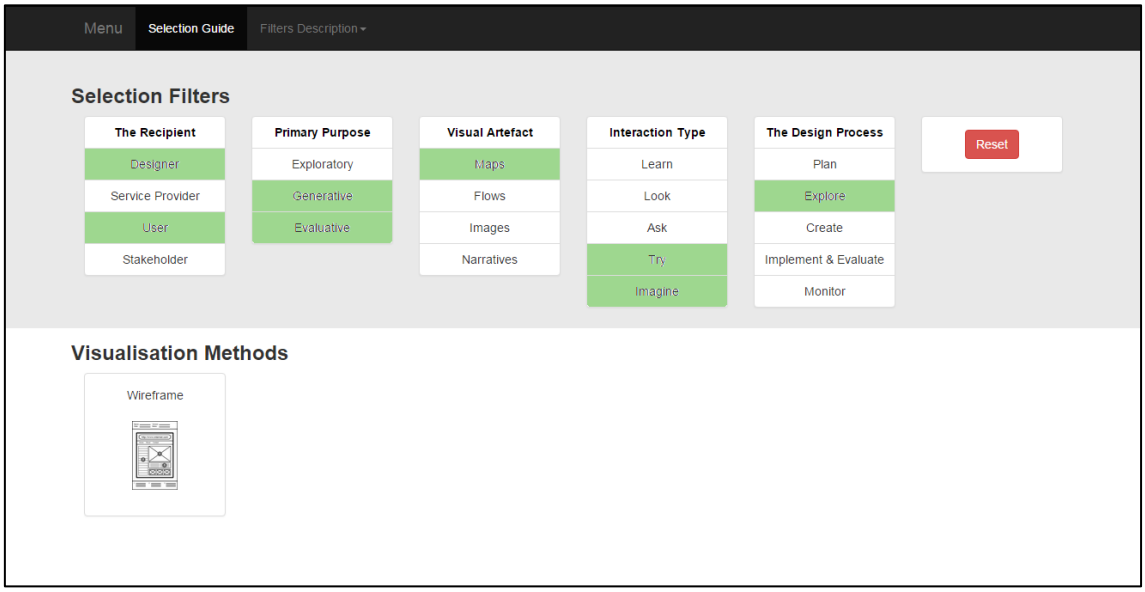


Figure 42 - One visualisation method was derived for Design Challenge B

Table 33 - The visualisation methods derived from the Selection Guide and their suitability for Design Challenge B

Visualisation Method	Method Suitability	Reason
Wireframe	Yes	This method is specifically for the design of screen layouts.

7.2.1.3 Design Challenge C: Transforming the Instructions into a Game

The choice of categories for each Selection Filter is presented in Table 34. The application of the Selection Guide to Design Challenge C resulted in six visualisation methods (Figure 43), this includes: *Desktop Walkthrough, Paper and Interactive Prototype, Persona, Scenario, Service Prototype,* and *Storyboard*.

Table 34 - The categories selected in each Selection Filter Design Challenge C

Selection Filter	Category Selection	Reason
The Recipient	Designer / User	The game flow is to be designed. It will be evaluated by the design team and potential users.
Primary Purpose	Generative / Evaluative	The game flow is being generated and finalised.
Visual Archetype	Narrative	The step-by-step process is to be presented to show the game flow.
Interaction Type	Try / Imagine	The designer is required to imagine the designer and evaluate the game flow.
The Design Process	Explore	The designer is exploring ideas for the game flow.

Of the six visualisation methods identified, three methods are not suitable (*Desktop Walkthrough, Persona,* and *Service Prototype*), one method is partially suitable (*Scenario*), and two methods are suitable (*Paper and Interactive Prototype* and *Storyboard*) for Design Challenge C (Table 35). Between the two suitable methods, the *Paper and Interactive Prototype* method was chosen for this design challenge. This is because Design Challenge C consists of a number of features to be considered, even though the *Storyboard* method could help designers to pinpoint how the features would be placed in the game, it is lacking the flexibility of the *Paper and Interactive Prototype* method that allows the design to be tested and changed as it evolved.

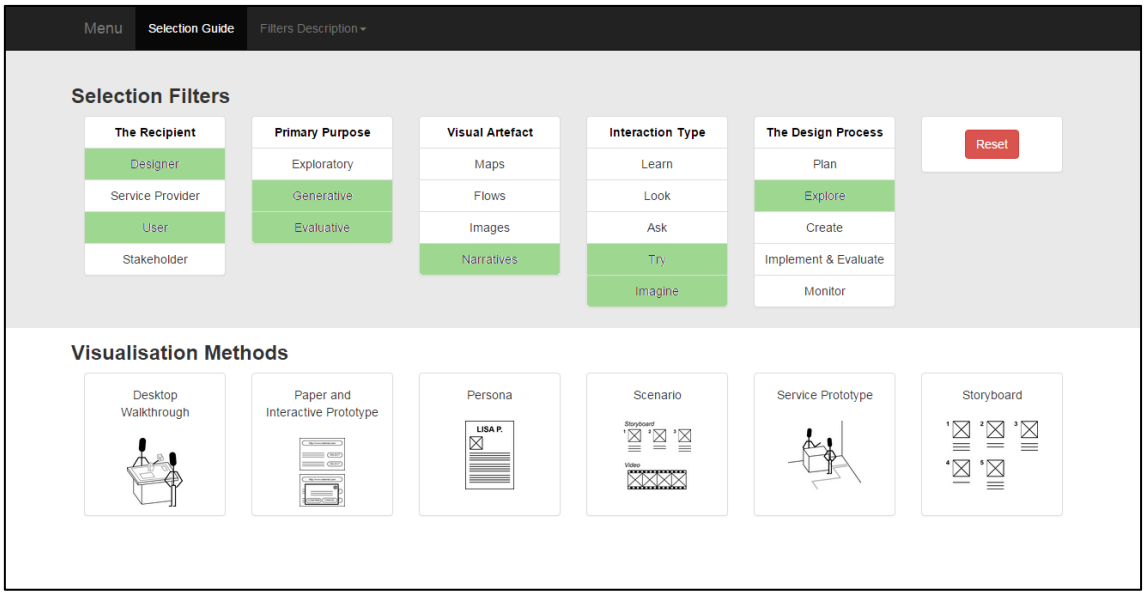


Figure 43 - Six visualisation methods were derived for Design Challenge C

Table 35 - The visualisation methods derived from the Selection Guide and their suitability Design Challenge C

Visualisation Method	Method Suitability	Reason
Desktop Walkthrough	No	This method involves the creation of the setting of the service interaction. This is not suited for a design challenge that is designing the screen area.
Paper and Interactive Prototype	Yes	This method is for representing and testing the screen interface design. This method enables designers to refine the design early on in the design process.
Persona	No	This method involves gaining understanding of the end user. The artefact created is used to remind the design team of the type of user they are designing for but, by itself, this method does not help to generate screen designs.
Scenario	Yes/No	This method involves the creation of a future scenario from the user's perspective. It helps designers to think of the features the screen design will need to incorporate but, on its own, screen designs are not generated.
Service Prototype	No	This methods is use for testing a service delivery, which is not suitable for the design challenge that is to do with transforming manufacturing instructions into a game.
Storyboard	Yes	This method consists of a series of drawing to show a sequence of events. This could be used to show the variation of the screen as users interact with it.

7.2.1.4 Design Challenge D: Designing Feedback System

The choice of categories for each Selection Filter is presented in Table 36. The application of the Selection Guide to Design Challenge D resulted in two visualisation methods (Figure 44), this includes: *Card Sort* and *Mind Map.*

Table 36 - The categories selected in each Selection Filter Design Challenge D

Selection Filter	Category Selection	Reason
The Recipient	Designer	The feedback system is being designed. It will be discussed within the design team.
Primary Purpose	Exploratory	The design team came up with rough ideas of how the feedback system would function. Further exploration is required to develop the feedback system.
Visual Archetype	Map	Map was chosen to help connect the manufacturing procedure to the type of mistakes that could be made and the point at which feedback may be provided.
Interaction Type	Learn / Imagine	The designer is required to learn of the manufacturing procedure and identify areas in which the feedback system could support the user.
The Design Process	Explore	The designer is exploring ideas for the feedback system.

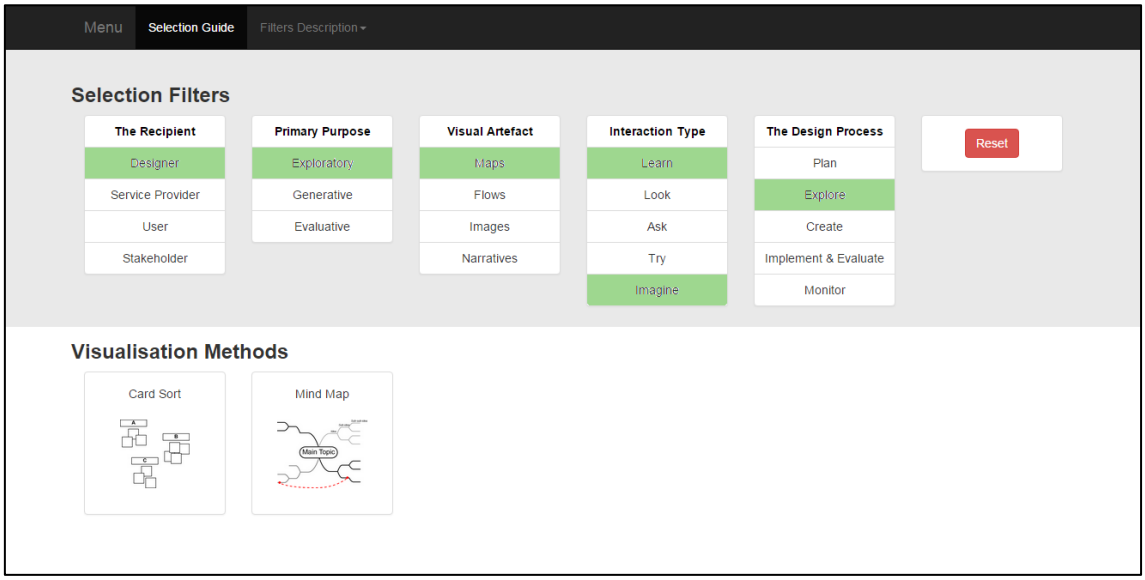


Figure 44 - Two visualisation methods were derived for Design Challenge D

Of the two visualisation methods identified, the *Mind Map* method was chosen for Design Challenge D. This is because the *Mind Map* method is suitable for externalising and connecting related ideas for designing the feedback system (Table 37). The *Card Sort* method was not chosen because this method required a number of participants. This resource was not available at the time of the research.

Table 37 - The visualisation methods derived from the Selection Guide and their suitability Design Challenge D

Visualisation Method	Method Suitability	Reason
Card Sort	No	This method is used by the designer to note down know elements of the scenario and ask participants to organise them into relevant groups. This method is unsuitable because it required external participants which were available at the time of study.
Mind Map	Yes	This method helps designers to extract out thoughts and their connections. Clarify their thoughts and connects pieces of information.

7.2.2 Serious Training Game Development: Visualisation Method Application

Section 7.2.1 presented how the Selection Guide was employed to identify appropriate visualisation methods for the design challenges. The resulting visualisation methods were analysed, and based on the design challenge the most suitable method was selected for each design challenge. This section presents how the chosen method in each design challenge was applied.

7.2.2.1 Design Challenge A: Composing Design Ideas

For Design Challenge A, the *Sketching* method was selected. The reasons for selecting *Sketching* was discussed in Section 7.2.1. The five-step methodology is show below along with the designer's response to each step.

1 Identify Problem

After forming an initial understanding of the instruction manuals, the next step was to consider how it can be converted into a game format. Two questions were identified:

- How does a player collect a tools, materials and equipment?
- How does a player interact with the jig?

2 Create Props

No props were created.

3 Recruit Participant

This visualisation method was used by one designer. No participant was recruited.

4 Create Artefact

Initial sketches were made to visualise the appearance of the game (Figure 45):

- **PPE selection (image 1):** This shows how users would select the required PPE for each operation,
- **Game navigation (image 2):** This shows how a user would navigate to different rooms in the game,
- **Initial interface design (image 3):** This shows how the training instructions would be presented to the users,
- **Material selection (image 4):** This shows how the user would select the required materials for each instruction manual.

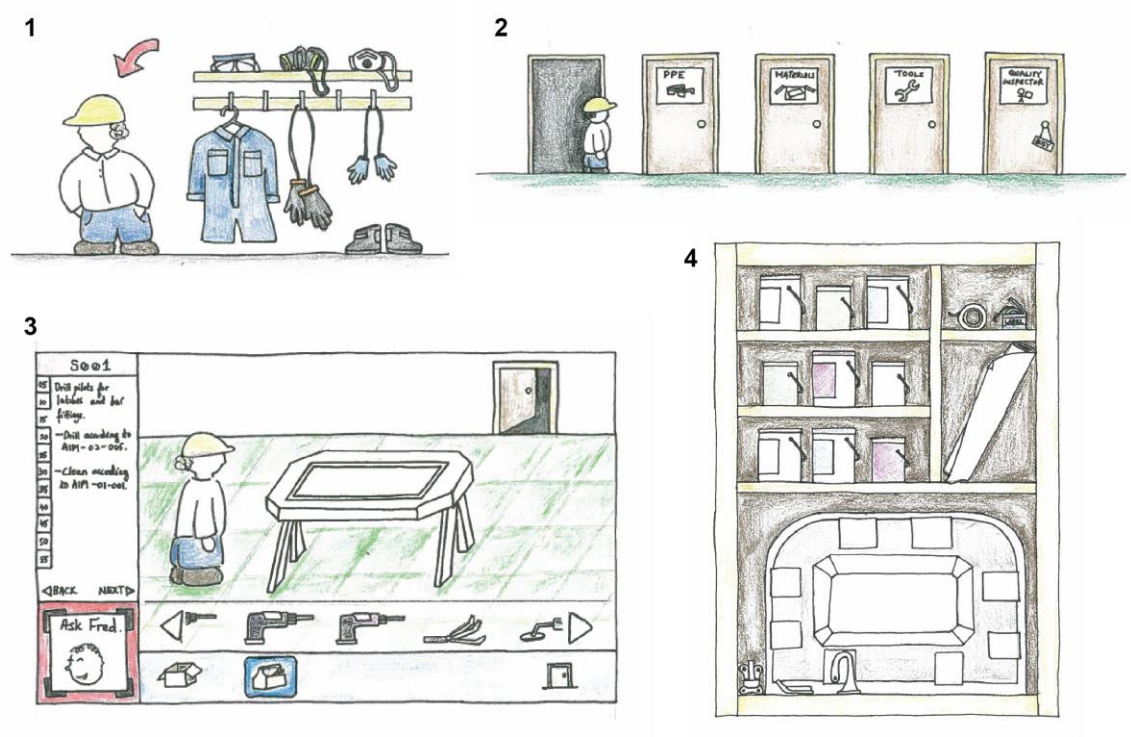


Figure 45 **- Four initial sketches of the game interface: 1) an area consisting of PPE equipment, 2) users enter different room to perform different function, 3) a sketch of the game interface showing where the instructions are and the place in which materials and tools are stored, and 4) a sketch of how the materials are presented in the materials room**

Think of Alternatives

Alternative ideas for tool and material selection were created (Figure 46).

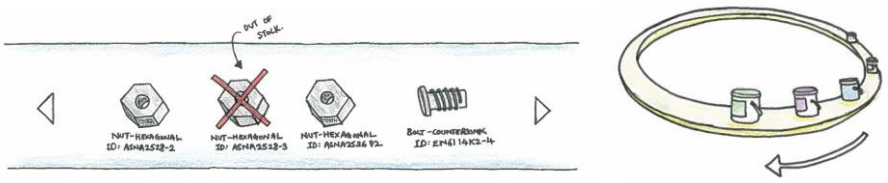


Figure 46 - Sketches of ideas for tools and materials selection, the red cross represent that the item is out of stock

Mix and Match Ideas

Ideas were combined to show how a user would perform an action. Figure 47 shows how the drilling process can be performed. The player would first select a tool and drag it to the avatar. They can then click to select the assembly jig. The jig would rotate to the bird's eye view, allowing the player to select relevant areas to be drilled.

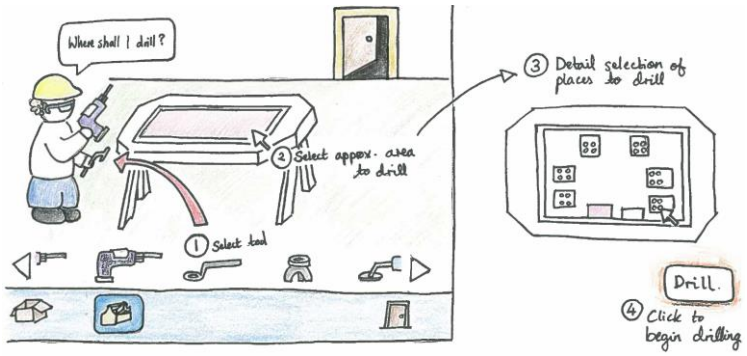


Figure 47 - A sketch of the drilling process: 1) the player selects tools from the bottom tool bar, 2) once equipped the player selects the material part that they would like to interact with, 3) the player selects the area on the part in which they would like to interact with, and 4) the player confirms the action that they are performing on the part

5 Next Step

Discuss in Team

The sketches were presented, by the designer who made the sketches, to the design team of two programmers, a subject matter expert (in complex manufacturing), and a visual designer. The sketches were first explained by the designer. As the discussion progress, the team began to arrange the sketches to represent the game flow. Figure 48 shows the team's final arrangement of the sketches. It was decided that at the start of the game, the game player should be in the corridor area. This would allow the player to navigate to the different rooms which have individual functions.

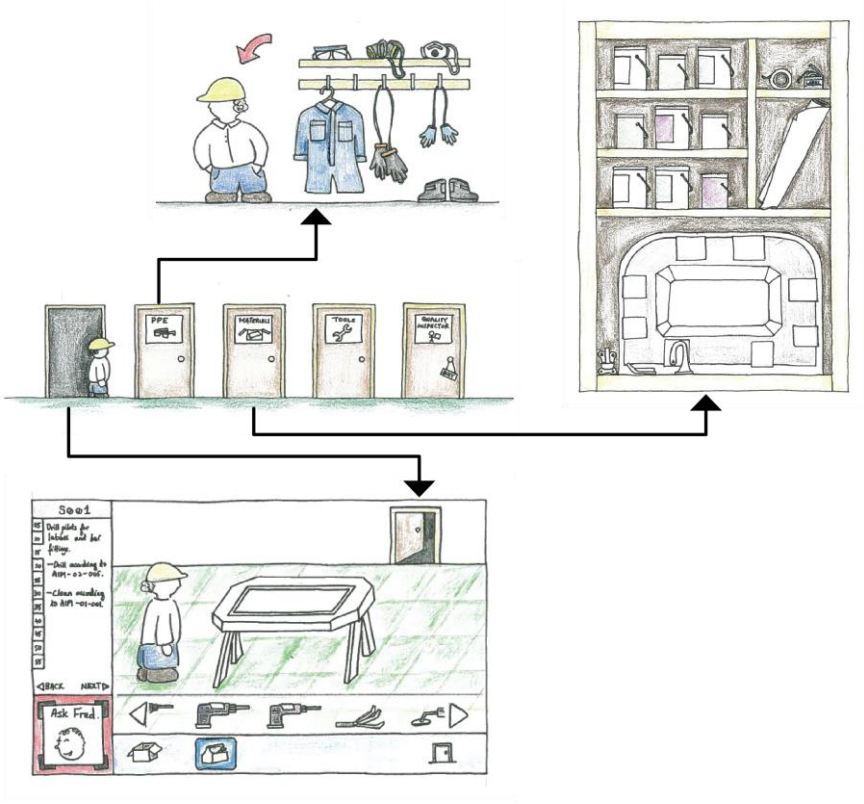


Figure 48 **- A diagram to show how the individual sketches were organised in the team discussion, the game begins with the player in the correct and enters into different rooms to perform various tasks**

Identify Best Idea

From the identification of the game flow, gaps were identified with the current design. The team made suggestions for each feature, these includes:

- **Materials and Tools Inspection:** This is a major task in the manufacturing process. In real life, the worker would check the material for defects, and test tools before they are used. This is difficult to re-enact within a game environment. The team suggested the inspection could be simplified as a scanning procedure. The player will need to identify the tools and materials for inspection. Once these are identified, the act of

inspection itself is represented as a scan (using graphics and sounds).

- **Points and Health System:** One important aspect of a serious training game is to provide competitiveness. The team discussed ideas for a point and health to inform players of how well they are performing.

- **Game Navigation:** Two questions were identified regarding game navigation: 1) what are the necessary rooms, and 2) how would you enter and leave each room?

7.2.2.2 Design Challenge B: Composing the User Interface Design

For Design Challenge B, the *Wireframe* method was employed. The reasons for selecting *Wireframe* was discussed in Section 7.2.1.

1 Identify Problem

The *Wireframes* to be created are:

- The game starting screen.
- The materials room.

Sketch out Each Frame

Rough layouts of each frame were already established in Design Challenge B. The purpose of Design Challenge B is to revise the interface design based on the problems identified in the team discussion of Design Challenge A, and to consider:

- How the game instruction would appear.
- How user would move through the game.
- How to select different materials and tools for each operation.

2 Tool Selection

The designer chose to use Adobe Illustrator because this is a drawing application that the designer was already familiar with.

3 Create Props

A template of the game interface was created. The game instruction is provided in the manual on the right. This will guide users throughout the game. The bottom grey manual contains the tool and material box. Equipment and materials selected in the respectively rooms are placed in the boxes, which will then be made selectable once the users are in the shop floor.

4 Create Artefact

Two wireframes were created. The first wireframe shows the start screen (Figure 49). The players are confronted with a series of doors which leads to individual rooms. The purpose of each room is labelled on the door. A player would first read the instruction on the right to find out the task they have to perform before navigating to the individual rooms to perform that task.

The second wireframe is the material room (Figure 50). The material room contains a cupboard of materials and an area for inspection. The materials are provided in imagery form. This is to help familiarise the game players with the tools and materials in the assembly process. This step is important because it helps to train workers to review the materials list at the start of the manufacturing process, and collect all the necessary materials in one go. This prevents time being wasted for going back and forth to collect individual items. The inspection area is to train players of mandatory inspections. The cupboard is designed to contain all the materials which appeared in the training instructions.

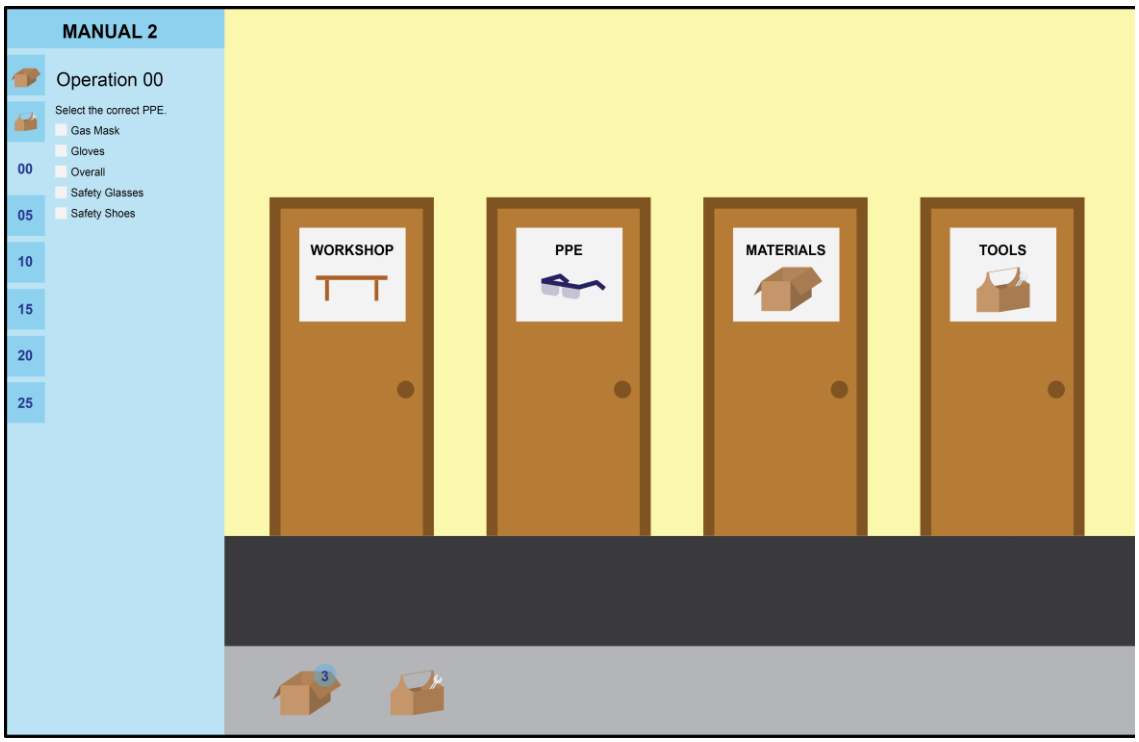


Figure 49 - A wireframe showing the start screen of the TG

Figure 50 - A wireframe showing how materials are collected, to exit the room player would click on the green arrow in the top right hand corner

5 Next Step

Discuss in Team

In the team discussion, the following issues were identified:

- **Materials Selection:** The cupboard in the materials room (Figure 50) was designed to contain all the materials that appeared in the training instructions. The size of the cupboard was determined by the number of materials there were. In the team discussion, one question came up: “can we add more items if necessary”? Training manuals could be amended if the manufacturing process changes. Hence the design team needed to consider what would happen if materials are added or removed. The team decided that each shelf could become a scroll list (Figure 51). This means the cupboard size is no longer determined by the number of items, and additional items and be added easily.

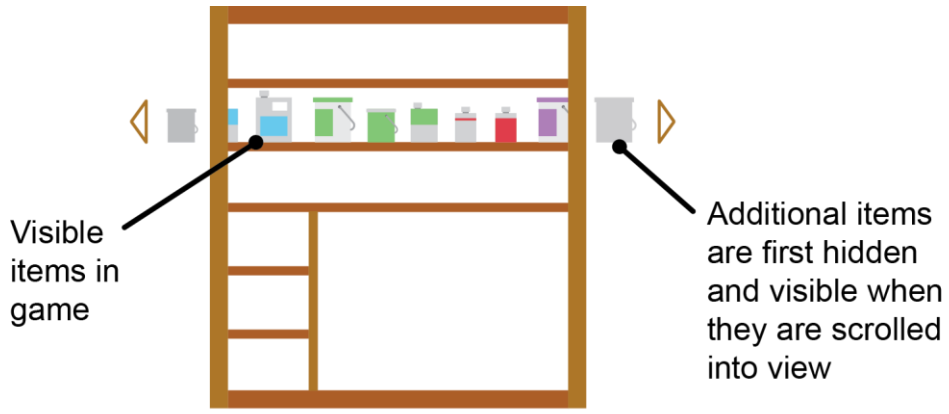


Figure 51 - The materials cupboard has a scroll feature, which allows additional items to be listed within compromising on the size and clarity of each item

- **Inspection Room:** The team decided that the inspection should be performed in a separate room to where the materials

are collected. This is because some tools (which are collected from a different room to the materials) also need to be inspected.

- **Game Flow:** At this stage of the design project, the programmers began to develop game interface based on the initial sketches composed in Design Challenge A. To further the game design, the design team suggested that the training instruction needs to be mapped to the interface design to show how the game is played out. This would provide a detailed account of how a user would proceed in the game. Also, it would help to identify if any features are missing.

7.2.2.3 Design Challenge C: Transforming the Instructions into a Game

For Design Challenge C, the *Paper and Interactive Prototype* method was selected. The reasons for selecting *Wireframe* was discussed in Section 7.2.1.

1 Identify Problem

The interface screen design has already been established in Design Challenge B. The interface design will need to accommodate for the tasks within the first manufacturing instruction manual.

2 Create Artefact

Figure 52 shows the *Paper and Interactive Prototype* of how a user would perform the training using the interface screen design. The prototype is mainly composed in black and white. Only features related to a task are highlighted in colour. For example, the game starts in the corridor area where the user can choose to enter into different rooms. The first task is to collect PPE. On the first screen, the door to the PPE room is highlighted. The next screen shows the features within the PPE room. The required PPE are highlighted as well as the exit button to leave the room. The third screen shows the user is now back in the corridor area.

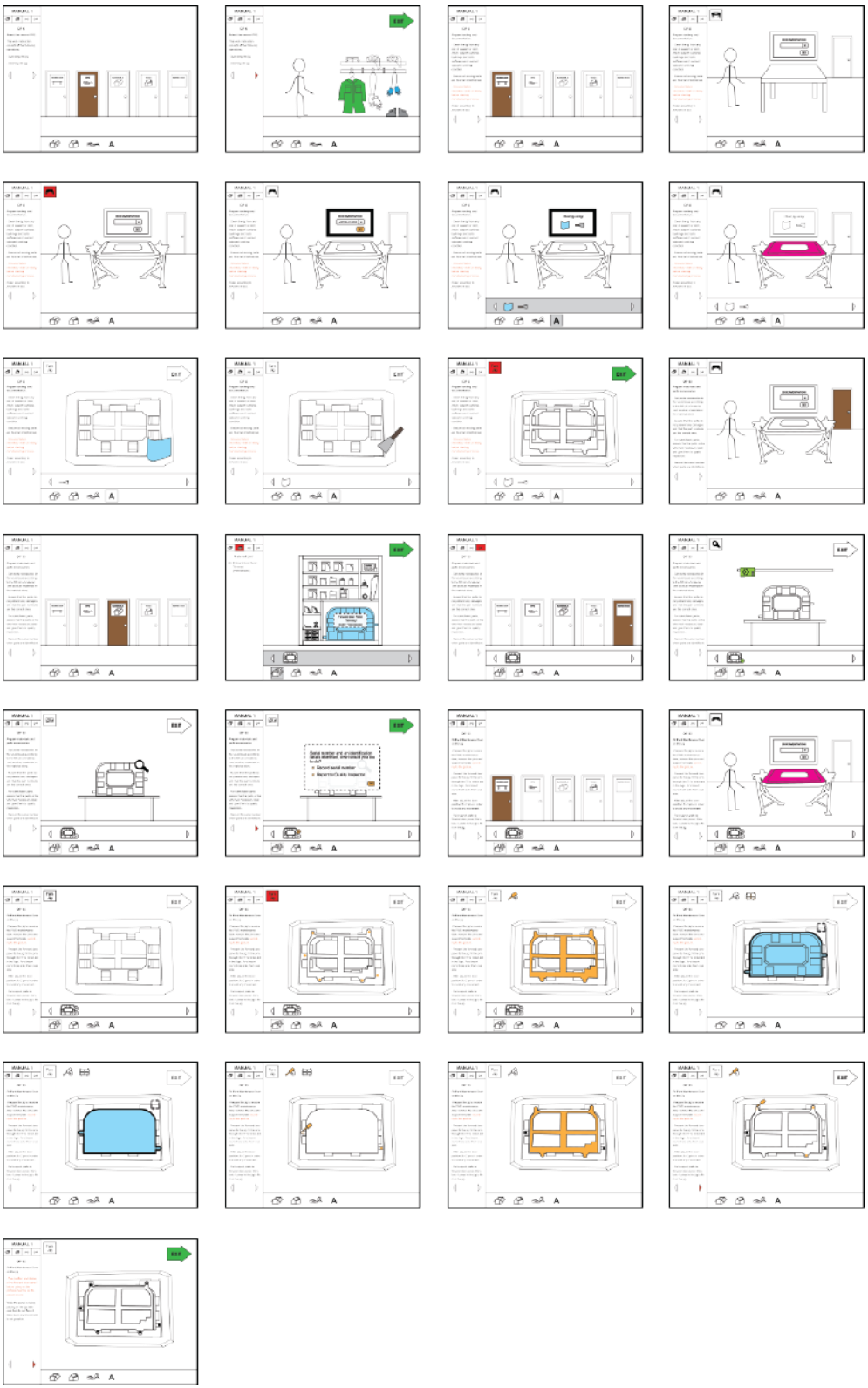


Figure 52 - *Paper and Interactive Prototype* developed to evaluate the game flow of the serious training game

3 Next Step

Recruit Participant

At this point of the project, the team did not have access to end users. This prototype were presented and evaluated within the design team instead.

Discuss in Team

The visual artefact was presented to the team and following issues were discussed:

- **Map Instruction to Interface Design:** The prototype shows the step by step process of the game, linking the manufacturing instructions to the interface design. As the prototype was presented to the team, the subject matter expert helped to clarify uncertainties surrounding the manufacturing instruction (such as the orientation in which the door panel is attached to the jig, and if tasks completed in the right order). In addition, it helped to team to consider what would happen if a certain task was not performed. Can the next task still be performed? How would it affect the overall manufacturing process?

- **Jig Rotation:** The assembly jig is rotated during the manufacturing process. In the prototype, the jig is rotated using a button click. However, the button design, which appears at the top of the screen, caused confusion within the team.

- **Go Back / Undo:** The team discussed if there should be a ‘Go Back’ or ‘Undo’ button to return to a previous step. As the actions performed in real life (such as drilling), cannot be undone, it was decided that the game should not have a

‘Go Back’ or ‘Undo’ button. This would train users to become more aware of the consequence of their actions.

- **Equipping the Avatar:** In reality, when a worker uses the drill, they would attach the appropriate drill bit onto the drill. It was debated in the team how this feature would be translated in the game. The team decided to simplify this process, rather than providing a standard drill with individual drill bits, the game would consists of with several drills with the drill bits already attached. This is because the intention of the game is not to teach the user how to use the drill, but the overall process of assembling a maintenance door.

7.2.2.4 Design Challenge D: Designing Feedback System

For Design Challenge D, the *Mind Map* method was employed. The reasons for selecting *Wireframe* was discussed in Section 7.2.1.

1 Identify Problem

The design challenge is to design the feedback system.

2 Tool Selection

Applications

A web application, Coggle (n.d.), was chosen and employed for this design challenge.

3 Create Artefact

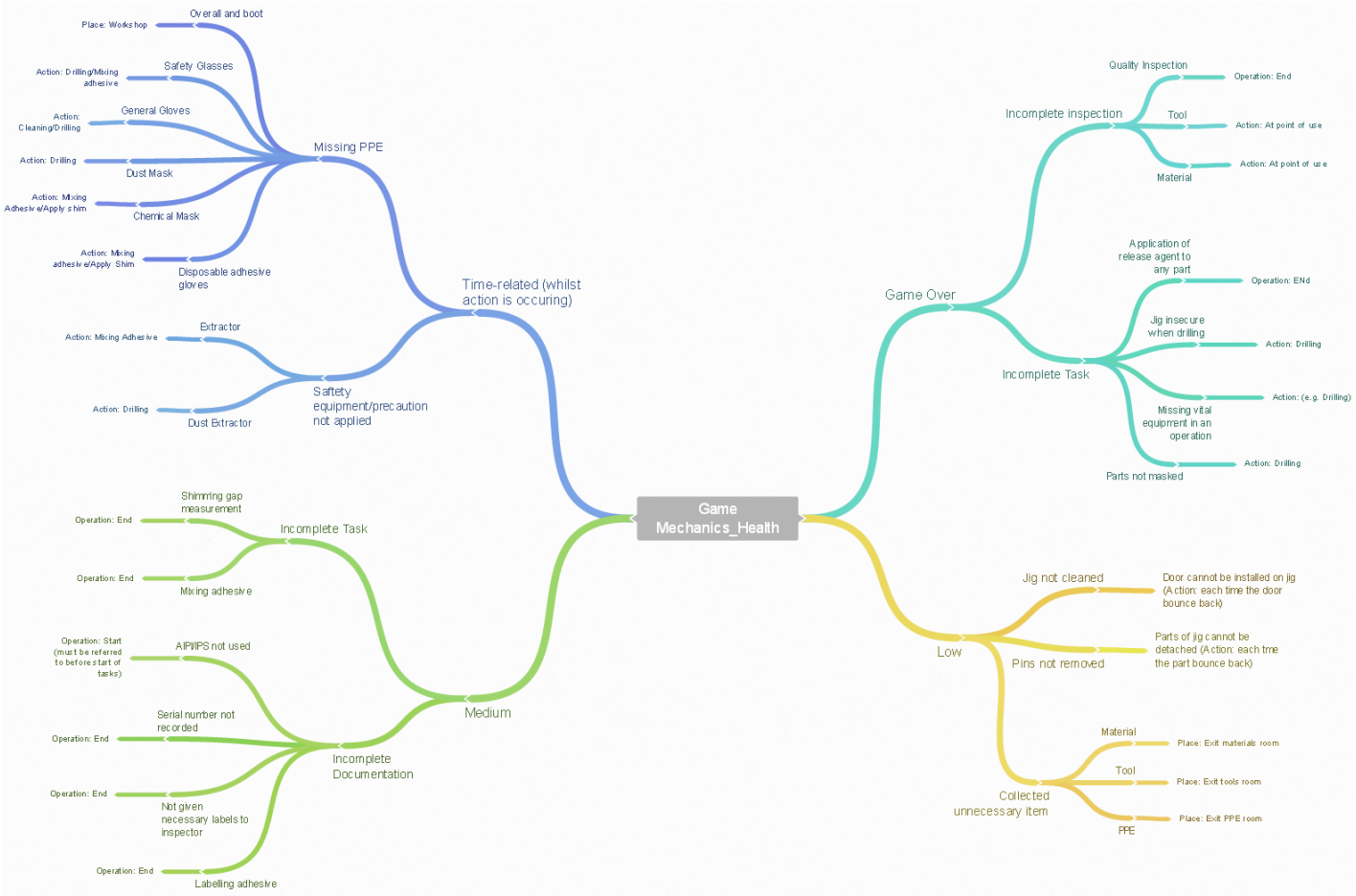


Figure 53 - A *Mind Map* to show the design of the feedback system

Define Problem at Centre

The health system is designed to provide feedback as the game is being played. The level of health fluctuates depending on how well the user is doing. The game is over when there is no health remaining.

Branch Out From Centre

The main branches show that health can be gained or lost in four ways (Figure 53):

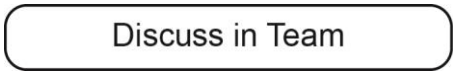
- **Time-Related:** If the user is not wearing the correct PPE, or using the necessary safety equipment when they are performing a task, health is deducted as soon as they are performing that task. This is to reflect the likelihood of an accident/injury if a user is not wearing or using the correct equipment.
- **Medium:** A considerable amount of health is deducted if a task or the document necessary for a task is not completed. The health is generally deducted at the end of an operation unless it is a document that the users are supposed to refer to prior to an operation.
- **Low:** A small amount of health is deducted if users forget to collect the correct materials, tools and PPE. This is to encourage users to collect the necessary equipment at the start to avoid time wasted later on. Health could also be deducted if the jig is not cleaned properly or if users try to move a part when there are pins are attached.
- **Game Over:** All health is lost and the game is over when the user performs any of the action in this category.

The secondary branches detail the type of task. The tertiary branches identify specific tasks that fit into this category. The

quaternary branches provide the point of time or the particular action that triggers the health lost.

No related branches were identified.

4



The resulting visual artefact was presented in a team meeting. Contrasting ideas were noted and the team came to an agreement on the health system design. The following issues were discussed:

- **Time-Related / Use-Related:** The time-related branch represented the type of action that causes health to be lost during the time they are performed. For example, if the user attempts to drill without wearing gloves, they would begin losing health as soon as they begin drilling. In the discussion, it was argued that this branch should be renamed as ‘Use-Related’ rather than ‘Time-related’. This is because the action of drilling is displaced by a mouse click in the game.

- **Game Over:** Another feature discussed was what happens when a user makes a major mistake. In the early phase of the game design, the team decided that when a user made a major mistake, the user will need be re-trained on that particular game level. The team considered whether the game should end straight away or if a player should be allowed to carry on and find out at the end that they need to be re-trained. In the end, the team decided that when a major mistake is performed, the game should end straight away. This way, the user would be alerted to the error they are making.

7.2.3 Overview of Serious Training Game

This section provides an overview of the serious training game. Textual information in the images has been obscured for confidentiality purposes.

The game begins in the corridor (Figure 54) in which players can select to go into different rooms, including:

- Personal Protective Equipment (PPE) room for collecting the required protective equipment.
- Materials room for collecting materials.
- Tools room for collecting tools.
- Inspection room for inspecting tools.
- Mixing room for mixing the required solutions.
- Workshop for assembling the aircraft door.

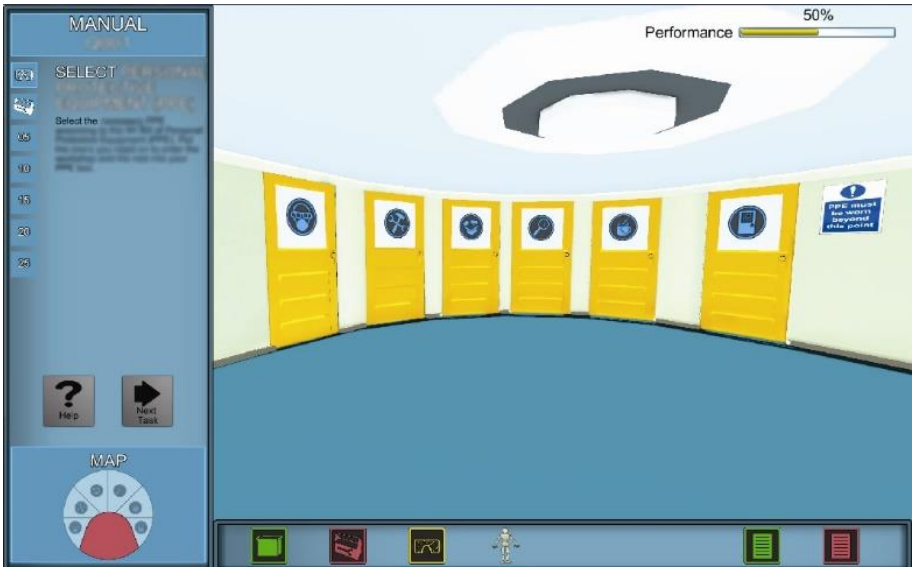


Figure 54 - The TG consists of a number of rooms with different functionalities, players can enter by clicking on the door

Manufacturing instructions are detailed on the left menu bar (Figure 55). These instructions are exactly the same as those in the PM. After the user has completed an operation, they would click next to move on to the next instruction. A player can view the work instructions, but they would not be scored on their performance until the 'Next Task' button is selected.

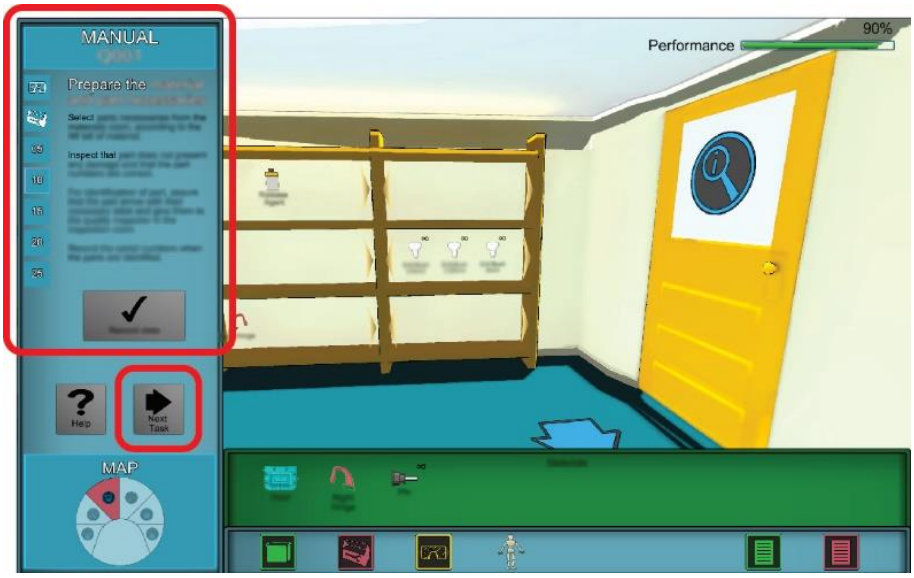


Figure 55 - Players are to follow the instructions on the left menu bar (shown in the top red box), once they have completed the required tasks they can move on to the next task by clicking the 'Next Task' button (shown in the bottom red box)

Supporting documents are provided in two different formats. First, lists of PPE, materials, and tools are located on the bottom menu bar (Figure 56). These are information that would have been provided within the PM. Secondly, additional information for regulations and procedures are selected using a 'computer' located in the workshop room (Figure 57). Currently, as in the PM, this feature only lists names of the supporting documents. This feature is intended to be further developed in later versions of the game so that on selection, the information of the supporting document is provided.

The bottom menu bar (Figure 58) consists of four icons: material box, tool box, PPE, and a mannequin. Players can select PPE, tools and materials from the appropriate rooms and drag them accordingly to associate icon. The mannequin represents the player. A player must equip the mannequin with correct PPE and tools before they can perform a task.

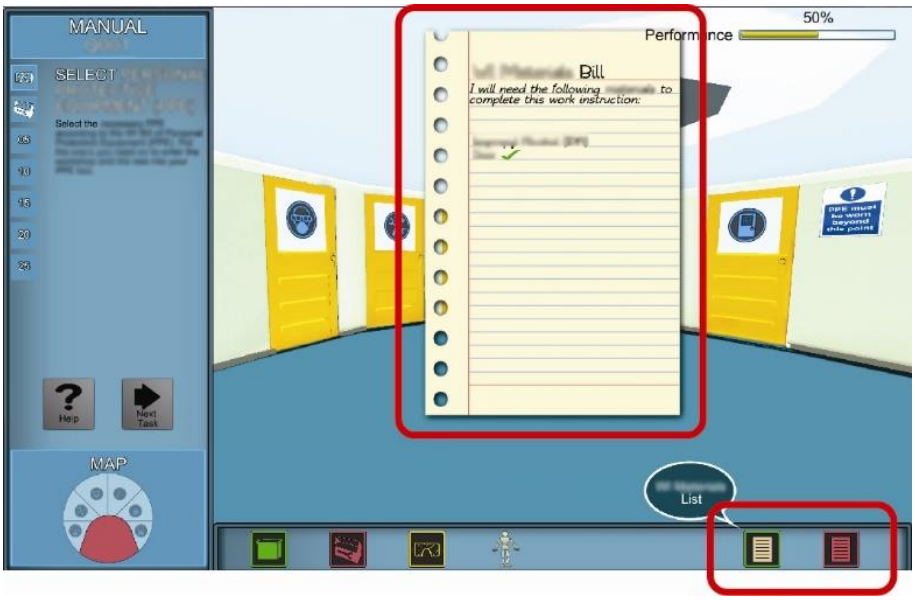


Figure 56 - Supporting documents for the required materials and tools for each operation are provided on the bottom task bar (shown in bottom red box), once this is clicked on the list of the required materials or tools are provided (shown in top red box)

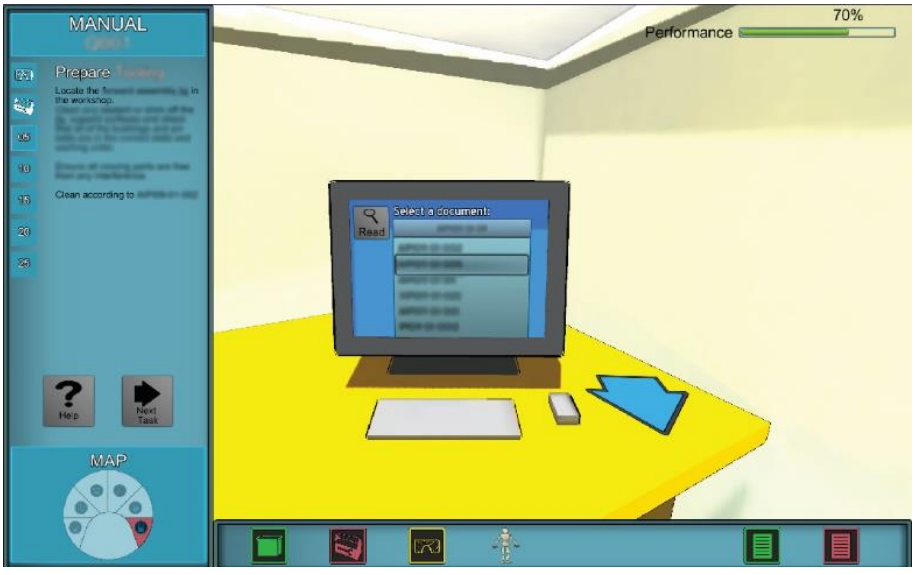


Figure 57 - Additional information for regulations and procedures are selected using a 'computer' located in the workshop room

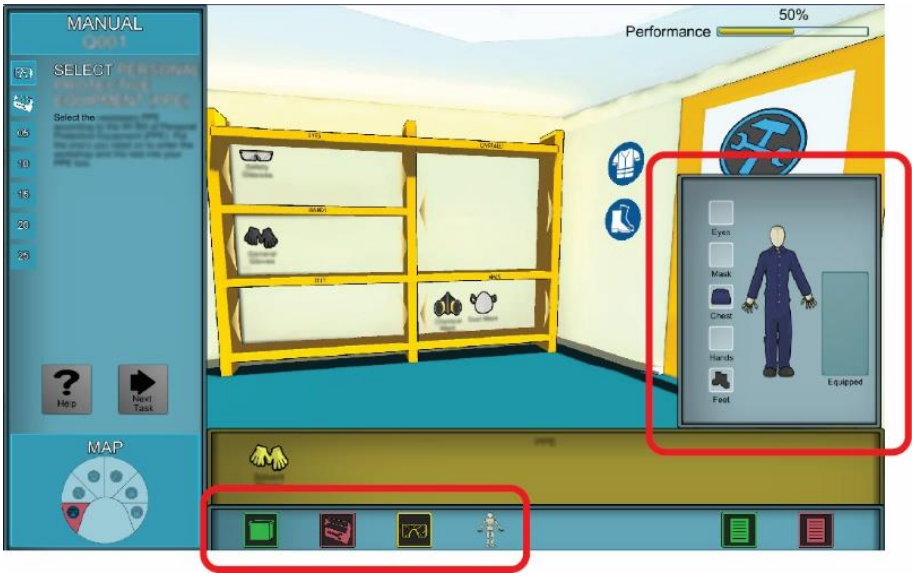


Figure 58 - PPE, tools, and materials are collected and stored on the bottom menu bar (shown in bottom red box), the mannequin represent the player, the top red box shows the figure that appears for players to be equipped with PPE

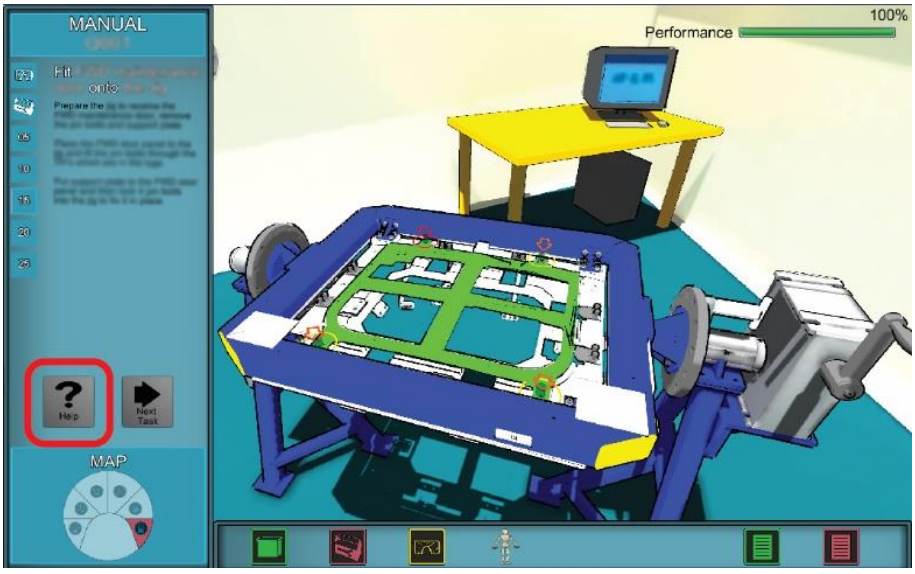


Figure 59 - Help is provided to guide players through the game, help is given when players select the 'Help' button (shown in red box), for this particular task red arrows can be seen above the green component to guide the player to the correct location in which the task takes place

If a player requires help, they can select the ‘Help’ button (Figure 59). Hints are provided to guide the users to complete the associated task. For example in Figure 59, four red arrows can be seen pointing at certain parts of the green coloured component. The arrows here were intended to direct the player to the component they are required to interact with.

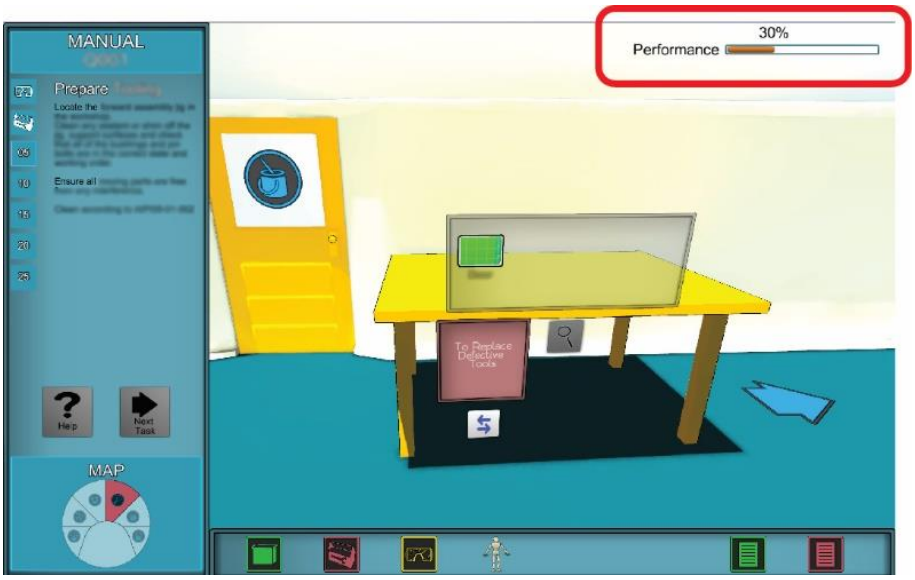


Figure 60 - The health bar (shown in red box) is provided to inform players of their performance, the health increases if a task is performed correctly and decreases if it is incorrect

The health bar is located in the top right hand corner (Figure 60). It provides feedback on how well a player is doing. The amount of health would fluctuate depending on whether the player is performing a task correctly (health is added) or not (health is deducted). The game ends if there is no health remaining.

Once the game ends, players can view their total score and health status (Figure 61). Details of how they performed on each task are presented. The time stamp provides feedback on how long they took to complete each operation. The tasks that were performed correctly are shown in green and the tasks that were incorrect are shown in red.

Figure 61 - Players can review their performance at the end of the game, tasks which were performed correctly are shown in green and tasks which were performed incorrect are shown in red

7.2.4 Serious Training Game Evaluation

In this study a serious TG was compared with a traditional PM as means of training new workers for a complex manufacturing process in the aeronautic industry. The instructional approaches were assessed based on two knowledge tests that were taken immediately after the manufacturing process was studied.

7.2.4.1 Knowledge Retention and Interpretation Test

The between-subjects ANOVA with the Knowledge Interpretation score and the experimental conditions (PM and TG) showed a significant the main effect ($F(1,18) = 6.933$, $p = 0.016$). Figure 62a shows the difference between the results of the PM condition ($M = 12.6$, $SD = 14.5$) and the TG condition ($M = 26.3$, $SD = 7.7$), being significantly higher in the game condition.

The between-subjects one-way analysis of variance (ANOVA) of the Knowledge Retention score with the experimental conditions (PM and TG) showed no significant differences between the two conditions ($F(1,18) = 1.35$, $p = 0.266$) (Figure 62b).

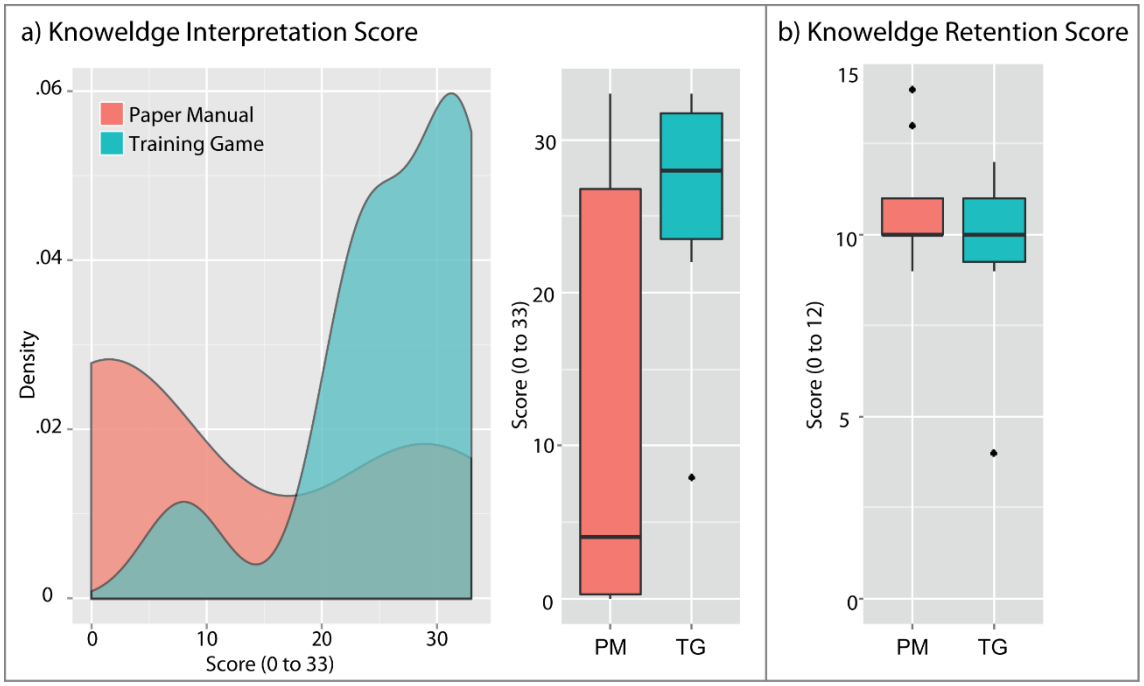


Figure 62 - Graphs showing: a) Knowledge Interpretation score (0 to 33) for the two experimental conditions, boxplot and participants density map and; b) Knowledge Retention score (0 to 14) boxplot for the two conditions. The boxplots show the minimum, maximum, the quartiles and the median values (horizontal line) for each condition, the points represent the outliers which are observation points distant from other values

The results show that the TG is comparable to the PM for learning factual-based information (Objective 1), as evident in the Knowledge Retention Test (Figure 62). Similar results were established in studies comparing SG and non-gaming application (Papastergiou, 2009), and SG with computerised flash cards (Sward et al., 2008). More optimistic results were reported in the use of SG for teaching adolescent cancer-related knowledge (Beale et al., 2007), whereby significant improvements in knowledge acquisition were identified. With regard to learning to apply procedural knowledge (Objective 2), the TG approach proved to be significantly more effective than the PM. On average, participants in the TG condition scored more than double that of the participants in the PM condition in the Interpretation Test (Figure 62). This result is in line with a previous study whereby students were trained to assess and priorities medical conditions in

emergency situations (Knight et al., 2010) and for teaching procedural knowledge in healthcare (Torrente et al., 2014).

Both Objective 1 and 2 were mapped based on Bloom's Taxonomy (Krathwohl, 2002; Buchanan et al., 2011; Anderson and Krathwohl, 2001). It should be noted that being able to apply information (Objective 2) requires higher order thinking skills compared to remembering information (Objective 1). As lower order skills are prerequisites to higher order skills (Pollock et al., 2002), it is evident that the TG is far superior to the PM in the context of complex manufacturing training. Even though TG and PM are comparable in imparting a low order thinking skill, the TG outperformed the PM in conveying a higher order skill.

7.2.4.2 Demographic Factors

Demographic factors such as the manufacturing experience, gaming exposure, and the learning type (VARK) did not show significant interactions when added to the ANOVA model, indicating that these factors did not significantly influence the Knowledge Retention and Interpretation of the participants for either experimental condition.

7.2.4.3 Attitudinal Survey

The average score on the Attitudinal Survey indicated the participant's overall confidence during the phases. Interestingly participants of the TG condition ($M = 3.53$, $SD = 1.6$) were significantly more confident during the Knowledge Interpretation Test than those in the PM condition ($M = 1.4$, $SD = 2.3$) (Wilcoxon rank sum test, $W = 23$, $p = 0.044$) (Figure 63a). No significant subjective differences were found for the Knowledge Retention Test or the Study Phase.

Regarding engagement in the Study Phase, participants in the TG condition ($M = 5.9$, $SD = 1.1$) scored significantly higher than those in the PM condition ($M = 4$, $SD = 1.4$) (Wilcoxon rank sum test $W = 14.5$, $p < 0.006$) (Figure 63b), i.e. engagement levels in the TG were higher than the PM. Furthermore, we find that participants overall enjoyed more the Knowledge Interpretation Test ($M = 5.7$, SD

= 1.4) than the Knowledge Retention Test (M = 4.5, SD = 1.2) (Wilcoxon rank sum test, W = 96, p = 0.004) (Figure 63c).

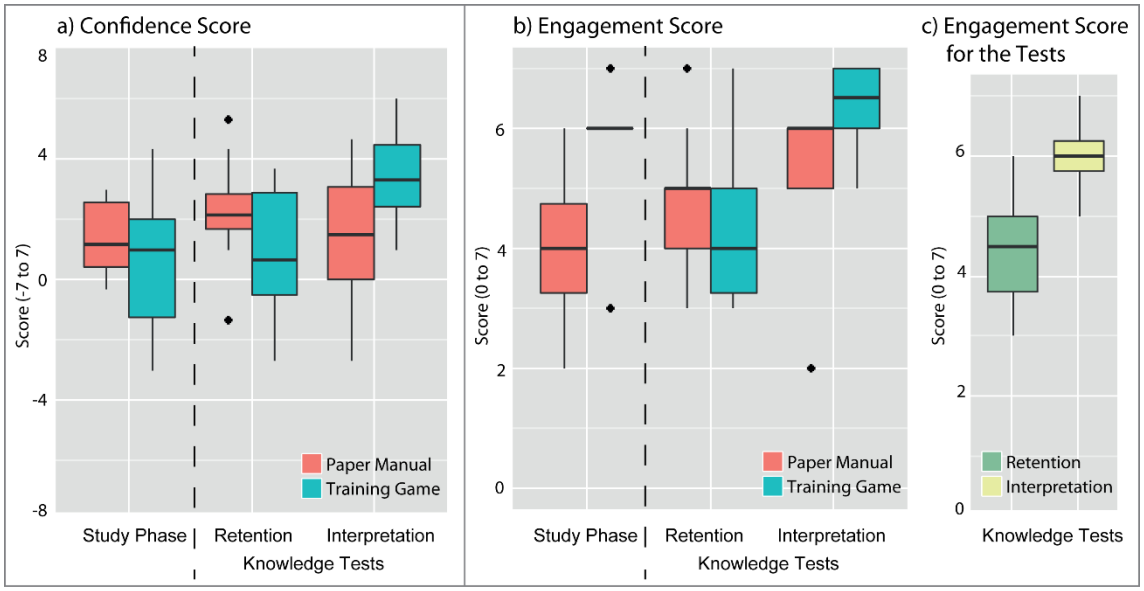


Figure 63 - Attitudinal Survey results: a) boxplot diagram showing the confidence score (-7 to 7) for each phase and condition; b) boxplot diagram showing the engagement score (0 to 7) for each phase and condition; c) boxplot diagram showing the engagement score

Participants in the TG condition (M = 6.4, SD = 0.7) scored significantly higher in the engagement part of the survey than those in the PM condition (M = 5, SD = 1.6) for the Knowledge Interpretation Test (Wilcoxon rank sum test W = 19, p = 0.012) (Figure 63c), but not for the Knowledge Retention Test, where participants from both conditions (game: M = 4.7, SD = 2.5; paper: M = 4.4, SD = 1.3) had similar levels of engagement (Wilcoxon rank sum test W = 58, p = 0.55) (Figure 63c).

From the Attitudinal Survey it can be seen that participants in TG condition were more confident and engaged in the Knowledge Interpretation Test compared with participants in the PM condition. Although no significant difference of confidence level was identified in the Study Phase, participants in the TG condition also reported higher engagement level here. Overall, participants were more engaged in the Knowledge Interpretation Test compared with the Knowledge Retention Test.

7.2.4.4 Participant Comments on the Two Conditions

Aside from the confidence and engagement levels, participants' opinions of the two study methods were collected in the Attitudinal Survey. They were asked to provide written feedback to an open-ended question: *What did you like or dislike about the study session?*

In the TG condition, participants responded positively to the gaming environment: *"I liked working in game environment", "The experience was good"*. A number of suggestions were also offered to improve the game design. For example, the TG was designed to score the player immediately after a task meaning the player cannot replay a task unless they start the game again. One participant found *"the inability to go back to a previous incomplete process was a bit disappointing"*. The TG also seems to have a steep learning curve: *"Not familiar with gaming environment, does not know where to look for documents/instructions. Not used to this type of interface"*, leading to some participants proposing more didactic features: *"The game can give an overview of the process as a video in the first instance"and "More emphasis on key points could be made, not walls of text".*

In the PM condition, participants found main hinderence of learning to be the ambigurity of the visual information: "*Pictures were not very clear which made it difficult when it came to the practical test", "Picture quality could be better but that's usually the case for instruction manuals", "It was difficult to visualise the assembly process"*. In particular, one participant stated that the PM need to be more precise when referring to the position of parts and materials *"It would be better if there were diagrams referring to the location of the bolts. This is not clear in the manual"*. The technicality of the PM was also a challenge *"The wording of the instructions was not suitable for purpose"*.

7.2.5 Guide Validation from Serious Training Game

The Guide was validated in this chapter. In the serious training game development, the Guide was employed for visualisation method selection (Section 7.2.1) and application (Section 7.2.2). This has demonstrated that it is possible to identify and apply suitable visualisation method using the Guide for

HCI system design. In the serious training game evaluation (Section 7.2.4), the game was evaluate for its learning effectiveness. Compared with the tradition training method (paper manual, the serious training game was found to be just as effective for learning factual knowledge. With regard to procedural knowledge, the game approach was significantly more effective that the paper manual approach. This shows that the Guide has aided the development of a successful HCI system.

7.3 Summary

In this chapter, the Guide was validated in two parts. First, the application of the Guide is demonstrated in the design of a serious training game. For each of the design challenge identified, a suitable visualisation method was selected and applied using the Guide. Second, a user study was carried out to evaluate the learning effectiveness of the serious training game. The user study found that the serious training game was more effective in training procedural knowledge. This demonstrates that the Guide has successfully aided the development of a HCI system.

8 DISCUSSION AND CONCLUSIONS

This chapter will first present the findings of this research, highlighting the contribution to knowledge. Next, it will discuss the limitations and strengths of the research methodology and recommendations for future work. Lastly, the final discussion is presented.

8.1 Summary of Findings

The summary of findings is organised according to the chapters of the thesis.

8.1.1 Phase 1: Data Collection and Analysis (Chapter 4)

In this phase, case studies were carried out to investigate the requirements capture and design activities surrounding three HCI systems development. Two different aspects of HCI system development were studied. The first two case studies were concerned with the user requirements capture activities in the early phase of HCI system development (detailed in Section 8.1.1.1). The third case study was concerned with a later phase where the user requirements were provided at the start of the study (detailed in Section 8.1.1.2). The purpose of the case studies was to form deeper understanding of the challenges designers face in HCI system development. Understanding the type of challenges designers face assisted the author to assess whether the Selection Approaches identified in the literature review (Chapter 2) were appropriate for method selection. This informed the development of the Guide development in Phase 2.

8.1.1.1 Requirements Capture in Case Study I and II (Chapter 4)

In investigating the requirements capture aspect of interactive system development, two case studies were identified from the parent project. A four-phase methodology was followed. Visual artefacts were developed in the information gathering phase to identify the key stakeholders and form an initial understanding of the proposed interactive systems. Interviews were conducted in the requirements elicitation phase with relevant actors. The requirements were transformed into Storyboards and an animation clip for validation and

communication with non-experts. In this chapter, a four-step methodology was followed. The findings from each step are presented in the following sub-sections.

Step 1: Information Gathering

The purpose of this phase was to establish what is currently known about the concept systems. This involved identifying the relevant stakeholders in the project, the resources available, and the context of the design project.

- **Case Study I (Wheel Alignment):** Two visual artefacts were created for this project (Figure 10 and Figure **11**). At the time of the artefacts creation, a basic demo of the wheel assembly system was developed and presented to the design team. Figure **11** shows what this demo was composed of. It captured the three phases of the automation process (*detect*, *compare*, and *feedback*). From discussions with stakeholders, there were contradictory views on the composition of the automated system (whether the assembly process is only automated for the wheel rotation or if both the wheel rotation and attachment are automated). These diagrams show the two possible new scenarios compared with the current method of working. Compared with Figure 10, Figure **11** shows the system at a higher level. From the development of the visual artefacts, knowledge gaps were identified, which were addressed in the interview questions in Step 2.

- **Case Study II (Carbon Fibre Placement):** In this project four key actors were identified. Figure 12 was developed to show how each actor contributes to the various stages of the system development. Similar to the *Wheel Alignment* project, knowledge gaps identified in conceptual design were addressed in interview questions design in Step 2.

Step 2: Requirements Elicitation

A semi-structured interview was designed for the requirements elicitation. A list of questions were prepared prior to the interview. These questions were designed to validate what is currently known about the conceptual systems as well as to delve into gaps in knowledge. New topics were discussed during the interview.

This was to explore the different perspectives of the stakeholders as well as to gain more domain-specific knowledge.

Step 3: Envisioning

In Envisioning, the information captured in Requirements Elicitation was transformed into pictorial formats. The visual artefacts were designed in a simplistic style that could be used to validate the requirements captured and to act as a communication tool with non-experts.

- **Case Study I (Wheel Alignment):** A Storyboard was created to show the context (currently workers avoid using the gantry leading to health issues) of the current situation and what is required for the system to be developed (the developer will need access to the assembly line to capture data for further system development). The interactive nature of the end system resulted in the creation of an animation clip, which shows how the position of the car hub and wheel is detected, and rotated to match before the wheel is attached.

- **Case Study II (Carbon Fibre Placement):** A Storyboard was created to show the problems with the current system as well as the four stages to develop the automated system. The Storyboard shows what type of information is captured by Kinect™ (in Figure 20: Stage 2 the carbon fibre position, time stamp, and speech tags are captured), and how this information is transformed at each stage to compose the fully automated system (in Figure 21: Stage 3 the information captured are translated into a tabulated format before it is converted into a re-usable format in Figure 21: Stage 4a).

Step 4: Evaluation

The *Storyboards* and animation clip were evaluated with team members and relevant stakeholders. This is to ensure that team members and stakeholders agree with the requirements and any feedback captured can be used to refine the requirements.

8.1.1.2 Interaction Design in Case Study III (Chapter 4)

Case Study II presented the interaction design of a geocollaborative system. From the design challenges identifies, visualisation methods were adopted to both aid design processes as well as to communicate design ideas between the stakeholders of this project. This section discusses how the visualisation methods were used in three phases of system development.

Step 1: Developing Natural Gestures

The first phase involved identifying applicable natural gestures that were possible to be developed within the timeframe of the project. Previous research has investigated the use of natural gestures for navigation of 2D and 3D maps, but no research discussed the use of natural gestures to add and edit mapping features. Hence, following the identification of applicable gestures, it was necessary to develop sequences in which the functions could be manifested. As only four gestures were found applicable, it was a not a straight forward case of corresponding each gesture to one function; there were more functions than the available gestures. The *Storyboard* method was used to break-down the sequence of each gesture. This method helped to show how different functions can be performed depending on the type of objects being selected, the role of the user, or position on the display screen. The visual artefact produced from this method was used to communicate between the stakeholders to evaluate the design and gain feedback. It helped to design gestures that were more natural to use and avoiding gestures that acted like a mouse click.

Step 2: Designing the Interface

Three visualisation methods were adapted to aid the interface design. The first was the *Static Wireframe* method. This method was used to quickly generate a number of possible layouts. By using simple sketches and colour coding the groups of necessary features, it became clear at this early stage that listing all of the necessary features on the interface would take up too much space. Hence a decision was made to hide some of the features when not in use.

The second visualisation method used was the *Paper and Interactive Prototype* method. A physical prototype was made out of cardstock. This method enabled the dynamic features of the interface to be tested, which was not possible in the previous method. For example, the location of the menus can be examined to see the amount of screen space available when they are fully extended. Making tangible versions of the mapping features also helped to reconsider their size and scales. Different scenarios can be tested on the prototype to ensure all the design features have been considered. This method enabled the dynamic features of the interface to be tested, which was not possible using the static Wireframe.

An interactive *Wireframe* was used to present the structure of the collaborative system. The paper prototype allowed different scenarios to be tested in turn but required the presence of the designer to implement the changes to the prototype. Compared with the *Static Wireframe* and *Paper and Interactive Prototype*, this method is more time consuming to employ. However, resulting visual artefact permits the system to be evaluated independent of the designer.

Step 3: Communicating the Design

Once the initial design was evaluated, a fifth visual artefact was created to communicate the refined design with the programmer. It made use of the *Wireframe* method in combination with images of gestures. The resulting visual artefact is useful for people who are using the *Kinect Demonstrator* for the first time. It communicates the vocabulary required to operate the system.

8.1.2 Phase 2: Guide Development (Chapters 5 and 6)

Phase 2 was concerned with the development of the Guide. This consisted of two parts: the development of the Selection Guide (this helps the designers to elect an appropriate method) and the development of the Application Guide (this consist of the methodology for the visualisation method).

8.1.2.1 Visualisation Method Selection Guide (Chapter 5)

Chapter 5 presented the first part of the Guide development, which is the creation of the Selection Guide. The Selection Approaches identified in the literature

review (Chapter 2) were evaluated through an analysis of six design challenges identified in three case studies (Chapter 4). Two factors were identified in this evaluation: 1) not all the approaches were applicable in each design challenge, and 2) more than one category may be appropriate for a selection approach.

Based on the findings from this initial evaluation, the Selection Guide was developed in an HTML format. The five Selection Approaches are turned into filters. The guide is internally constructed. Users do not have to make a selection for each filter and more than one category may be chosen for a given filter. When more than one category are selected in one filter, the results would show the visualisation method categorised in either category. If categories are selected from different filter, only the visualisation methods categorised in the categories selected for both filters would remain (Section 5.2.3.1).

The Selection Guide was evaluated using design challenges identified in Chapter 4. Based on each design challenge, categories were selected for them in each filter in the Selection Guide. The resulting visualisation methods were presented and their suitability for that design challenge was discussed. This evaluation has shown that it is possible to identify suitable visualisation methods from the Selection Guide.

8.1.2.2 Visualisation Method Application Guide (Chapter 6)

Chapter 6 presented the second part of the Guide development, which is the creation of the Application Guide. The methodology for 23 visualisation methods were determined and analysed. Based on findings from this chapter and previous chapters, an HTML Application Guide was developed. An individual HTML page was developed for each visualisation method. The guide for each method is composed of 5 areas, which includes:

- **Filters:** This shows how the visualisation method is categorised in each filter.

- **Description:** A brief description of the visualisation method is provided. A diagram is presented to show how the visual artefact is composed.

- **How to use:** The methodology for the visualisation method is provided. Seven key steps were identified, including: Identify Problem, Tool Selection, Technique Selection, Create Props, Recruit Participants, Create Artefact, and Next Step. The methodology for each visualisation method was organised based on the key steps. This ensures that the methodologies are comparable and coherent information is provided for each method.

- **Examples:** Visual artefacts developed in Chapter 4 are provided as examples.

- **Reference:** References are provided for further reading.

The methodology provides an overview of what is needed to create the artefact. The structure ensures that concise information is provided in each methodology.

8.1.3 Phase 3: Guide Application (Chapter 7)

The Guide was applied to the development of a serious training game. It detailed design challenges encountered, how visualisation methods were selected, and the application of each visualisation method. This chapter has shown that the Guide did not dictate every part of the development, but suggests suitable methods based on the problem encountered. Furthermore, it has demonstrated the application of the Guide in the selection and application of visualisation methods.

8.1.4 Phase 4: Guide Validation (Chapter 7)

Phase 3 has demonstrated the application of the Guide in the development of a serious training game. In this Phase, a user study was designed to evaluate the effectiveness of the HCI system developed in Phase 3. As the design of this HCI system was supported by the application of the Guide, the effectiveness of this system validates the Guide.

A user study was designed to evaluate the learning effectiveness of the serious training game compared with the traditional paper manual. The user study had a

number of strengths. Throughout the development of the TG and in the planning of this study, a Subject Matter Expert with extensive experience in manufacturing was involved, which gives credence to the quality of both the game and the validation process. The training instructions used in the game was derived from a paper manual currently used in industry. Both learning methods consist of the same written manufacturing instructions. In addition, a number of demographic factors were analysed to examine the extent of their influence on the test results, including: learning preferences, manufacturing experience, and gender. As none of these factors were found to have had significant influence on the results, it adds to the value of this study despite only 20 volunteers participated.

As a result, this user study has found that the serious training game was significantly more effective in terms of training procedural knowledge compared with the traditional paper manual. In terms of factual knowledge, it was just as effective as the paper manual. This demonstrates that Guide has successfully aided the development of a HCI system.

8.2 Addressing Research Objectives

The aim of this research was to develop a selection and application guide for visualisation methods that supports design and development of HCI systems. Four objectives were derived from the research aim to investigate the current visualisation methods utilised in HCI system design, how they are categorised and how applicable they are in industrial settings. The following sections discuss how the findings of this research addressed each objective.

8.2.1 Addressing Objective 1: To Identify the Visualisation Methods and Categorisation Approaches Used in Human-Computer Interaction (HCI)

Objective 1 was addressed by the literature review in Chapter 2. The literature review was conducted to investigate the body of knowledge surrounding HCI visualisation methods and approaches for their selection. This investigation resulted in the identification of 23 visualisation methods and 5 selection approach. The methods were categorised in each selection approaches and the advantages

and disadvantages of each selection approach were discussed. The methods and selection approaches identified formed the basis of the Guide in Phase 3. The findings of literature review are shown in Table 38.

Table 38 - Findings addressing Objective 1

Objective 1	Findings
To identify the visualisation methods and categorisation approaches used in Human-Computer Interaction (HCI).	Literature Review (Chapter 2): • From 13 initial sources, 23 visualisation methods were derived. • Five selection approaches are identified in literature: *The Recipient*, *Primary Purpose*, *Visual Archetype*, *Interaction Type*, and *The Design Process*. • The 23 visualisation methods were categorised in each of the selection approach. The advantages and disadvantages of each selection approach were identified.

8.2.2 Addressing Objective 2: To Undertake Case Studies to Develop Better Understanding of How Visualisation Methods are Selected and Utilised in the Development of Human-Computer Interaction Systems

Case studies were undertaken to explore the challenges faced by designers in the development of HCI systems. They were conducted to identify arising design issues and how they are addressed. The findings captured in this phase contributed to the formation of design requirements for the Guide. The findings from Chapter 4 are shown in Table 39.

8.2.3 Addressing Objective 3: To Propose a Guide for the Selection and Application of Visualisation Methods

In Chapters 5 and 6, the Guide is developed based on the design requirements derived from the case studies (Chapter 4). The Guide is composed of two parts: a Selection Guide and an Application Guide. The Selection Guide is designed to help a user to select a suitable visualisation method for a given design challenge. The Application Guide provides the methodologies for employing the visualisation methods. The findings from Chapters 5 and 6 are shown in Table 40.

Table 39 - Findings addressing Objective 2

Objective 2	Findings
To undertake case studies to develop better understanding of how visualisation methods are selected and utilised in the development of Human-Computer Interaction systems.	Requirements Capture Case Studies (Chapter 4): • Identification of three design challenges. • Two *Storyboards* and an animation clip were developed.
	Interaction Design Case Study (Chapter 4): • Identification of three design challenges. • Three visualisation methods were employed (*Wireframe*, *Paper and Interactive Prototype*, and *Storyboard*) in the development of a geocollaborative system.

Table 40 - Findings addressing Objective 3

Objective 3	Findings
To propose a guide for the selection and application of visualisation methods.	Selection Guide Development (Chapter 5): • Evaluated the Selection Approaches identified in the literature review based on six design challenges in Chapter 4. • Developed Selection Guide in HTML format.
	Application Guide Development (Chapter 6): • Seven key steps were derived: *Identify Problem*, *Tool Selection*, *Technique Selection*, *Create Props*, *Recruit Participants*, *Create Artefact*, and *Next Step*. • Identified the methodology for 23 visualisation methods. • Identified associated methods for producing the visual artefacts. • Developed the Application Guide in HTML format. Each visualisation method is presented on an individual page, which contains 5 areas: *Filters*, *Description*, *How to Use*, *Examples*, and *Reference*.

Table 41 - Findings addressing Objective 4

Objective 4	Findings
To apply and validate the proposed guide.	Serious Training Game Design (Chapter 7): • Four design challenges are presented. • The Selection Guide (Chapter 5) was adopted to select a suitable visualisation method for each challenge. • The application of the visualisation methods is presented in detail. The Application Guide (Chapter 6) was followed for each method. • The findings from the utilisation of the methods are discussed.
	Serious Training Game Evaluation (Chapter 7): • A user study was designed to evaluate the serious training game designed using the Guide. • The study compared the learning effectiveness of the serious training game with a paper manual and found that the game was more effective for training procedural skills.
	Validation Using Serious Training Game (Chapter 7): • Using the Selection, suitable visualisation methods were identified for the design challenges in the serious training game development. • The visualisation methods selected were applied using the Application Guide. • The results in the user study shows that the Guide has aided the development of a successful HCI system.

8.2.4 Addressing Objective 4: To Apply and Validate the Proposed Guide

Chapter 7 presented the design and evaluation of a serious training game. This case study was conducted to validate the Guide. The Guide was used in the development of the serious training game. The design challenges, choice of the visualisation method, and the visual artefact produced were recorded to assess

the suitability of the Guide. Subsequently, the resulting serious training game was evaluated through a user study. As the design of the serious training game was supported by the use of the Guide, the effectiveness of the game validates the Guide. The findings are shown in Table 41.

8.3 Key Contributions

This research has developed a selection and application guide for visualisation methods that supports design and development of HCI systems. The key contributions are:

- **Identification and categorisation of HCI visualisation methods:** The compilation of HCI visualisation methods establishes design methods that support interactive system development through the use of visual artefacts (refer to Chapter 2: Section 2.3.1 and Appendix C). The identification of Selection Approaches brings together the ways in which visualisation methods are organised and grouped. A clear description of each approach and their relevant categories are provided (refer to Chapter 2: Section 2.3.2). By categorising visualisation methods to Selection Approaches, this study has provided a way for practitioners to select visualisation methods to support their design practice. The advantages and disadvantages of each Selection Approach are discussed to highlight gaps (refer to Chapter 2: Section 2.3.3).

- **Provision of a Selection Guide:** The Selection Guide helps designers to select a suitable visualisation method for a given design challenge. This guide consists of five filters, which is to help designers to understand the nature of their design challenge to arrive at a suitable visualisation method (refer to Chapter 5).

- **Provision of an Application Guide:** The Application Guide consists of the methodologies of the visualisation methods. The methodologies are presented in a consistent format to enable the ease of method comparison and to ensure there is comprehensive information for each method (refer to Chapter 6 and Appendix F).

- **Validation using a user study:** The thesis presents a user study showing how a serious training game is evaluated in terms of learning effectiveness. Two learning objectives were identified and mapped to Bloom's Taxonomy to advocate an approach for like-to-like comparison with future studies (refer to Chapter 7: Section 7.1.2). The serious training game was development using the Guide. The effectiveness of the serious training game demonstrates that the Guide has successfully aided the development of a HCI system.

8.4 Limitations

This section reflects upon the limitations of the research design.

8.4.1 Phase 2: Guide Development

Representative techniques: A visualisation method may have more than one representational technique. In the composition of the methodologies (Chapter 5), a representative technique was chosen and presented for methods. Further investigation to determine and differentiate the properties of the technique variation would add more depth to the Guide.

Relevance of visualisation methods: This list of visualisation methods was derived from published literature. Further investigation in visualisation methods used by HCI practitioners would provide a more up-to-date range of methods which is not available in published literature. Nevertheless, at the time of writing no inventory of HCI visualisation methods existed. This collection, therefore, can act as a basis for future investigations.

8.4.2 Phase 3: Guide Application

Guide application: To demonstration its applicability, the Guide was employed in a case study (Chapter 7). How the Guide was applied could be limited by the designer's ability to identify the design challenges, subjective selection of visualisation methods, and interpretation of the methodology. To maintain the reliability of this study, each step of the selection procedure was clearly

documented. Furthermore, it presented, step-by-step, how the methodology was followed to create the visual artefacts.

8.4.3 Phase 4: Guide Validation

Limitation of the case study: The sensitive nature of the learning content restricted the recruitment of participants. Running the same study with a bigger participant sample could unveil stronger evidence on validation. The Knowledge Interpretation Test was not based on a real assembly jig, but a model representation. This could have affected the results because even though the model representation can be used to measure how participants apply procedural knowledge to an extent, it does not truly reflect how participants would react on a real jig. However, the model representation had all the moving parts implemented and was a scaled reproduction of the CATIA-CAD model, the same model was used in the evaluation phase for both conditions. The engagement level may have been influenced by the novelty of the serious training game. Participants are likely to be familiar with paper-based learning; therefore learning through a game may temporarily appear more compelling. Nevertheless, the author believe that the effects were not just due to the novelty but rather to the exercise of learning by doing.

Limitation of validating the Guide using the case study: Validating the Guide using a case study provided indirect validation. Even though the results has shown that suitable visualisation methods can be selected and applied, the Guide was only validated using one case study. Furthermore the validation did not deal with the usability aspects of the Guide. Additional research involving case studies of different HCI design aspects, as well as taking into account the usability issues could improve the Guide.

8.5 Suggestions for Further Research

At the start of this study there was is no method selection process in literature to help designers narrow down the choice of visualisation methods and the procedure for the application of each visualisation method varies in terms of both the level of details and contents. In response, a Guide of visualisation method

was developed. Limitation to this study (discussed in Section 8.4) should be addressed in future research to improve and extend the usability of the Guide. These include:

- This research focused on collating HCI visualisation methods. Nonetheless, non-visual design methods are sometimes necessary for obtain information before a graphical representation can be created (Section 6.2.4.2). Research is needed to provide better guide designers to employing non-visual design methods.
- As no inventory of HCI visualisation methods existed prior to this research, this study was concerned with HCI visualisation methods derived from published literature. This means that the methods identified may not necessarily be the most novel ones used by practising designers. Future research is required to address new visualisation methods that are developed and used by HCI practitioners.
- The designer's ability to identifying design challenges, selection of visualisation methods and the interpretation of the methodology could influence the design outcome. Future work needs to address the usability of the Guide to see it can be employed successfully by less experienced designers.

8.6 Final Discussion

With increasingly complex HCI challenges arising from technological advancement (Ziegler et al., 2014), it is important for multidisciplinary teams to work together to meet these challenges. One key factor that is hindering multidisciplinary teams in HCI is the discipline language and design approaches (Haesen et al., 2010; Mendel, 2012). This research has focused on the use of graphical representation of information (visualisation methods) to overcome challenges in collaborative design.

The purpose of employing a visualisation method is not simply to create an image or object; the challenge is to provide relevant information that furthers the design process (Houde and Hill, 1997). Within a design team, each member may be an

expert in their own field, but may not necessarily be familiar with HCI design. This has huge impact on the design process because which relevant information is provided can be affected by the expertise of the team members in HCI design (Haesen et al., 2009; Self et al., 2014) as well as their awareness and understanding of available design methods (Weevers and van Kuijk, 2012). Therefore there is a need to support selection amongst the growing number of design methods (Bryan-Kinns and Hamilton, 2002; Houde and Hill, 1997; Tidball et al., 2010).

At the start of this research, there were already books (Rogers et al., 2011; Stickdorn and Schneider, 2010), websites (Tassi, 2009; Weevers and van Kuijk, 2012; Royal College of Art, n.d.), and papers (Maguire, 2001) presenting various tools and techniques for HCI design. However, there are some short comings with the existing literature. The existing selection tools tend to focus on a facet of HCI methods, such as usability (Usability Net, 2006), UCD (Royal College of Art, n.d.; Weevers and van Kuijk, 2012; Maguire, 2001), and Service Design (Mendel, 2012; Tassi, 2009; Segelström and Holmlid, 2011; Stickdorn and Schneider, 2010; Alves and Nunes, 2013). At the time, no research has attempted to assemble a collection of HCI visualisation methods. In this context, the aim of this research was to develop a selection and application guide for visualisation methods that supports design and development of HCI systems.

This research began with a literature review of HCI visualisation methods and their categorisation approaches in Chapter 2. It resulted in 1) the creation of an inventory of 23 HCI visualisation methods, 2) the provision of an analysis of the current categorisation approaches, and 3) the categorisation of visualisation methods using each approach.

The literature review focused on HCI visualisation methods in websites and published literature. This means that the methods identified may not necessarily be the most novel ones used by practising designers. Nevertheless, at the time of writing, no inventory of HCI visualisation methods existed. Therefore, the author deemed it important to first clarify what visualisation methods are commonly known in the literature.

This review focused on visualisation methods, which means that some common but non-visual methods are excluded (such as *Questionnaire*). As discussed in Chapter 2: Section 2.4, one visualisation method on its own may not be enough to address a design problem. Depending on the information they have at hand and what their design intentions are, designers may require other methods to obtain the necessary information. This issue was further addressed in Chapter 6: Section 6.2.4.2.

This research contributed to an Innovate UK (previously known as Technology Strategy Board) funded parent project (Using Gaming Technology to Digitise Complex Manufacturing Process Knowledge, project reference: 101251, 2012-2015). The aim of the parent project was to leverage commercial gaming technology to capture and re-use human knowledge in the context of complex manufacturing. The author worked with a multidisciplinary team in the planning, design, and evaluation of industrial HCI systems (Chapters 4 and 7). The research carried out is reported in this thesis as case studies for the development of the Guide.

Existing selection tools were either university initiatives, such as Tassi (2009), Weevers and van Kuijk (2012), Royal College of Art (n.d.), or created by experts in the field, such as Stickdorn and Schneider's (2010) book titled '*This is Service Design Thinking: Basics, Tools, Cases*', Design Council (n.d.a, n.d.b), and IDEO (2003). There is little information of when and how designers uses the tools. Hence, in developing the Guide, the author began by examining this issue. To acquire deeper understanding of challenges designers face in HCI system design and how they would approach it, a flexible design approach was chosen in the form of a Case Study. Robson (2011, p.136) described a Case Study as a "strategy for doing research which involves an empirical investigation of a particular contemporary phenomenon within its real life context using multiple sources of evidence". The nature of the design challenges could be very different depending on the stages of design and the types of actors and technology involved, hence conducting case studies was appropriate for the author to gain better understanding of the design challenges in a real context.

Six design challenges were identified from case studies (detailed in Chapter 4). The design challenges were used to evaluate the suitability of the Selection Approaches (from Chapter 2) for visualisation method selection. Two factors were identified: 1) not all the approaches were applicable in each design challenge, and 2) more than one category may be appropriate for a selection approach. As a result of these findings, the first part of the Guide (the Selection Guide) was developed in an HTML format. The five Selection Approaches are converted into filters. Users do not have to make a selection for each filter and more than one category may be chosen for a given filter. The Selection Guide consists of five filters, which is to help designers to understand the nature of their design challenge to arrive at a suitable visualisation method.

The second part of the Guide is the Application Guide. The Application Guide consists of five parts: Filter, Description, How to use, Examples, and Reference. The Application Guide presents each visualisation method in a consistent format to allow ease of method comparison and to ensure that there is comprehensive information for each method.

The Guide does not factor in the time, cost, and experience of the designers required for employing the methods. Even though these elements were considered in some cases (Weevers and van Kuijk, 2012; Lengler and Eppler, 2007; Royal College of Art, n.d.), there was little coherence in literature for the author to factor in these elements in the Guide.

To validate the Guide, it was applied in the development of a serious training game (Chapter 7). The resulting game was evaluated in a user study. As the serious training was developed with the help of the Guide, the effectiveness of the game validates the Guide. The validation was presented in the form of a Case Study. How the Guide was applied could be limited by the designer's ability to identify the design challenges, subjective selection of visualisation methods, and interpretation of the methodology. To maintain the reliability of this study, each step of the selection procedure was clearly documented. Furthermore, it presented, step-by-step, how the methodology was followed to create the visual

artefacts. The serious training game was evaluated based on the users' learning effectiveness.

8.7 Conclusions

With the increasing diversity of disciplines involved in HCI design, and increasing complexity in ICT technologies, this research aimed to develop a selection and application guide for visualisation methods that supports design and development of HCI systems.

A literature review resulted in the identification of 23 visualisation methods and 5 categorisation approaches. Case studies were untaken to gather information on typical processes in interaction design: requirements capture and interaction design. For each case study, the design challenges and the resulting visual artefacts were recorded. This was to help better understand the nature of design problems the designers face and how they are dealt with.

The findings from the case studies fuelled the development of the Guide. The Guide is composed of two parts: a Selection Guide and an Application Guide. The Selection Guide consists of 5 filters that help designers to search for a suitable visualisation method for a particular design problem. The Application Guide provides the description, methodology, and examples of how a visualisation method is used.

The applicability of the Guide was demonstrated in a case study; the Guide was utilised in the development of a game for training new workers in manufacturing tasks. A user study was conducted to evaluate the learning effectiveness of this serious training game.

The following points sum up what was learned in this research:

- A literature review was performed concerning the state of the arts for HCI visualisation method categorisation and selection approaches. It was identified that no selection and application guide for HCI visualisation methods exists. This literature review resulted in the creation of an inventory of visualisation methods for HCI design, an analysis of current categorisation approaches, and the categorisation of visualisation

methods using the approaches identified. In addition, two gap were identified in this research; the need to help designers narrow down the choice of methods effectively, and to investigate the procedure for the application of each visualisation method.

- Inductive case studies were carried out to better understand when and how visualisation methods are utilised in HCI system development. As a result, it was possible to capture real industrial design challenges.

- An analysis of the Selection Approaches identified that not all the approaches were applicable in each design challenge. Furthermore, more than one category may be appropriate for a selection approach. In response, the Selection Guide was developed in a HTML-based interactive format. This format allows users to down select by applying various combinations of Selection Approaches (otherwise known as Selection Filters in Chapter 5). More than one category can be chosen for each Selection Approach (Selection Filter).

- An Application Guide was developed. Through the analyses of the visualisation methods, seven common key steps were identified. As a result, the methodology for each visualisation method was structured in a consistent manner. Providing a structured methodology ensures comprehensive information is provided for each visualisation method and facilitates the comparison of visualisation methods.

- The Guide was validated through a case study. The Guide was employed in the development of a serious training gaming. Visualisation methods were selected using the Selection Guide and applied by following the methodology in the Application Guide. Once developed, the effectiveness of the game was evaluated. The results show that the Guide can aid the development of HCI systems. The method selection and application has been demonstrated.

REFERENCES

Abate, A.F., Guida, M., Leoncini, P., Nappi, M. and Ricciardi, S. (2009), A Haptic-Based Approach to Virtual Training for Aerospace Industry, *Journal of Visual Languages and Computing*, 20(5), pp.318–325.

Adamczyk, P.D. and Twidale, M.B. (2007), Supporting Multidisciplinary Collaboration: Requirements From Novel HCI Education, In: *25th SIGCHI Conference on Human Factors in Computing Systems, CHI 2007*. San Jose, CA, 28 April - 3 May 2007, pp. 1073–1076.

Aguilar-Savén, R.S. (2004), Business Process Modelling: Review and Framework, *International Journal of Production Economics*, 90(2), pp.129–149.

Aldersey-Williams, H., Bound, J. and Coleman, R. eds. (1999), *The Methods Lab: User Research for Design*, Design for Ageing Network (DAN).

All, A., Castellar, E.P.N. and Van Looy, J. (2015), Towards a Conceptual Framework for Assessing the Effectiveness of Digital Game-Based Learning, *Computers & Education*, 88(1), pp.29–37.

All, A., Nuñez Castellar, P.E. and Looy, J. Van (2014), Measuring Effectiveness in Digital Game-Based Learning: A Methodological Review, *International Journal of Serious Games*, 1(2), pp.3–21.

Alves, R. and Nunes, N.J. (2013), Towards a Taxonomy of Service Design Methods and Tools, In: *4th International Conference on Exploring Services Science, IESS 2013*. Porto, 7-8 February 2013, pp. 215–229.

Anderson, L.W. and Krathwohl, D.R. (2001), *A Taxonomy for Learning, Teaching, and Assessing: A Revision of Bloom's Taxonomy of Educational Objectives*, New York: Longman.

Arnheim, R. (1969), *Visual Thinking*, Berkeley: University of California Press.

Aziz, E.-S.S., Chang, Y., Esche, S.K. and Chassapis, C. (2014), Virtual Mechanical Assembly Training Based on a 3D Game Engine, *Computer-Aided Design and Applications*, 12(2), pp.119–134.

Bailey, B.P., Biehl, J.T., Cook, D.J. and Metcalf, H.E. (2007), Adapting Paper Prototyping for Designing User Interfaces for Multiple Display Environments, *Personal and Ubiquitous Computing*, 12(3), pp.269–277.

Bal, M. (2012), Virtual Manufacturing Laboratory Experiences for Distance Learning Courses in Engineering Technology, In: *119th ASEE Annual Conference and Exposition*. San Antonio, TX, 10-13 June 2012, pp. 1–12.

Bartoli, G., Del Bimbo, A., Faconti, M., Ferracani, A., Marini, V., Pezzatini, D., Seidenari, L. and Zilleruelo, F. (2012), Emergency Medicine Training With Gesture Driven Interactive 3D Simulations, In: *2012 ACM International Workshop on User Experience in E-Learning and Augmented Technologies in Education, UXeLATE 2012, Co-Located With ACM Multimedia 2012*. Nara, 2 November 2012, pp. 25–29.

Beale, I.L., Kato, P.M., Marin-Bowling, V.M., Guthrie, N. and Cole, S.W. (2007), Improvement in Cancer-Related Knowledge Following Use of a Psychoeducational Video Game for Adolescents and Young Adults With Cancer, *The Journal of Adolescent Health*, 41(3), pp.263–70.

Bellotti, F., Kapralos, B., Lee, K., Moreno-Ger, P. and Berta, R. (2013), Assessment in and of Serious Games: An Overview, *Advances in Human-Computer Interaction*, 2013, pp.1–11.

Benyon, D. (2013), *Designing Interactive Systems: A Comprehensive Guide to HCI and Interaction Design* 3rd ed., Harlow: Pearson Education Limited.

Berg, T. and Pooley, R. (2013), Contemporary Iconography for Rich Picture Construction, *Systems Research and Behavioral Science*, 30(1), pp.31–42.

Bitner, M.J., Ostrom, A.L. and Morgan, F.N. (2008), Service Blueprinting: A Practical Technique for Service Innovation, *California Management Review*, 50(3), pp.66–94.

Borsci, S., Lawson, G. and Broome, S. (2015), Empirical Evidence, Evaluation Criteria and Challenges for the Effectiveness of Virtual and Mixed Reality Tools for Training Operators of Car Service Maintenance, *Computers in Industry*, 67, pp.17–26.

Boulos, M.N.K., Blanchard, B.J., Walker, C., Montero, J., Tripathy, A. and Gutierrez-Osuna, R. (2011), Web GIS in Practice X: A Microsoft Kinect Natural User Interface for Google Earth Navigation, *International Journal of Health Geographics*, 10(1), pp.1–14.

British Standard Institution (2010), *BS EN ISO 9241-210:2010 Ergonomics of Human-System Interaction: Human-Centred Design for Interactive Systems*, London: BSI.

Bryan-Kinns, N. and Hamilton, F. (2002), One for All and All for One: Case Studies of Using Prototypes in Commercial Projects, In: *2nd Nordi Conference on Human-Computer Interaction, NordiCHI 2002*. Aarhus, 19-23 October 2003, pp. 91–100.

Buchanan, L., Wolanczyk, F. and Zinghini, F. (2011), Blending Bloom's Taxonomy and Serious Game Design, In: *International Conference on Security and Management*. Las Vegas, NV, 18-21 January 2011, pp. 1–6.

Buckle, P., Clarkson, P.J., Coleman, R., Bound, J., Ward, J. and Brown, J. (2010), Systems Mapping Workshops and Their Role in Understanding Medication Errors in Healthcare, *Applied Ergonomics*, 41(5), pp.645–656.

Buley, L. (2013), *The User Experience Team of One: A Research and Design Survival Guide*, Brooklyn, N.Y.: Rosenfeld Media.

Buxton, B. (2007), *Sketching User Experiences: Getting the Design Right and the Right Design*, San Francisco, CA: Morgan Kaufmann.

Buzan, T. (2011), Mind Mapping, [online] Available at: <http://www.tonybuzan/anout/mind-mapping/> [Accessed September 30, 2015].

Buzan, T. (2014), *Mind Maps for Business: Using the Ultimate Thinking Tool to Revolutionise How You Work* 2nd ed., Harlow: Pearson Education.

Caddick, R. (2011), *Communicating the User Experience: A Practical Guide for Creating Useful UX Documentation*, Hoboken, NJ: Wiley.

Carroll, J.M. (2000), Five Reasons for Scenario-Based Design, *Interacting With Computers*, 13(1), pp.43–60.

Carroll, J.M. (2003), Introduction: Toward a Multidisciplinary Science of Human-Computer Interaction, In: J. M. Carroll, ed. *HCI Models, Theories, and Frameworks: Toward a Multidisciplinary Science*. San Francisco, CA: Elsevier Science, pp. 1–19.

Catterall, B.J. (1990), The HUFIT Functionality Matrix, In: *Third International Conference on Human-Computer Interaction, INTERACT 1990*. Cambridge, 27-31 August 1990, pp. 377–381.

Checkland, P. and Scholes, J. (1990), *Soft Systems Methodology in Action*, Chichester: John Wiley & Sons.

Coggle (n.d.), Coggle: A Clear Way to Share Complex Information, [online] Available at: <https://coggle.it> [Accessed September 28, 2015].

Connolly, T.M., Boyle, E.A., MacArthur, E., Hainey, T. and Boyle, J.M. (2012), A Systematic Literature Review of Empirical Evidence on Computer Games and Serious Games, *Computers & Education*, 59(2), pp.661–686.

Cooper, A. (2004), *The Inmates are Running the Asylum: Why High-Tech Products Drive Us Crazy and How to Restore the Sanity* 2nd ed., Indianapolis, IN: Sams Publishing.

Crystal, A. and Ellington, B. (2004), Task Analysis and Human-Computer Interaction: Approaches, Techniques, and Levels of Analysis, In:

Proceeding of Americas Conference of Information Systems, AMCIS 2004. New York City, NY, 6-8 August 2004, pp. 3202–3210.

Design Council (n.d.a), Design Methods, [online] Available at: <http://www.designcouncil.org.uk/about-design/How-designers-work/Design-methods/> [Accessed September 30, 2015].

Design Council (n.d.b), The Open Resource of Design Methods, [online] Available at: <http://www.methodbank.com> [Accessed September 30, 2015].

Diana, C., Pacenti, E. and Tassi, R. (2009), Visualtiles: Communication Tools for (Service) Design, In: *First Nordic Conference on Service Design and Service Innovation*. Oslo, 24-26 November 2009, pp. 1–12.

Dickinson, J.K., Woodard, P., Canas, R., Ahamed, S. and Lockston, D. (2011), Game-Based Trench Safety Education: Development and Lessons Learned, *Journal of Information Technology in Construction*, 16, pp.118–132.

Döweling, S., Tahiri, T., Sowinski, P., Benedikt, Schmidt and Khalilbeigi, M. (2013), Support for Collaborative Situation Analysis and Planning in Crisis Management Teams Using Interactive Tabletops, In: *Proceedings of the 2013 ACM International Conference on Interactive Tabletops and Surfaces, ITS 2013*. St. Andrews, 6-9 October 2013, pp. 273–282.

Ekanayake, H., Backlund, P., Ziemke, T., Ramberg, R. and Hewagamage, K. (2010), Game Interaction State Graphs for Evaluation of User Engagement in Explorative and Experience-Based Training Games, In: *International Conference on Advances in ICT for Emerging Regions, ICTer 2010*. Colombo, Sri Lanka, 29 September - 1 October 2010, pp. 40–44.

Fallman, D. (2003), Design-Oriented Human-Computer Interaction, In: *Conference on Human Factors in Computing Systems*. Lauderdale, FL, 5-10 April 2003, pp. 225–232.

Fincher, S. and Tenenberg, J. (2005), Making Sense of Card Sorting Data, *Expert Systems*, 22(3), pp.89–93.

Fleming, N. (2015), VARK: A Guide to Learning Styles, [online] Available at: <http://vark-learn.com/> [Accessed February 15, 2016].

Fox, D. (2015), Using the Business Origmai Technique to Understand Complex Ecosystems, In: T. K. Judge and C. Neustaedter, eds. *Studying and Designing Technology for Domestic Life: Lessons from Home*. Walktham, MA: Morgan Kaufmann, pp. 93–110.

Garris, R., Ahlers, R. and Driskell, J.E. (2002), Games, Motivation, and Learning: A Research and Practice Model, *Simulation & Gaming*, 33(4), pp.441–467.

Gillen, J., Cameron, C.A., Tapanya, S., Pinto, G., Hancock, R., Young, S. and Gamannossi, B.A. (2007), A Day in the Life: Advancing a Methodology for the Cultural Study of Development and Learning in Early Childhood, *Early Child Development and Care*, 177(2), pp.207–218.

Girard, C., Ecalle, J. and Magnan, A. (2013), Serious Games as New Educational Tools: How Effective Are They? A Meta-Analysis of Recent Studies, *Journal of Computer Assisted Learning*, 29(3), pp.207–219.

Gonzalez-Franco, M., Gilroy, S. and Moore, J.O. (2014), Empowering Patients to Perform Physical Therapy at Home, In: *36th Annual International Conference of the IEEE Engineering in Medicine and Biology Society, EMBC 2014*. Chicago, IL, 26-30 August 2014, pp. 6308–6311.

González-Franco, M., Peck, T.C., Rodríguez-Fornells, A. and Slater, M. (2014), A Threat to a Virtual Hand Elicits Motor Cortex Activation, *Experimental Brain Research*, 232(3), pp.875–887.

González-Franco, M., Pérez-Marcos, D., Spanlang, B. and Slater, M. (2010), The Contribution of Real-Time Mirror Reflections of Motor Actions on Virtual Body Ownership in an Immersive Virtual Environment, In: *IEEE Virtual Reality 2010, VR 2010*. Waltham, MA, 20-24 March 2010, pp. 111–114.

Gray, D., Brown, S. and Macanufo, J. (2010), *Gamestorming: A Playbook for Innovators, Rulebreakers, and Changemakers*, Sebastopol, CA: O'Reilly.

Gredler, M.E. (2004), Games and Simulations and Their Relationships to Learning, In: D. H. Jonassen, ed. *Handbook of Research for Educational Communications and Technology*. Mahwah, NJ: Lawrence Erlbaum Associates, pp. 571–582.

Greuter, S., Tepe, S., Peterson, J.F., Boukamp, F., D'Amazing, K., Quigley, K., van der Waerden, R., Harris, T., Goschnick, T. and Wakefield, R. (2012), Designing a Game for Occupational Health and Safety in the Construction Industry, In: *8th Australasian Conference on Interactive Entertainment: Playing the System, IE 2012*. Auckland, 21-22 July 2012.

Haesen, M., Meskens, J., Luyten, K. and Coninx, K. (2010), Draw Me a Storyboard: Incorporating Principles and Techniques of Comics to Ease Communication and Artefact Creation in User-Centred Design, In: *Proceedings of the 24th BSC Interaction Specialist Group Conference, BSC '10*. pp. 133–142.

Haesen, M., Meskens, J., Luyten, K. and Coninx, K. (2009), Supporting Multidisciplinary Teams and Early Design Stages Using Storyboards, In: *13th International Conference on Human-Computer Interaction, HCI International 2009*. San Diego, CA, 19-24 July 2009, pp. 616–623.

Hanington, B.M. (2007), Generative Research in Design Education, In: *International Association of Societies of Design Research, IASDR 2007*. Hong Kong, 12-15 November 2007, pp. 1–15.

Hartson, R. and Pyla, P.S. (2012), *The UX Book: Process and Guidelines for Ensuring a Quality User Experience*, Walktham, MA: Morgan Kaufmann.

Holtzblatt, K., Wendell, J.B. and Wood, S. (2005), *Rapid Contextual Design: A How-to Guide to Key Techniques for User-Centred Design*, San Francisco, CA: Morgan Kaufmann.

Houde, S. and Hill, C. (1997), What Do Prototypes Prototype, In: M. G. Helander, T. K. Landauer, and P. V Prabhu, eds. *Handbook of Human-Computer Interaction*. Amsterdam: Elsevier, pp. 367–381.

IDEO (2003), Method Cards for IDEO: 51 Card Deck to Inspire Design, [online] Available at: <http://www.ideo.com/work/method-cards/> [Accessed September 30, 2015].

Jang, J. and Schunn, C.D. (2012), Physical Design Tools Support and Hinder Innovative Engineering Design, *Journal of Mechanical Design*, 134(4), pp.1–9.

Kang, J. and Jain, N. (2011), Merit of Computer Game in Tacit Knowledge Acquisition and Retention, In: *28th International Symposium on Automation and Robotics in Construction, ISARC 2011*. Seoul, 29 June 2011 - 2 July 2011, pp. 1091–1096.

Kantola, N. and Jokela, T. (2007), SVSb: Simple and Visual Storyboards. Developing a Visualisation Method for Depicting User Scenarios, In: *Australasian Computer-Human Interaction Conference, OZCHI '07*. Adelaide, Australia; 28-30 November 2007, pp. 28–30.

Kim, B.C., Potter, K. and Weaver, P.M. (2012), Continuous Tow Shearing for Manufacturing Variable Angle Tow Composites, *Composites Part A: Applied Science and Manufacturing*, 43(8), pp.1347–1356.

Knight, J.F., Carley, S., Tregunna, B., Jarvis, S., Smithies, R., de Freitas, S., Dunwell, I. and Mackway-Jones, K. (2010), Serious Gaming Technology in Major Incident Triage Training: A Pragmatic Controlled Trial, *Resuscitation*, 81(9), pp.1175–9.

Kolko, J. (2011), *Thoughts on Interaction Design: A Collection of Reflections* 2nd ed., Burlington, MA: Morgan Kaufmann.

Krathwohl, D.R. (2002), A Revision of Bloom' s Taxonomy: An Overview, *Theory into Practice*, 41(4), pp.212–218.

Larkin, J.H. and Herbert, S.A. (1987), Why a Diagram Is (Sometimes) Worth Ten Thousand Words, *Cognitive Science*, 11(1), pp.65–99.

Larson, J.S., Bradlow, E.T. and Fader, P.S. (2005), An Exploratory Look at Supermarket Shopping Paths, *International Journal of Research in Marketing*, 22(4), pp.395–414.

Lazar, J., Feng, J. and Hochheiser, H. (2010), *Research Methods: In Human-Computer Interaction*, Chichester: Wiley.

Van der Lelie, C. (2006), The Value of Storyboards in the Product Design Process, *Personal and Ubiquitous Computing*, 10(2-3), pp.159–162.

Lengler, R. and Eppler, M.J. (2007), Towards a Periodic Table of Visualization Methods for Management, In: *2007 IASTED International Conference on Graphics and Visualization in Engineering, GVE 2007*. Clearwater, FL, 3-5 January 2007, pp. 83–88.

Lewis, M.A. and Maylor, H.R. (2007), Game Playing and Operations Management Education, *International Journal of Production Economics*, 105(1), pp.134–149.

Lidwell, W., Holden, K. and Butler, J. (2003), *Universal Principles of Design*, Gloucester, MA: Rockport.

Lili, Z. and Yanli, W. (2010), Design of Harmonious Human-Computer Interaction Based on Intelligence Technology Development, In: *2010 International Conference on Intelligent System Design and Engineering Application, ISDEA 2010*. Changsha, Hunan, 13-14 October 2010, pp. 574–577.

Ma, M. and Zheng, H. (2011), Virtual Reality and Serious Games in Healthcare, In: S. Brahnam and L. C. Jain, eds. *Advanced Computational Intelligence Paradigms in Healthcare 6. Virtual Reality in Psychotherapy, Rehabilitation, and Assessment*. Springer Berlin Heidelberg, pp. 169–192.

Maguire, M. (2001), Methods to Support Human-Centred Design, *International Journal of Human-Computer Studies*, 55(4), pp.587–634.

Maguire, M. and Bevan, N. (2002), User Requirements Analysis, In: *Proceedings of the International Federation for Information Processing 17th World Computer Congress*. Montreal, 25-30 August 2002, pp. 133–148.

Marshall, R., Cook, S., Mitchell, V., Summerskill, S., Haines, V., Maguire, M., Sims, R., Gyi, D. and Case, K. (2015), Design and Evaluation: End Users, User Datasets and Personas, *Applied Ergonomics*, 46(Part B), pp.311–317.

Martin, B. and Hanington, B. (2012), *Universal Methods of Design: 100 Ways to Research Complex Problems, Develop Innovative Ideas, and Design Effective Solutions*, Beverly, MA: Rockport.

Mayas, C., Hörold, S. and Krömker, H. (2013), Extending the Information of Activity Diagrams with a User Input Classification, In: *15th International Conference on Human-Computer Interaction, HCI International 2013*. Las Vegas, NV, 21-26 July 2013, pp. 391–400.

McDonagh, D., Bruseberg, A. and Haslam, C. (2002), Visual Product Evaluation: Exploring Users' Emotional Relationships With Products, *Applied Ergonomics*, 33(3), pp.231–240.

Mendel, J. (2012), A Taxonomy of Models Used in the Design Process, *Interactions*, 19(1), pp.81–85.

MindJet (2015), Homepage, [online] Available at: <https://www.mindjet.com> [Accessed September 30, 2015].

MindMapper (n.d.), Homepage, [online] Available at: <https://www.mindmapper.com/main/main.asp> [Accessed September 30, 2015].

Mital, A., Pennathur, A., Huston, R.L., Thompson, D., Pittman, M., Markle, G., Kaber, D.B., Crumpton, L., Bishu, R.R., Rajurkar, K.P., Rajan, V., Fernandez, J.E., McMulkin, M., Deivanayagam, S., Ray, P.S. and Sule, D. (1999), The Need for Worker Training in Advanced Manufacturing Technology (AMT) Environments: A White Paper, *International Journal of Industrial Ergonomics*, 24(2), pp.173–184.

Mitchell, A. and Savill-Smith, C. (2004), *The Use of Computer and Video Games for Learning: A Review of the Literature*, London: Learning and Skills Development Agency.

Mitgutsch, K. and Alvarado, N. (2012), Purposeful by Design: A Serious Game Design Assessment Framework, In: *Proceedings of the International Conference on the Foundations of Digital Games, FDG 2012*. Raleigh, NC, 30 May - 1 June 2012, pp. 121–128.

Morcos, M. and Henshaw, M. (2009), A Soft Systems Methodology for Transforming Organisations to Product-Service Systems: Application in Defence and Construction Industry, In: *7th Annual Conference on Systems*

Engineering Research 2009, CSER 2009. Loughborough, UK, 20-23 April 2009, pp. 1–11.

Moritz, S. (2005), *Service Design: Practical Access to an Evolving Field*, London: Köln International School of Design (KISD). [online] Available at: <http://stefan-moritz.com/Book.html>.

Nielsen, L. (2013), *Personas: User Focused Design*, London: Springer.

O'Neil, H.F., Wainess, R. and Baker, E.L. (2005), Classification of Learning Outcomes: Evidence From the Computer Games Literature, *The Curriculum Journal*, 16(4), pp.455–474.

Ong, S.K. and Mannan, M.A. (2004), Virtual Reality Simulations and Animations in a Web-Based Interactive Manufacturing Engineering Module, *Computers & Education*, 43(4), pp.361–382.

Paelke, V., Nebe, K., Geiger, C., Klompmaker, F. and Fischer, H. (2012), Designing Multi-Modal Map-Based Interfaces for Disaster Management, In: *The Fifth International Conference on Advances in Computer-Human Interactions, ACHI 2012*. Valencia, 30 January - 4 February 2012, pp. 95–100.

Papastergiou, M. (2009), Digital Game-Based Learning in High School Computer Science Education: Impact on Educational Effectiveness and Student Motivation, *Computers & Education*, 52(1), pp.1–12.

Peck, T.C., Seinfeld, S., Aglioti, S.M. and Slater, M. (2013), Putting Yourself in the Skin of a Black Avatar Reduces Implicit Racial Bias, *Consciousness and Cognition*, 22(3), pp.779–87.

Petrie, H., Power, C., Cairns, P. and Seneler, C. (2011), Using Card Sorts for Understanding Website Information Architectures: Technological, Methodological and Cultural Issues, In: *13th IFIP TC13 International Conference on Human-Computer Interaction, INTERACT 2011*. Lisbon, 5-9 September 2011, pp. 309–322.

Phipps, D.L., Meakin, G.H. and Beatty, P.C.W. (2011), Extending Hierarchical Task Analysis to Identify Cognitive Demands and Information Design Requirements, *Applied Ergonomics*, 42(5), pp.741–748.

Pierce, J. (2014), On the Presentation and Production of Design Research Artifacts in HCI, In: *2014 ACM SIGCHI Conference on Designing Interactive Systems, DIS 2014*. Vancouver, BC, 21-25 June 2014, pp. 735–744.

Pollock, E., Chandler, P. and Sweller, J. (2002), Assimilating Complex Information, *Learning and Instruction*, 12(1), pp.61–86.

Pruitt, J. and Grudin, J. (2003), Personas: Practice and Theory, In: *Proceedings of the 2003 Conference on Designing for User Experiences, DUX 2003*. San Francisco, CA, 6-7 June 2003, pp. 313–334.

Robson, C. (2011), *Real World Research* 3rd ed., Chichester: Wiley.

Rogers, Y., Sharp, H. and Preece, J. (2011), *Interaction Design: Beyond Human-Computer Interaction* 3rd ed., Chichester: Wiley.

Römer, A., Weißhahn, G. and Hacker, W. (2001), Effort-Saving Product Representations in Design: Results of a Questionnaire Survey, *Design Studies*, 22(6), pp.473–491.

Royal College of Art (n.d.), Choose the Right Methods for Your Project, [online] Available at: <http://designingwithpeople.rca.ac.uk/methods> [Accessed September 30, 2015].

Rugg, G. and McGeorge, P. (1997), The Sorting Techniques: A Tutorial Paper on Card Sorts, Picture Sorts and Item Sorts, *Expert Systems*, 14(2), pp.80–92.

Rydén, F. (2012), Tech to the Future: Making a “Kinection” With Haptic Interaction, *IEEE Potentials*, 31(3), pp.34–36.

Saffer, D. (2010), *Designing for Interaction: Creating Innovation Applications and Devices* 2nd ed., Berkeley: New Riders.

Samaroo, R., Brown, J.M., Biddle, R. and Greenspan, S. (2013), The Day-in-the-Life Scenario: A Technique for Capturing User Experience in Complex Work Environments, In: *10th International Conference and Expo on Emerging Technologies for a Smarter World, CEWIT 2013*. Melville, NY, 21-22 October 2013, pp. 1–7.

Sampanes, A.C., Snyder, M., Rampoldi-Hnilo, L. and White, B.-K. (2011), Photo Diaries: A Peek Into a Mobile Worker’s Life, In: *1st International Conference on Design, User Experience and Uability: Theory, Methods, Tools and Practice, DUXU 2011*. Orlando, FL, 9-14 July 2011, pp. 640–647.

Sanders, E.B.N. and William, C.T. (2003), Harnessing People’s Creativity: Ideation and Expression Through Visual Communication, In: J. Langford and D. McDonagh, eds. *Focus Groups: Supporting Effective Product Development*. London: Taylor & Francis, pp. 137–148.

Schafer, W. a., Ganoe, C.H., Xiao, L., Coch, G. and Carroll, J.M. (2005), Designing the Next Generation of Distributed, Geocollaborative Tools, *Cartography and Geographic Information Science*, 32(2), pp.81–100.

Seffah, A., Gulliksen, J. and Desmarais, M.C. (2005), An Introduction to Human-Centered Software Engineering: Integrating Usability in the Development Process, In: A. Seffah, J. Gulliksen, and M. C. Desmarais, eds. *Human-Centered Software Engineering: Interfrating Usability in the Software Development LIfecycle*. Dordrecht, The Netherlands: Springer, pp. 3–16.

Segelström, F. and Holmlid, S. (2011), Service Design Visualisations Meet Service Theory: Strengths, Weaknesses and Perspectives, In: *Art & Science of Service*. San Jose, California, 8-10 June 2011, pp. 1–18.

Self, J., Evans, M. and Dalke, H. (2014), The Influence of Expertise Upon the Designer's Approach to Studio Practice and Tool Use, *Design Journal*, 17(2), pp.169–193.

Shostack, G.L. (1982), How to Design a Service, *European Journal of Marketing*, 16(1), pp.49–63.

Sitzmann, T. (2011), A Meta-Analytic Examination of the Instructional Effectiveness of Computer-Based Simulation Games, *Personnel Psychology*, 64(2), pp.489–528.

Spanlang, B., Normand, J.-M., Borland, D., Kilteni, K., Giannopoulos, E., Pomés, A., González-Franco, M., Perez-Marcos, D., Arroyo-Palacios, J., Muncunill, X.N. and Slater, M. (2014), How to Build an Embodiment Lab: Achieving Body Representation Illusions in Virtual Reality, *Frontiers in Robotics and AI*, 1, pp.1–22.

Stellmach, S., Jüttner, M., Nywelt, C., Schneider, J. and Dachselt, R. (2012), Investigating Freehand Pan and Zoom, In: H. Reiterer and O. Deussen, eds. *Mensch & Computer 2012*. Munchen: Oldenbourg Verlag, pp. 303–312.

Stickdorn, M. and Schneider, J. (2010), *This is Service Design Thinking: Basics, Tools, Cases*, Amsterdam: BIS Publishers.

Sun, S.H. and Tsai, L.Z. (2012), Development of Virtual Training Platform of Injection Molding Machine Based on VR Technology, *The International Journal of Advanced Manufacturing Technology*, 63(5-8), pp.609–620.

Suri, J.F. and Marsh, M. (2000), Scenario Building as an Ergonomics Method in Consumer Product Design, *Applied Ergonomics*, 31(2), pp.151–7.

Sward, K.A., Richardson, S., Kendrick, J. and Maloney, C. (2008), Use of a Web-Based Game to Teach Pediatric Content to Medical Students, *Ambulatory Pediatrics*, 8(6), pp.354–359.

Tague, N.R. (2005), *The Quality Toolbox* 2nd ed., Milwaukee: ASQ Quality Press.

Tassi, R. (2009), Service Design Tools: Communication Methods Supporting Design Processes, [online] Available at: <http://www.servicedesigntools.org/repository> [Accessed September 30, 2015].

Tidball, B., Stappers, P.J. and Mulder, I. (2010), Models, Collections and Toolkits for Human Computer Interaction: What Can We Learn, In: *Proceedings of the 2010 Bristish Computer Society Conference on Human Computer Interaction, BCS-HCI 2010*. Dundee, 6-10 September 2010, pp. 1–9.

Torrente, J., Borro-Escribano, B., Freire, M., del Blanco, A., Marchiori, E.J., Martinez-Ortiz, I., Moreno-Ger, P. and Fernandez-Manjon, B. (2014), Development of Game-Like Simulations for Procedural Knowledge in Healthcare Education, *IEEE Transactions on Learning Technologies*, 7(1), pp.69–82.

Tovey, M., Porter, S. and Newman, R. (2003), Sketching, Concept Development and Automotive Design, *Design Studies*, 24(2), pp.135–153.

Truong, K.N., Hayes, G.R. and Abowd, G.D. (2006), Storyboarding: An Empirical Determination of Best Practices and Effective Guidelines, In: *Proceedings of the Conference on Designing Interactive Systems: Processes, Practices, Methods, and Techniques, DIS*. University Park, PA, 26-28 June 2006, pp. 12–21.

Tversky, B. and Suwa, M. (2009), Thinking With Sketches, In: A. B. Markman and K. L. Wood, eds. *Tools for Innovation: The Science Behind the Practical Methods That Drive New Ideas*. Oxford: Oxford University Press, pp. 75–84.

Usability Net (2006), Methods Table, [online] Available at: <http://usabilitynet.org/tools/methods.htm> [Accessed September 30, 2015].

Vincent, C.J. and Blandford, A. (2014), The Challenges of Delivering Validated Personas for Medical Equipment Design, *Applied Ergonomics*, 45(4), pp.1097–1105.

Vizendo (2014), Homepage, [online] Available at: <http://vizendo.se/> [Accessed May 5, 2015].

Wania, C.E., Atwood, M.E. and Mccain, K.W. (2007), Mapping the Field of Human-Computer Interaction (HCI), *Proceedings of the American Society for Information Science and Technology*, 43(1), pp.1–7.

Weevers, T. and van Kuijk, J. (2012), UCDtoolbox.com: Helping Practitioners Explore, Select and Apply UCD Methods, In: J. van Kuijk, ed. *Design for Usability: Methods & Tools - A Practictioner's Guide*. Delft: Design United/IOP-IPCR Design for Usability Research Project, pp. 49–59.

Williams-Bell, F.M., Murphy, B.M., Kapralos, B., Hogue, A. and Weckman, E.J. (2015), Using Serious Games and Virtual Simulation for Training in the Fire Service: A Review, *Fire Technology*, 51(3), pp.553–584.

WiseMapping (n.d.), WiseMapping: Visual Thinking Evolution, [online] Available at: <https://app.wisemapping.com/> [Accessed September 30, 2015].

Wouters, P., Nimwegen, C. Van, Oostendorp, H. Van, Spek, E.D. Van Der and Games, S. (2013), A Meta-Analysis of the Cognitive and Motivational Effects of Serious Games, *Journal of Educational Psychology*, 105(2), pp.249–265.

Wouters, P., van der Spek, E. and van Oostendorp, H. (2009), Current Practices in Serious Game Research: A Review From a Learning Outcomes Perspective, In: T. Connolly, M. Stansfield, and L. Boyle, eds. *Games-Based Learning Advancements for Multi-Sensory Human Computer Interfaces: Techniques and Effective Practices*. Hershey, PA: Information Science Reference, pp. 232–250.

Yoo, J. and Pan, Y. (2014), Expanded Customer Journey Map: Interaction Mapping Framework Based on Scenario, In: *HCI International 2014*. Heraklion, 22-27 June 2014, pp. 550–555.

Ziegler, J., Campos, J.C. and Nigay, L. (2014), HCI Engineering: Charting the Way Towards Methods and Tools for Advanced Interactive Systems, In: *Proceedings of the 2014 ACM SIGCHI symposium on Engineering interactive computing systems, EICS 2014*. Rome, 17-20 June 2014, pp. 299–300.

Zimmerman, J., Forlizzi, J. and Evenson, S. (2007), Research Through Design as a Method for Interaction Design Research in HCI, In: *25th SIGCHI Conference on Human Factors in Computing Systems, CHI 2007*. San Jose, CA, 28 April - 3 May 2007, pp. 493–502.

Zyda, M. (2005), From Visual Simulation to Virtual Reality to Games, *Computer*, 38(9), pp.25–32.

APPENDICES

Appendix A – Deriving Visualisation Methods from HCI Design Methods

Appendix A shows a table of HCI design methods identified in literature and the source they were identified in (Chapter 2: Section 2.3.1). The last column indicate whether it is a visualisation method.

Appendix B – Design Methods Excluded From Literature Review

Appendix B shows a table of the design methods excluded from the literature review and the source they were identified in (Chapter 2: Section 2.3.1).

Appendix C – Visualisation Method Definition

Appendix C provides a table with the definition of each of the visualisation methods identified in the literature review (Chapter 2: Section 2.3.1).

Appendix D – Evidence of Mapping

Appendix D presents a table of evidence supporting the categorisation of each method to the five approaches (Chapter 2: Section 2.2.2).

Appendix E – Interview Transcript for Case Study I (Wheel Alignment)

The section presents a transcript of the interview designed to gain understanding of the Wheel Alignment case study of the Requirements Capture case study (Chapter 4: Section 4.2.1).

Appendix F – Procedures to Employ a Visualisation Method

The methodology for each visualisation method is structured using the key steps. Appendix F presents the methodology each of the 23 visualisation methods (Chapter 6, Section 6.2.2).

Appendix G – Demographic Questionnaire

Appendix G presents the demographic questionnaire that was completed by participants in the user study as part of the Guide validation (Chapter 3: Section 3.4.1.3).

Appendix H – Knowledge Retention Test

Appendix H presents the written test completed by the participants in the user study as part of the Guide validation (Chapter 3: Section 3.4.1.3). Some parts of the test has be replaced by ‘xxx’ for confidentiality reasons.

Appendix A – Deriving Visualisation Methods from HCI Design Methods

		Source													Visualisation Method
		(Buley, 2013)	(Caddick, 2011)	(Design Council, n.d.a)	(Design Council, n.d.b)	(IDEO, 2003)	(Maguire, 2001)	(Martin and Hanington, 2012)	(Mendel, 2012)	(Royal College of Art, n.d.)	(Segelström and Holmlid, 2011)	(Stickdorn and Schneider, 2010)	(Tassi, 2009)	(Usability Net, 2006)	
1	A Day in the Life / Day in the Life					•				•		•			✓
2	Affinity Diagram / Affinity Diagramming					•	•	•					•	•	✓
3	Behaviour Mapping					•		•							✓
4	Being Your Users / Be Your Customer / Try it Yourself			•	•	•									
5	Blueprint / Service Blueprint			•							•	•	•		✓
6	Bodystorming					•		•							
7	Brainstorming														
8	Capability Simulators / Simulation Exercises / Empathy Tools				•	•		•							
9	Card Sort / Card Sorting					•	•	•						•	✓
10	Co-Creation / Participatory Design							•				•			
11	Cognitive Walkthrough							•					•		
12	Collage					•		•							✓

		Source													Visualisation Method
		(Buley, 2013)	(Caddick, 2011)	(Design Council, n.d.a)	(Design Council, n.d.b)	(IDEO, 2003)	(Maguire, 2001)	(Martin and Hanington, 2012)	(Mendel, 2012)	(Royal College of Art, n.d.)	(Segelström and Holmlid, 2011)	(Stickdorn and Schneider, 2010)	(Tassi, 2009)	(Usability Net, 2006)	
13	Competitive Product Survey / Competitive Testing / Competitor Analysis / Existing System					•	•	•						•	
14	Context / Context of Use Analysis						•							•	
15	Contextual Inquiry / Contextual Interview / Contextual Inquiry Interview				•			•				•		•	
16	Critical Incident Technique							•						•	
17	Cultural Probes							•		•		•			
18	Customer / User Journey / Customer Journey / Customer Journey Maps			•	•			•	•		•	•	•		✓
19	Design Guidelines / Design Guidelines and Standards						•							•	
20	Desktop Walkthrough / Business Origami / Scale Modelling					•		•			•	•			✓
21	Evaluative Research / Evaluative Prototype /						•	•						•	

		Source													Visualisation Method
		(Buley, 2013)	(Caddick, 2011)	(Design Council, n.d.a)	(Design Council, n.d.b)	(IDEO, 2003)	(Maguire, 2001)	(Martin and Hanington, 2012)	(Mendel, 2012)	(Royal College of Art, n.d.)	(Segelström and Holmlid, 2011)	(Stickdorn and Schneider, 2010)	(Tassi, 2009)	(Usability Net, 2006)	
	Participatory Evaluation														
22	Experience Prototype / Experience Prototyping					•		•					•		
23	Five Whys?					•						•			
24	Fly on the Wall / Unobtrusive Measures / Field Study of Observation					•		•							
25	Focus Group			•	•		•	•		•				•	
26	Heuristic Evaluation / Heuristic or Expert Evaluation						•	•					•	•	
27	Ideas Generation Models								•			•			
28	Interviews / User Requirements Interview						•	•		•				•	
29	Mind Map							•					•		✓
30	Mood Board / Image Board				•			•					•		✓
31	Observation / User Observation	•		•	•		•			•					
32	Paper and Interactive Prototype / Prototypes /Physical Prototyping / Paper Prototyping / Rough Prototyping / Rapid Prototyping / Quick and Dirty Prototyping	•		•	•	•	•	•	•	•			•	•	✓

		Source													Visualisation Method
		(Buley, 2013)	(Caddick, 2011)	(Design Council, n.d.a)	(Design Council, n.d.b)	(IDEO, 2003)	(Maguire, 2001)	(Martin and Hanington, 2012)	(Mendel, 2012)	(Royal College of Art, n.d.)	(Segelström and Holmlid, 2011)	(Stickdorn and Schneider, 2010)	(Tassi, 2009)	(Usability Net, 2006)	
33	Parallel Prototyping / Parallel Design						•	•						•	
34	Persona / Character Profile		•					•	•	•	•	•	•		✓
35	Personal Inventory					•		•							
36	Photo Studies / Camera Journal					•		•							✓
37	Planning / Usability Planning and Scoping						•							•	
38	Poster / Predict Next Year's Headlines / Tomorrow Headlines					•							•		✓
39	Process Model / Process Analysis								•	•					✓
40	Questionnaires / UX Questionnaire / Satisfaction Questionnaire	•					•	•		•				•	
41	Role Playing			•	•	•		•	•	•		•	•		
42	Scenario			•	•	•		•	•	•		•	•	•	✓
43	Secondary Research				•	•		•							
44	Service Prototype											•	•		✓
45	Shadowing					•		•		•		•			
46	Sketching / Draw Your… / Draw the Experience / Fast Visualisation / Group Sketching	•		•	•	•							•		✓

		Source													Visualisation Method
		(Buley, 2013)	(Caddick, 2011)	(Design Council, n.d.a)	(Design Council, n.d.b)	(IDEO, 2003)	(Maguire, 2001)	(Martin and Hanington, 2012)	(Mendel, 2012)	(Royal College of Art, n.d.)	(Segelström and Holmlid, 2011)	(Stickdorn and Schneider, 2010)	(Tassi, 2009)	(Usability Net, 2006)	
47	Stakeholders Map / Stakeholder Analysis / System Map						•	•			•	•	•		✓
48	Story Telling														
49	Storyboard / Storyboarding						•	•			•	•	•	•	✓
50	Survey / Survey & Questionnaires / User Survey / Survey of Existing Users / Quantitative Surveys			•	•	•	•	•						•	
51	Task Analysis / Cognitive Task Analysis / Task Model / Task Flow	•	•			•	•	•						•	✓
52	Task Mapping / Function Mapping / Task Analysis Grid						•						•		✓
53	Usability Testing / User Testing / Pleasure Based Approach							•					•	•	
54	Usability Test Report		•					•							
55	User Diaries / Diary Studies / Diary Keeping			•	•		•	•							
56	Wireframe	•	•												✓
57	Wizard of Oz / Wizard of Oz Prototyping						•	•					•	•	

Appendix B – Design Methods Excluded From Literature Review

		Source												
		(Buley, 2013)	(Caddick, 2011)	(Design Council, n.d.a)	(Design Council, n.d.b)	(IDEO, 2003)	(Maguire, 2001)	(Martin and Hanington, 2012)	(Mendel, 2012)	(Royal College of Art, n.d.)	(Segelström and Holmlid, 2011)	(Stickdorn and Schneider, 2010)	(Tassi, 2009)	(Usability Net, 2006)
1	A/B Testing							•						
2	Activity Analysis					•								
3	Actors Map												•	
4	AEIOU							•						
5	Agile Development											•		
6	Allocation of Function						•							
7	Anthropometric Analysis					•								
8	Artifact Analysis							•						
9	Assessment Criteria			•										
10	Assisted Evaluation						•							
11	Attitude Models								•					
12	Audit Framework								•					
13	Automated Remote Research							•						
14	Behavioural Sampling					•								
15	Behavioural Archaeology					•								
16	Black Hat Session	•												
17	Brainstorm Graphic Organisers							•						
18	Brand Borrowing				•									

		Source												
		(Buley, 2013)	(Caddick, 2011)	(Design Council, n.d.a)	(Design Council, n.d.b)	(IDEO, 2003)	(Maguire, 2001)	(Martin and Hanington, 2012)	(Mendel, 2012)	(Royal College of Art, n.d.)	(Segelström and Holmlid, 2011)	(Stickdorn and Schneider, 2010)	(Tassi, 2009)	(Usability Net, 2006)
19	Business Model Canvas											•		
20	Case Studies							•						
21	Choosing a Sample			•	•									
22	Cluster and Vote			•	•									
23	Cognitive Mapping							•						
24	Cognitive Maps					•								
25	Comparative Assessment	•												
26	Comparing Notes			•	•									
27	Comparison Frameworks								•					
28	Conceptual Landscape					•								
29	Concept Mapping							•						
30	Constructive Interaction												•	
31	Content Analysis							•						
32	Content Inventory & Audit							•						
33	Content Requirements		•											
34	Content Panorama												•	
35	Content Pattern	•												
36	Contextual Design							•						
37	Controlled User Testing						•							
38	Creative Toolkits							•						
39	Cross-Cultural Comparisons					•								

		Source												
		(Buley, 2013)	(Caddick, 2011)	(Design Council, n.d.a)	(Design Council, n.d.b)	(IDEO, 2003)	(Maguire, 2001)	(Martin and Hanington, 2012)	(Mendel, 2012)	(Royal College of Art, n.d.)	(Segelström and Holmlid, 2011)	(Stickdorn and Schneider, 2010)	(Tassi, 2009)	(Usability Net, 2006)
40	Crowdsourcing							•						
41	Customer Experience Audit							•						
42	Customer Lifecycle Maps											•		
43	Data Gathering and Organising Frameworks								•					
44	Design Brief	•												
45	Design Charette							•						
46	Design Conceptual Models								•					
47	Design Documentaries				•									
48	Design Ethnography							•						
49	Design Games												•	
50	Design Principles	•												
51	Design Workshops							•						
52	Desirability Testing							•						
53	Diagnostic Evaluation													•
54	Directed Storytelling							•						
55	Dott 007				•									
56	Drivers and Hurdles			•	•									
57	Ecosystems								•					
58	Elito Method							•						
59	Emotional Timeline				•									

		Source												
		(Buley, 2013)	(Caddick, 2011)	(Design Council, n.d.a)	(Design Council, n.d.b)	(IDEO, 2003)	(Maguire, 2001)	(Martin and Hanington, 2012)	(Mendel, 2012)	(Royal College of Art, n.d.)	(Segelström and Holmlid, 2011)	(Stickdorn and Schneider, 2010)	(Tassi, 2009)	(Usability Net, 2006)
60	Energy Workshop				•									
61	Ergonomic Analysis							•						
62	Error Analysis					•								
63	Evaluating Existing System													•
64	Evaluation Walkthrough or Discussion						•							
65	Evaluation Workshop						•							
66	Everything-I-Touch				•									
67	Evidence-Based Design							•						
68	Evidencing												•	
69	Expectation Maps											•		
70	Experience Sampling Method							•						
71	Experiment							•						
72	Exploratory Research							•						
73	Extreme User Interviews					•								
74	Eyetracking							•						
75	Five-Second Test	•												
76	Flexible Modelling							•						
77	Flow Analysis					•								
78	Foreign Correspondents					•								
79	Funnel Diagram		•											

		Source												
		(Buley, 2013)	(Caddick, 2011)	(Design Council, n.d.a)	(Design Council, n.d.b)	(IDEO, 2003)	(Maguire, 2001)	(Martin and Hanington, 2012)	(Mendel, 2012)	(Royal College of Art, n.d.)	(Segelström and Holmlid, 2011)	(Stickdorn and Schneider, 2010)	(Tassi, 2009)	(Usability Net, 2006)
80	Generative Research							•						
81	Getting Started													•
82	Graffiti Walls							•						
83	Guerrilla Research	•												
84	Guided Tours					•								
85	Half a Profile				•									
86	Heuristic Markup	•												
87	Historical Analysis					•								
88	Hopes and Fears			•	•									
89	Identify Stakeholders						•							
90	Immersive Workshop									•				
91	Informance					•								
92	Interaction Table												•	
93	Interface Design Patterns													•
94	Intervention / Provocation									•				
95	ISO 13407													•
96	Issue Cards												•	
97	Kano Analysis							•						
98	Key Performance Indicators							•						
99	KJ Technique							•						
100	Laddering							•						
101	Lateral Thinking									•				
102	Learning Plan	•												
103	Lego Serious Play												•	

		Source												
		(Buley, 2013)	(Caddick, 2011)	(Design Council, n.d.a)	(Design Council, n.d.b)	(IDEO, 2003)	(Maguire, 2001)	(Martin and Hanington, 2012)	(Mendel, 2012)	(Royal College of Art, n.d.)	(Segelström and Holmlid, 2011)	(Stickdorn and Schneider, 2010)	(Tassi, 2009)	(Usability Net, 2006)
104	Listening Tour	•												
105	Long-Range Forecasts					•								
106	The Love Letter & the Breakup Letter							•						
107	Mental Model Diagrams							•						
108	Mobile Ethnography											•		
109	Mock Up												•	
110	Motivation Matrix												•	
111	Narration					•								
112	Navigation Structures								•					
113	Nomenclature and Metadata Rules Systems								•					
114	Object Hierarchies and Template Structures								•					
115	Offering Map												•	
116	Organizational Prototype						•							
117	Opportunity Workshop	•												
118	Parallel Experiences				•									
119	Participant Observation							•						
120	Participatory Action Research							•						
121	Participatory Design Game									•				
122	Performance Testing													•

		Source												
		(Buley, 2013)	(Caddick, 2011)	(Design Council, n.d.a)	(Design Council, n.d.b)	(IDEO, 2003)	(Maguire, 2001)	(Martin and Hanington, 2012)	(Mendel, 2012)	(Royal College of Art, n.d.)	(Segelström and Holmlid, 2011)	(Stickdorn and Schneider, 2010)	(Tassi, 2009)	(Usability Net, 2006)
123	Picture Cards							•						
124	POINT (Problems, Opportunities, Insights, Needs, Themes and Solutions)				•									
125	Prioritisation Frameworks								•					
126	Project Brief	•												
127	Project Space			•	•									
128	Proto-Persona	•												
129	Prototyping: Experience			•										
130	Pseudo Documentary									•				
131	Quick and Dirty Usability Test	•												
132	Rapid Ethnography					•								
133	Rapid Iterative Test & Evaluation							•						
134	Remote Moderated Research							•						
135	Requirements Meeting													•
136	Research Through Design							•						
137	Roadmaps								•					
138	Role Script												•	
139	Scenario Description Swimlanes							•						
140	Scenario Testing					•								

		Source												
		(Buley, 2013)	(Caddick, 2011)	(Design Council, n.d.a)	(Design Council, n.d.b)	(IDEO, 2003)	(Maguire, 2001)	(Martin and Hanington, 2012)	(Mendel, 2012)	(Royal College of Art, n.d.)	(Segelström and Holmlid, 2011)	(Stickdorn and Schneider, 2010)	(Tassi, 2009)	(Usability Net, 2006)
141	Scribble-Say-Slap Brainstorming			•	•									
142	Selecting Participants				•									
143	Semantic Differential							•						
144	Semiotic Research Frameworks / Databases								•					
145	Service Image												•	
146	Service Safaris											•		
147	Service Specification												•	
148	Service Staging											•		
149	Site Search Analytics							•						
150	Sitemaps		•											
151	Sketchboards	•												
152	Social Enterprise									•				
153	Social Network Mapping					•								
154	Software Prototyping						•							
155	Speed Dating							•						
156	Stakeholder Meeting													•
157	Stakeholder Walkthrough							•						
158	Still-Photo Survey					•								
159	Strategy Workshop	•												
160	Style Guides													•

		Source												
		(Buley, 2013)	(Caddick, 2011)	(Design Council, n.d.a)	(Design Council, n.d.b)	(IDEO, 2003)	(Maguire, 2001)	(Martin and Hanington, 2012)	(Mendel, 2012)	(Royal College of Art, n.d.)	(Segelström and Holmlid, 2011)	(Stickdorn and Schneider, 2010)	(Tassi, 2009)	(Usability Net, 2006)
161	Subjective Assessment / Subjective Evaluation / Remote Evaluation													•
162	Territory Maps							•						
163	Thematic Networks							•						
164	Think-Aloud Protocol							•						
165	Time-Aware Research							•						
166	Time-Lapse Video					•								
167	Touchpoints Matrix												•	
168	Touchstone Tours							•						
169	Trend Maps								•					
170	Triading							•						
171	Triangulation							•						
172	Unfocus Group					•								
173	Usability Cost-Benefit Analysis						•							
174	Use Cases												•	
175	User Cost-Benefit Analysis						•							
176	User Forum									•				
177	User Journeys		•											
178	User, Usability and Organizational Requirements						•							
179	UX Health Check	•												
180	UX Project Plan	•												

		Source												
		(Buley, 2013)	(Caddick, 2011)	(Design Council, n.d.a)	(Design Council, n.d.b)	(IDEO, 2003)	(Maguire, 2001)	(Martin and Hanington, 2012)	(Mendel, 2012)	(Royal College of Art, n.d.)	(Segelström and Holmlid, 2011)	(Stickdorn and Schneider, 2010)	(Tassi, 2009)	(Usability Net, 2006)
181	Value Opportunity Analysis							•						
182	Weighted Matrix							•						
183	What's in the Fridge				•									
184	What a Wonderful World				•									
185	What If…											•		
186	Word Clouds							•						
187	Word-Concept Association					•								
188	Workshop Toolkit			•	•									

Appendix C – Visualisation Method Definition

	Method	Definition
1	A Day in the Life (Gillen et al., 2007; Samaroo et al., 2013)	This method enables designers to build up a realistic picture of what happens to their subject throughout a typical day. Visualising their daily activities, the time when it occurs (Royal College of Art, n.d.), and in the context where it occurs (IDEO, 2003), will help to reveal contextual information that may be missed otherwise (Stickdorn and Schneider, 2010).
2	Affinity Diagram (Holtzblatt et al., 2005; Kolko, 2011)	This method is used to gather and organise large amounts of data, ideas, and insights (Diana et al., 2009). Starting with a problem statement, participants externalise their ideas by writing them on pieces of papers (Martin and Hanington, 2012). By identifying the connections between ideas, similar ideas could be clustered together to make sense of the information at hand (IDEO, 2003; Tassi, 2009).
3	Behaviour Mapping (Larson et al., 2005)	This method is used to reveal people's spatial behaviour in different locations (IDEO, 2003). Subjects are tracked based on their activity and time spent in a location and recorded using maps, architectural plans, video or time-lapsed photography (Martin and Hanington, 2012).
4	Blueprint (Bitner et al., 2008; Shostack, 1982)	A *Blueprint* is a schematic diagram for visualising the functions of a process from both the users' and service providers' perspectives (Stickdorn and Schneider, 2010). The process flow is organised into layers based on the actors involved (Segelström and Holmlid, 2011) to help each actor understand their role (Design Council, n.d.a). The line of visibility separates all the process that is visible to the user to the backstage processes. This helps to align the backstage process to the user experience (Tassi, 2009).
5	Card Sort (Fincher and Tenenberg, 2005; Petrie et al., 2011; Rugg and McGeorge, 1997)	A *Card Sort* is used to identify a person's mental model of a concept or idea (Usability Net, 2006). An unsorted list of items, which could be design features or functions, are created and participants would be asked to sort them into groups (Martin and Hanington, 2012). The results reflect the participant's understanding and expectations of the design attributes (IDEO, 2003; Usability Net, 2006).
6	Collage (Sanders and William, 2003)	A *Collage* involves a collection of images that can be used to communicate a user's thought, feelings and desires (Martin and Hanington, 2012). Users are asked to choose and arrange a collection of images. Explanation of their selection and arrangement provides designers with insights of the participant's thoughts and perceptions (IDEO, 2003).
7	Customer / User Journey (Diana et al., 2009; Kolko, 2011; Yoo and Pan, 2014)	A *Customer / User Journey* provides a structured representation of a user's service experience (Segelström and Holmlid, 2011; Stickdorn and Schneider, 2010; Tassi, 2009). By capturing the step by step interactions of the user throughout a service it a) highlights touch-points or moments in the service to be evaluated and improved (Design Council,

		n.d.a, n.d.b; Martin and Hanington, 2012; Mendel, 2012; Tassi, 2009), and b) exposes the events that occur before and after an interaction to provide insights into the emotion triggers of users' experiences (Segelström and Holmlid, 2011).
8	Desktop Walkthrough (Fox, 2015)	The creation of a, usually paper, model of a setting allowing designers to test enact the service or product delivery. Low cost, miniature models representing people, artefacts, and the environment acts as tangible props to develop design ideas (Segelström and Holmlid, 2011; Stickdorn and Schneider, 2010; Martin and Hanington, 2012).
9	Mind Map (Buzan, 2011, 2014; Diana et al., 2009)	This method helps designers to extract out thoughts and their connections (Tassi, 2009). By starting with a problem or idea and building links around the starting point, this method helps to externalise information from the mind. This will allow the designer to clarify their thoughts and connect pieces of information that may, at first, seem to be unrelated (Martin and Hanington, 2012).
10	Mood Board (Diana et al., 2009; McDonagh et al., 2002; Moritz, 2005; Saffer, 2010)	*Mood Boards* provide a visual perception of the atmosphere, emotions, or inspirations of a design (Design Council, n.d.a). These are articulated to the audience through a composition of images, sketches, and materials (Martin and Hanington, 2012; Tassi, 2009).
11	Paper and Interactive Prototype (Bailey et al., 2007; Houde and Hill, 1997; Lidwell et al., 2003)	*Paper and Interaction Prototype* involve the creation of working models that transfer concepts into a tangible object, or experience in the context of use (Martin and Hanington, 2012). This allows designers and users to refine the design early on in the design process (Mendel, 2012) to avoid the risk of costly mistakes (Royal College of Art, n.d.). The fidelity of the prototype can vary throughout the design process (Mendel, 2012).
12	Persona (Cooper, 2004; Holtzblatt et al., 2005; Marshall et al., 2015; Nielsen, 2013; Pruitt and Grudin, 2003; Vincent and Blandford, 2014)	A *Persona* is used to represent the targeted end user (Design Council, n.d.b; Segelström and Holmlid, 2011; Stickdorn and Schneider, 2010). It is created from research, such as through observation or interview, of an archetype user (IDEO, 2003). A fictional character is generated based on the details identified from the research, such as their habits, social and demographic characteristics, their needs and desires, and cultural background (Caddick, 2011; Mendel, 2012; Tassi, 2009). The purpose of this method is to reveal patterns of behaviour so that designers can understand the user's lifestyle(Royal College of Art, n.d.). It acts as an artefact that reminds the design team of the type of user they are designing for (Tassi, 2009). By communicating the values of a typical user, this method can help in decision making and justifying ideas to others (Design Council, n.d.a). Although Personas describe a fictional person, they are based on real people. This method helps to humanises the design focus (Martin and Hanington, 2012).
13	Photo Studies (Sampanes et al., 2011)	*Photo Studies* are used to gain insight of users' activities in a less intrusive manner. Participants are asked to take photos of objects or environment according to set criteria. These photos are analysed by the designers to reveal their point of

		views or any patterns of behaviour (Martin and Hanington, 2012).
14	Poster (Gray et al., 2010)	A *Poster* is about foreseeing how the product or service idea will work in reality. This method requires the designers to think about what impact their design will have and whether it can sustain a customer base (IDEO, 2003). Envisaging the appearance and function of the design would make it more tangible and aids the communication and development between designers (Tassi, 2009).
15	Process Model (Aguilar-Savén, 2004)	This method is used to understand what happens in a process, which could be a task, transaction, activity or journey (Royal College of Art, n.d.). Through interview and observation, designers maps out the steps to a process. This is used to understand when activities happen and why (Mendel, 2012).
16	Scenario (Carroll, 2000; Suri and Marsh, 2000)	A *Scenario* can be written, drawn, or videoed (Design Council, n.d.a, n.d.b; Stickdorn and Schneider, 2010) account of a design concept from the user's point of view (IDEO, 2003; Martin and Hanington, 2012). The *Scenario* method make the design concepts "explicit and concrete" (Martin and Hanington, 2012, p.152) to discuss and explore the idea (Royal College of Art, n.d.; Stickdorn and Schneider, 2010).
17	Service Prototype (Saffer, 2010)	This method involves the enactment of a service delivery. Props are created and placed in where the service will eventually take place. This method is used to test how the service will function and identify whether any potential interference to the service delivery (Tassi, 2009). This method is useful because it can help designers to develop understanding of service scenarios that may be missed in written or visual descriptions (Stickdorn and Schneider, 2010).
18	Sketching (Hartson and Pyla, 2012; Rogers et al., 2011; Tovey et al., 2003)	*Sketching* involves the creation of simple drawings (Tassi, 2009) for eliciting experiences (Design Council, n.d.a, n.d.b; IDEO, 2003) or ideas (Buley, 2013; Design Council, n.d.b). It can be adapted in two ways: 1) it is used by a designer or the design team to explore and communicate what they are thinking (Buley, 2013), or 2) the designer could ask end users to make sketches based on a decided topic. The sketches produced helps the designer to understand the perceptions of the user (IDEO, 2003).
19	Stakeholders Map (Buckle et al., 2010; Gray et al., 2010)	A *Stakeholders Map* is used to provide an overview of the relationships and interactions between people within a work group (Martin and Hanington, 2012). The resulting visual representation is used to highlight issues concerning multiple users. By grouping these users together, effectively solutions can be sort to resolve to the problem (Stickdorn and Schneider, 2010).
20	Storyboard (Diana et al., 2009; Gray et al., 2010; Holtzblatt et al., 2005; Kantola and Jokela, 2007; Truong et	A *Storyboard* consists of a series of drawings to present a sequence of events (Segelström and Holmlid, 2011; Stickdorn and Schneider, 2010). It is used to project the context in which an experience is formed as well as the key

	al., 2006; van der Lelie, 2006)	steps that make up the experience (Martin and Hanington, 2012; Tassi, 2009).
21	Task Analysis (Crystal and Ellington, 2004; Phipps et al., 2011; Rogers et al., 2011; Saffer, 2010)	A *Task Analysis* is used to show the stages that users have to go through to complete a task. At each stage, it presents what users do, how they expect to complete a goal (their behaviour), and the specific requirements at that stage. This helps designers to create a system that matches the user expectation (Caddick, 2011).
22	Task Mapping (Catterall, 1990)	*Task Mapping* is used to match the required function for different tasks and sub-tasks (Maguire, 2001). It helps to prioritise the importance of each function to exclude less important ones. This method presents the entire scope of the project and all the features in one place (Tassi, 2009).
23	Wireframe (Benyon, 2013; Hartson and Pyla, 2012; Rogers et al., 2011; Saffer, 2010)	A *Wireframe* is used present the design of a screen layout (Hartson and Pyla, 2012), specifically the content, the functionality, and the means to navigate to them (Saffer, 2010). It allows design teams to see if the data is structured correctly, how the functions will be developed, and how the page will be laid out (Caddick, 2011).

Appendix D – Evidence of Mapping

	Visualisation Methods	Selection Approach				
		The Recipient	**Primary Purpose**	**Visual Archetype**	**Interaction Type**	**The Design Process**
1	A Day in the Life	It has been categorised as *For / With* (Royal College of Art, n.d.). *A Day in the Life* is used by designer to gain understanding of what happens to their subject in a typical day (Royal College of Art, n.d.).	This method is used to gather information showing the activities of potential users throughout a day. It is used by designers to gain insight to the users' routines (Stickdorn and Schneider, 2010).	A user's routine can be depicted in varies ways. The use of simple drawings and comic strips are quick and inexpensive to produce. In comparison, photos and video provide more realistic and richer portrayals (Stickdorn and Schneider, 2010).	It has been categorised as *Look* (IDEO, 2003; Royal College of Art, n.d.).	It has been categorised as *Explore* (Stickdorn and Schneider, 2010) and *Discover* (Royal College of Art, n.d.).
2	Affinity Diagram	It has been categorised as *Stakeholders / Professionals* (Tassi, 2009).	It has been categorised as *Generative* (Martin and Hanington, 2012).	It has been categorised as *Graph* (Tassi, 2009) and *Maps* (Diana et al., 2009). This method is used to group together related topics or issues to reveal fundamental themes (Holtzblatt et al., 2005; Usability Net, 2006).	It has been categorised as *Learn* (IDEO, 2003). *Affinity Diagram* is used to analyse data gathered in research (Usability Net, 2006).	It has been categorised as *Co-designing* (Tassi, 2009), *Exploration / Concept Generation / Evaluation / Launch and Monitor* (Martin and Hanington, 2012), R*equirements* (Usability Net, 2006), and *Design* (Maguire, 2001).
3	Behaviour Mapping	*Behaviour Mapping* is used to extract patterns of behaviours for designers to gain better	It has been categorised as *Exploratory* (Martin and Hanington, 2012).	Human activities are recorded using "annotated maps, plans, video, or time-lapse photography" (Martin	It has been categorised as *Look* (IDEO, 2003). This method is for recording observations	It has been categorised as *Exploration* (Martin and Hanington, 2012).

	Visualisation Methods	Selection Approach				
		The Recipient	**Primary Purpose**	**Visual Archetype**	**Interaction Type**	**The Design Process**
		understanding of the target users (Larson et al., 2005).		and Hanington, 2012, p.18).	of location-based behaviours (Martin and Hanington, 2012).	
4	Blueprint	It has been categorised as *Stakeholders / Professionals* (Tassi, 2009). *Blueprints* are best developed with a cross-functional team and could involve the input of the end users (Bitner et al., 2008).	This method is for detailing the interactions between different parties of a service (Design Council, n.d.a; Stickdorn and Schneider, 2010).	It has been categorised as *Graph* (Tassi, 2009) and *Flow* (Diana et al., 2009).	*Blueprints* facilitate the design and analyse of a service. They can be used to support refinement of a single step, or to create an overview of the entire service design (Bitner et al., 2008).	It has been categorised as *Testing and Prototyping / Implementing* (Tassi, 2009), *Create & Reflect / Implement* (Stickdorn and Schneider, 2010), and *Develop* (Design Council, n.d.a).
5	Card Sort	A *Card Sort* is used by designers to evaluate how their target users understand and structure a set of concepts or information (Martin and Hanington, 2012; Maguire, 2001).	It has been categorised as *Generative* (Hanington, 2007) *and Exploratory / Generative* (Martin and Hanington, 2012).	Functions, features, and design attributes are presented on individual cards and are categorised into groups (IDEO, 2003; Usability Net, 2006).	It has been categorised as *Ask* (IDEO, 2003). Two steps are associated with *Card Sort*; to categorise the cards and the analysis of data resulted from the card sort (Fincher and Tenenberg, 2005).	It has been categorised as *Design* (Maguire, 2001), *Exploration / Concept Generation* (Martin and Hanington, 2012), and *Requirements* (Usability Net, 2006).
6	Collage	A *Collage* is used by designers to elicit information end users. It involves asking people to arrange a set of pictures and words based on instructions determined by the designer (Sanders and William, 2003).	It has been categorised as *Generative* (Hanington, 2007) and *Generative* (Martin and Hanington, 2012).	This method makes use of images and photos. Participants are asked to select and arrange the images to compose collage (IDEO, 2003).	It has been categorised as *Ask* (IDEO, 2003).	It has been categorised as *Exploration / Concept Generation* (Martin and Hanington, 2012).

	Visualisation Methods	Selection Approach				
		The Recipient	**Primary Purpose**	**Visual Archetype**	**Interaction Type**	**The Design Process**
7	Customer / User Journey	It has been categorised as *Stakeholders / Professionals* (Tassi, 2009).	It has been categorised as *Evaluative* (Martin and Hanington, 2012) and *Understanding Users* (Design Council, n.d.b).	It has been categorised as *Graph* (Tassi, 2009) and *Flow* (Diana et al., 2009).	A *Customer / User Journey* is used to map user experience. This information is established either through interviews or asking the users to create the map themselves (through blogging or video diaries) (Stickdorn and Schneider, 2010).	It has been categorised as *Envisioning* (Tassi, 2009), *Explore* (Stickdorn and Schneider, 2010), *and Define* (Design Council, n.d.a).
8	Desktop Walkthrough	A *Desktop Walkthrough* is used to analyse and test a service touchpoint. Models are used to provide a common language which enables various stakeholders to partake in the assessment (Stickdorn and Schneider, 2010, p.116).	It has been categorised as *Exploratory / Generative* (Martin and Hanington, 2012).	This method is used to test a service flow. The service delivery is enacted on a scaled model, which consists of key touchpoints. Tangible objects and people are often represented by figurines or drawn on with markers, so the service delivery can be enacted (Segelström and Holmlid, 2011, p.8).	It has been categorised as *Try* (IDEO, 2003). *Desktop Walkthroughs* let designers to visualise and try out a service design (Segelström and Holmlid, 2011)	It has been categorised as *Create & Reflect* (Stickdorn and Schneider, 2010) and *Planning / Exploration* (Martin and Hanington, 2012).
9	Mind Map	It has been categorised as *Stakeholders / Professionals* (Tassi, 2009).	It has been categorised as *Exploratory* (Martin and Hanington, 2012).	It has been categorised as *Graph* (Tassi, 2009) *and Maps* (Diana et al., 2009).	*Mind Maps* are used to help the designer to clarify their thoughts and pieced together related information (Martin and Hanington, 2012).	It has been categorised as *Co-Designing* (Tassi, 2009) and *Exploration* (Martin and Hanington, 2012).

	Visualisation Methods	Selection Approach				
		The Recipient	**Primary Purpose**	**Visual Archetype**	**Interaction Type**	**The Design Process**
10	Mood Board	It has been categorised as *Stakeholders* (Tassi, 2009).	It has been categorised as *Having Ideas* (Design Council, n.d.b).	It has been categorised as *Narratives* (Diana et al., 2009) and *Image* (Diana et al., 2009).	*Mood boards* are used to explore how emotions are evoked in a product or service (Saffer, 2010).	It has been categorised as *Envisioning* (Tassi, 2009) and *Exploration* (Martin and Hanington, 2012).
11	Paper and Interactive Prototype	It has been categorised as *For / With* (Royal College of Art, n.d.).	It has been categorised as *Generative / Evaluative* (Martin and Hanington, 2012) and *Prototyping* (Design Council, n.d.b).	*Paper and Interactive Prototypes* are working models that are used to explore or shows a design idea (Mendel, 2012).	It has been categorised as *Try* (IDEO, 2003; Royal College of Art, n.d.).	It has been categorised as *Concept Generation / Evaluation* (Martin and Hanington, 2012), *Design / Develop / Deliver* (Royal College of Art, n.d.), *Envision* (Mendel, 2012), *Design* (Maguire, 2001), *Testing and Validation* (Buley, 2013), and *Develop* (Design Council, n.d.a).
12	Persona	It has been categorised as *For / With* (Royal College of Art, n.d.) *and Stakeholders / Professionals* (Tassi, 2009).	It has been categorised as *Generative* (Martin and Hanington, 2012) and *Understanding Users* (Design Council, n.d.b).	It has been categorised as *Narratives* (Tassi, 2009).	It has been categorised as *Learn / Imagine* (Royal College of Art, n.d.) and *Learn* (IDEO, 2003). During development, Personas acts as reference for making design decisions (Caddick, 2011) and help designers to think about who the end users are, their needs, and the context in	It has been categorised as *Envisioning / Testing and Prototyping* (Tassi, 2009), *Explore / Create & Reflect / Implement* (Stickdorn and Schneider, 2010), *Concept Generation* (Martin and Hanington, 2012), *Discover* (Royal College of Art, n.d.), *Discover* (Mendel, 2012), *Requirements* (Maguire, 2001) and *Develop* (Design Council, n.d.a).

	Visualisation Methods	Selection Approach				
		The Recipient	**Primary Purpose**	**Visual Archetype**	**Interaction Type**	**The Design Process**
					which the product or service will be used (Nielsen, 2013).	
13	Photo Studies	Designers ask users to take photos of their experience towards a product or service in order to gather insights of their behaviour and impressions towards that product or service (Martin and Hanington, 2012).	It has been categorised as *Exploratory* (Hanington, 2007).	Participants are asked to take photos of their experience towards a product or service (Martin and Hanington, 2012).	In *Photo Studies*, participants are invited to document, through taking photos, their experience regarding a service or product (IDEO, 2003; Martin and Hanington, 2012)	It has been categorised as *Exploration* (Martin and Hanington, 2012).
14	Poster	It has been categorised as *Stakeholders* (Tassi, 2009).	A *Poster* is used to project how a product of service idea, showing how the final design could be utilised and the impact it could have on the users (IDEO, 2003; Tassi, 2009).	It has been categorised as *Narratives* (Tassi, 2009) and *Image* (Diana et al., 2009).	It has been categorised as *Try* (IDEO, 2003).	It has been categorised as *Envisioning / Testing and Prototyping* (Tassi, 2009).
15	Process Model	It has been categorised as *For* (Royal College of Art, n.d.). Steps of a process are mapped out by designers, which can then be validated through interviews with experts of the process (Royal College of Art, n.d.).	This methods break down an existing activity into a sequence of steps (Mendel, 2012), this helps to understand the different parts of the process and their relationships (Royal College of Art, n.d.).	*Process Models* unravel a process into a sequence of activities (Mendel, 2012, p.83).	It has been categorised as *Learn / Ask* (Royal College of Art, n.d.).	It has been categorised as *Reframe* (Mendel, 2012) and *Discover* (Royal College of Art, n.d.).

	Visualisation Methods	Selection Approach				
		The Recipient	**Primary Purpose**	**Visual Archetype**	**Interaction Type**	**The Design Process**
16	Scenario	It has been categorised as *For / With / By* (Royal College of Art, n.d.). *Scenarios* should be tested with users or team members and refined from their feedbacks (Design Council, n.d.b).	It has been categorised as *Generative* (Martin and Hanington, 2012) and *Prototyping* (Design Council, n.d.b).	*Scenarios* can be written, drawn or a video of a design concept (Design Council, n.d.a, n.d.b; Stickdorn and Schneider, 2010).	It has been categorised as *Learn / Imagine* (Royal College of Art, n.d.) and *Try* (IDEO, 2003).	It has been categorised as *Exploration / Concept Generation* (Martin and Hanington, 2012), *Design / Develop / Deliver* (Royal College of Art, n.d.), *Requirements* (Maguire, 2001) and *Develop* (Design Council, n.d.a).
17	Service Prototype	It has been categorised as *Users* (Tassi, 2009). A *Service Prototype* involves creating the service design in a tangible form so it can be evaluated through enactment with client and stakeholders (Saffer, 2010).	The method is used to evaluate a service design (Stickdorn and Schneider, 2010; Tassi, 2009).	It has been categorised as *Models* (Tassi, 2009) and *Narratives* (Diana et al., 2009).	A *Service Prototype* is the physical creation of service features to enable enactment of the service delivery (Saffer, 2010, p.180).	It has been categorised as *Testing and Prototyping / Implementing* (Tassi, 2009) and *Create & Reflect* (Stickdorn and Schneider, 2010).
18	Sketching	It has been categorised as *Service Staff / Users* (Tassi, 2009). *Sketching* is used to engage others to share your design ideas and to gain feedback (Buley, 2013). Asking users to drawing images of an experience or item can reveal perceptions that may be difficult to derive	It has been categorised as *Having Ideas / Understanding Users* (Design Council, n.d.b).	Simple drawings of ideas (Buley, 2013; Design Council, n.d.a; Tassi, 2009) or experiences (IDEO, 2003) are resulted from this method.	It has been categorised as *Ask* (IDEO, 2003). *Sketching* does not just present drawing to look at, but the sketch acts as "a conversation between the sketcher and the artefact" (Hartson and Pyla, 2012, chap.7.7) in that it helps to evoke designs.	It has been categorised as *Co-Designing* (Tassi, 2009), *Design* (Buley, 2013), and *Discover* (Design Council, n.d.a). *Sketching* is a low-fidelity design method that is simple and quick to produce and modify. Therefore, they are ideal for exploring design variations (Rogers et al., 2011). *Sketching* is

	Visualisation Methods	Selection Approach				
		The Recipient	**Primary Purpose**	**Visual Archetype**	**Interaction Type**	**The Design Process**
		verbally (Design Council, n.d.b).				different to prototyping in that it is not used to refine a design, but to explore design ideas (Hartson and Pyla, 2012).
19	Stakeholders Map	It has been categorised as *Stakeholders* (Tassi, 2009).	It has been categorised as *Exploratory* (Martin and Hanington, 2012).	It has been categorised as *Graphs* (Tassi, 2009). A *Stakeholder Map* is used to create diagrams that define the roles, activities, and relations of people involved in the design project (Martin and Hanington, 2012).	*Stakeholder Maps* are used to visually depict who their stakeholders are and their relationship. This enables the design team to come up with strategies for engaging them (Gray et al., 2010).	It has been categorised as *Envisioning* (Tassi, 2009), *Explore / Create & Reflect* (Stickdorn and Schneider, 2010), *Planning, Scoping, and Definition* (Martin and Hanington, 2012), and *Requirements* (Maguire, 2001).
20	Storyboard	It has been categorised as *Stakeholders / Professionals* / Service Staff / Users (Tassi, 2009).	It has been categorised as *Generative* (Martin and Hanington, 2012).	It has been categorised as *Narratives* (Tassi, 2009) and *Narratives* (Diana et al., 2009). A *Storyboard* is "a short graphical depiction of a narrative" (Truong et al., 2006, p.12).	*Storyboards* can be presented to people in the design team or potential end users to help them visualise the end product and to gain feedback from them (Maguire, 2001).	It has been categorised as *Co-Designing / Envisioning / Testing and Prototyping / Implementing* (Tassi, 2009), *Create & Reflect / Implement* (Stickdorn and Schneider, 2010), *Concept Generation* (Martin and Hanington, 2012), and *Design* (Maguire, 2001).
21	Task Analysis	Stakeholders, design team, and development team should be engaged in the development of the task model so they will have first-hand	It has been categorised as *Exploratory* (Martin and Hanington, 2012).	A *Task Analysis* is shaped by "the flow of tasks to complete a goal" (Caddick, 2011, p.47).	It has been categorised as *Learn* (IDEO, 2003). A *Task Analysis* is produced from research. User testing	It has been categorised as *Exploration* (Martin and Hanington, 2012), *Design* (Buley, 2013), and *Context of Use* (Maguire, 2001)

	Visualisation Methods	Selection Approach				
		The Recipient	**Primary Purpose**	**Visual Archetype**	**Interaction Type**	**The Design Process**
		understanding of the end users (Caddick, 2011).			can be conducted to validate the finished design, whether it is the final product or a prototype. The results can also be used refine the Task Analysis (Caddick, 2011).	A *Task Analysis* is used uncover the rationale behind how people complete a task. It is use to investigate in an existing situation rather than for envisioning new products or scenarios (Rogers et al., 2011).
22	Task Mapping	It has been categorised as *Stakeholders* (Tassi, 2009).	*Task Mapping* is used to clarity the type of function required for a product (Maguire, 2001).	It has been categorised as *Graph* (Tassi, 2009).	*Task Mapping* is used to define the required tasks (Maguire, 2001).	It has been categorised as *Implementing* (Tassi, 2009) and *Requirements* (Maguire, 2001).
23	Wireframe	A wide range of stakeholders could be included to discuss the content and functionality of the product (Caddick, 2011).	This method is for detailing an interface design (Caddick, 2011).	*Wireframes* allow the design team to see how content and features will be structured (Benyon, 2013; Caddick, 2011).	*Wireframes* are created to show how generic features are structured. The artefact produced can be evaluated with stakeholders (Benyon, 2013).	It has been categorised as *Design* (Buley, 2013). *Wireframes* are used in exploratory phases to create initial concepts of the interface (Rogers et al., 2011), or further along the design process to establish the detail of the design (Buley, 2013).

Appendix E – Interview Transcript for Case Study I (*Wheel Alignment*)

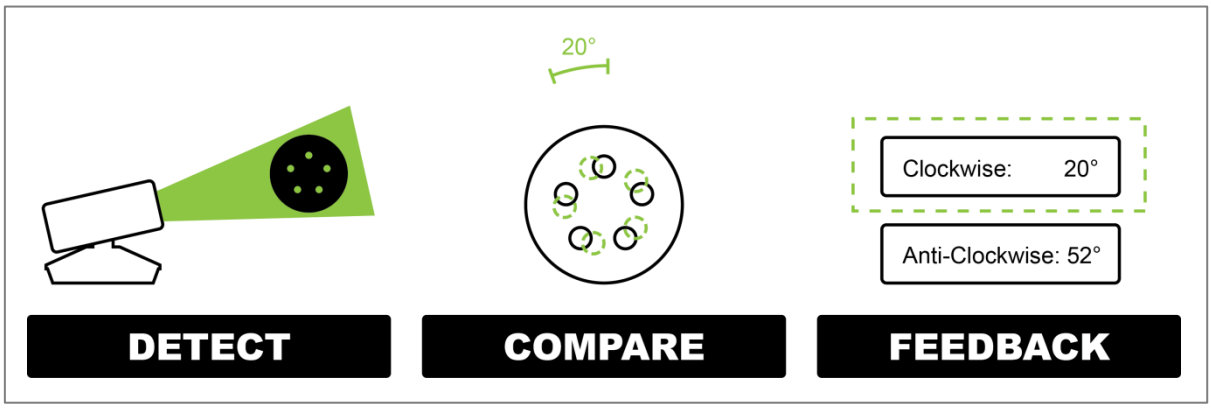
E.1 Background

The interview took place at Cranfield University, UK in February 2013. Two people were present in during the interview, the author of this study (Interviewer) and the programmer involved in the *Wheel Alignment* case study (Participant).

E.2 Interview Transcript

Interviewer: To start off with, I will show you a simple diagram of what I understand to be your work so far. We can begin our discussion using this and to see if it is correct.

[The first diagram was shown and explained to the participant]



Participant: This diagram is correct. For the use case I am using 2 wheels. But in the real application it may be one wheel.

Interviewer: In the use case you used two wheels, one bigger than the other and both with 5 holes, and used Kinect™ to find the angles between the holes. How would it be different in the real application?

Participant: Yes, the smaller one would be the hub, on the car axle. The wheel is a separate entity. In the real application Kinect™ will first look at the hub, look at the five locations of the holes, and then it will look at the five position of the

wheel. Base on the hub positions, it then moves or instruct how to move the wheel. So that when the wheel is placed on the hub, it will match the five holes.

Interviewer: With the current application, when does Kinect™ start detecting the holes?

Participant: So I place it in front of the Kinect™, then I mark a rectangle (square), then Kinect™ will check inside this shape and tries to fit a circular shape to what it finds. Once I know the circle, I look at the most 'x' and least 'x', and the most 'y' and least 'y' to find the centre.

Interviewer: Is that how you would see it in the real application?

Participant: Yes.

Interviewer: Would you also have to draw the square?

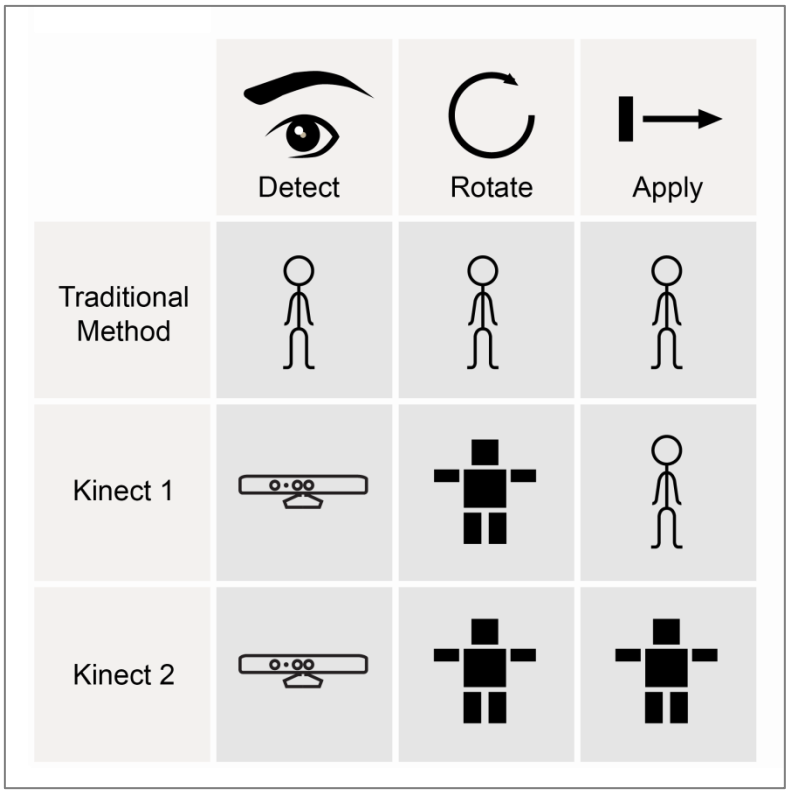
Participant: No, in the real application you would have a robot that pick up the wheel from a particular place and put it at a particular place. The Kinect™ will be stationed already to start looking at the wheel. So with the robot, the wheel will be placed in the same spot. If it find the wheel inside then it will do the rest of the stuff. If it doesn't find it, it won't do anything. So there is no button pressed, it's supposed to be fully automatic.

Interviewer: When you turn the wheel, why do you set it to find the shortest path? Wouldn't it be easier if it just turned in one direction?

Participant: There are multiple reasons. One is the amount of work required to move the tyre. The shorter it is (smaller distance to turn), the lower the error. Lower is the power consumption. One tyre is OK, but if you do it for the entire assembly line, about 200-300 cars come out every day. So that is 1200 wheels to be fitted. This avoids turning 60° when you could turn 12°. This doesn't always happen, sometimes it bang in the middle.

Interviewer: Now I am going to show you a second diagram.

[The second diagram was shown and explained to the participant]



Interviewer: The second or third scenario, which are you envisioning?

Participant: If you look at the bigger picture, auto companies are looking to automate assembly of components in a car when the body is moving. Currently it is being done manually. The seats, mirrors, and the wheels are the final parts. They are not able to do this because the car is moving. Humans are able to install components, walk along with the car at the same time and tighten the screws and put the bolts in the part. A robot cannot do this. But research is being done in Germany called *Assembly in Motion*. Wheel assemble is one of the research. This is what I think will happen in the future because it makes no sense otherwise.

Currently there is a gantry that holds the wheel. It's an overhead conveyor suspended to the ceiling. It has an arm that holds the wheel. This is to take the weight off the human, who then can focus on rotating and pushing the wheel. So, if the rotation part is being done automatically, you don't need a human to push. It would be an over kill if they employed humans to just push the wheel inside.

Interviewer: So you would just need some kind of robot to push the wheel in?

Participant: Yes.

Interviewer: Is the gantry already in used in the [a car manufacture] use case?

Participant: I think so. I've seen it in almost all the [car assembly lines].

Interviewer: At the moment the gantry is holding the wheel but it still requires a person to turn it?

V: Yes, currently just holding it. It is not turning it, not pushing it in. But I believe the human is more for alignment and not for pushing. The human does the alignment and pushing. Because he is doing alignment they let him push, but if the alignment is out of the picture I don't think they would just pay a human to push the wheel.

Interviewer: Is there something you have to add to the gantry to make it turn?

Participant: Yes, there would be some mechanism needed. It would need a motor, could be an electric motor. Right now the gantry allows you to turn but not very easily. It is so awkward that people are not using the gantry anymore. They are lifting the tyres themselves. So they are doing the lifting, detecting, rotating and the application.

Interviewer: How accurate can the Kinect™ detect? To decimal points?

Participant: No, the smaller the parts, the higher the errors. Now with my small prototype the error is 5-6° either ways. If it says its 5° misaligned, it could actually be 10° misaligned or it could be 0° (aligned).

Interviewer: How accurate does it need to be in the real application?

Participant: I think we should be OK with 5-6° [error], because with a bigger wheel the holes are much bigger. When you match the hub with the wheel it is not a micro-alignment. There's a lot of play. I think even up to 10° it would be fine. Currently it's very suitable. In fact there is less than 5° error if you look at bigger wheels.

[Soft System Methodology]

Interviewer: I'm going to ask you some questions based on the Soft System methodology. Who are the customers?

Participant: Car manufacturing companies, automotive manufacturing companies, e.g. [*car manufactures*].

Interviewer: Who are the actors that make this system happens?

Participant: Let say we get a contract from [*car manufacturer*] to do this for them. So it would then involve our team, people from [*car manufacturer*], who would know their assembly line much better. We would go there are see the place where the wheel assembly is done, how it is done today. After we observe this we would know where it would be a good place for the Kinect™ to be installed. So Kinect™ would be installed there say for a month or two. It is just to collect data as the car bodies come and identify the centre of the hubs. This would be an observation phase where Kinect™ collects data. And we would analyse the data from it. Once that is done, we would design the automation system on paper. Which robotic arm to use? What kind of grippers to use? Whether the robot arm needs to be on a linear sliding rail, or if it could be a stationary one. How do you match the speed of the car body at the point where the robot is going to install the wheel?

Then it would be outsourced to an automation house. We wouldn't be building the automation system. We would be more like consultants.

Interviewer: To summarise, you have designed the application on Kinect™ to turn the wheel. You would need the automotive company to inform you of the setting in which they manufacture cars, whether it is to see yourself, or to ask their engineers questions. The third party would be people that take the data from Kinect™ and apply it to an automation system.

Participant: We would still be doing the software side. The hardware part would be done by the automation house, including the robot arm or gripper. They will be able to tell us their programming interface then we would program that automation solution.

Interviewer: Who would be the owner of this system? Who would be the people that could stop it at any time? Would it be the manufacturing company?

Participant: Yes. Although I would not give them the code as such.

Interviewer: You will have the product, but it up to them to say “we would use it” or “we would not use it”?

Participant: Yes

Interviewer: Transformation, what is the input and output of this system?

Participant: The input is the information about the car body and information about the wheel that will eventually go to the car body. “Input parameter spec/space”. Once we have this, Kinect™ would extract more information from this data. Kinect™ will now get you the centre points of the 4 hubs. The centre points of the wheels and the 5 holes of the wheel, and the 5 holes on the hub. You would now need two automation systems on either side of the car – two Kinects.

Alignment is something that would happen on the fly. It is not the objective. The actual process is the automation of wheel installation on a car body without damaging it. If it requires alignment, our system would be able to do it without any human intervention.

Interviewer: What are the influences that could affect the system?

Participant: When the car body first arrive into the view of Kinect™, Kinect™ immediately views the centre of the hub, and the five positions. There are two degrees of freedom for this hub. One is because it is on a shock absorber, it could move up or down. The second, depending on the type of drive (e.g. front wheel drive) then this [the front axle] will be free to move and if this is the rear wheel drive then this [the rear axle] will be free to move. Assume that both will be free to move. We don’t know yet, but there might also be a push pull, so it might move in and out [sideways]. In fact there are 3 degrees of freedom here. This is just for a car, assuming that the conveyor doesn’t move the car body. On a conveyor belt I don’t think the car body can remain static as it moves along. The conveyor has

its own sway, inertia and all that. It will also have a small momentum. All this will affect our accuracy of finding the centre and the five holes. We have to assume initially is that, except for small sway of the car body, the rest of the things doesn't move related to the car body. That the axle won't go up and down because of this [the absorber]. And that it won't rotate as the car body moves and comes into the view of Kinect™.

We can compute these points every half a second to test the position and find out how much it moves. [We can] average it out as the car goes along. So all these movement can then be cancelled off automatically. That's the part we are assuming, but we would really need data from [*car manufacturer*]. But we can average it out and just before the wheel is installed we can do one last check.

[Other Questions]

Interviewer: At the moment does Kinect™ detect the holes continuously, or does it detect it once and tell it what to do?

Participant: No, it detects over 100 frames. If we do it once, even if the wheel is stationery the Kinect™ is very noisy. So if you do it once you won't know if it is really correct or not.

Interviewer: How long does it take?

Participant: For 100 frames, it takes me 3 seconds. Kinect™ gives an output 30 times per second. When the car body is moving every 100 frames, which means we have one at 3 seconds. The next 100 frames at the next 3 seconds. So let's say that it takes 21 seconds for the car to go to the target installation place, we would have computed the same thing 7 times. So we would have a double average now. Each time I get a point, I would average it across 100 readings. We would have 7 such readings which would again be averaged. So I believe the final reading should be mathematically very accurate. And we should be able to calculate the standard deviation to tell how accurate it is.

Interviewer: Now that you've done this part, what is next?

Participant: OK, the next is, now you know it is all stationary, I want to…I thought of it yesterday. So now I have one wheel, and I would show it the same wheel remember. I take that wheel and Kinect™ finds out five plus one [holes]. Then I take the wheel and I rotate it randomly and I out it back, that's to simulate 2 wheels. Now, I think we would actually have 2 wheels. Because each wheel would be different from the other. When I randomly rotated before, the only thing random is the rotation, but when I have two different wheels, there are other things which are random as well, the texture, the surface, maybe a slight difference in the position of the holes, the shapes of the holes and so on. So with 2 wheels, the system is now totally random, we don't influence anything. I would have something that has the same diameters as the wheels, but it would have these cords coming out, matching these 5 holes, and it would come out from both sides. So what I want to do now is I will make a small gantry, which will look something like this. So it will go to pick up one wheel, and Kinect™ will get the 6 data points for this wheel. Now, this wheel will be kept somewhere, then, the one with the core will be placed in a known position.

This is like a real emulation of what is going to happen eventually. We can just have the holes of two wheels and have people see that it matches. So you now have 2 unknown entities, just like your car set up, where the hub and the wheel is an unknown entity. But now you have the wheel and the wheel as the unknown entity. But this guy (the mid sandwich) will always be faced a position where you'd know. So, to ensure this, I could make one side flat, so every time I place it here I would know its position. Let's say the first wheel, that Kinect™ had already sense what it is this, which means you will need to move this guy slightly to the right to match, so that it would pick up this, Kinect™ already knows the five position here, because its fixed. It knows the position of this because it had just seen it, and then it would rotate this and it would place this in the eventual target place. The 5 bolts should go inside the 5 holes here. So that's the first installation. Now Kinect™ knows the position of the mid-section from the first wheel, it would pick up a second wheel, it will be rotated accordingly and complete the sandwich. Then we can pick up the sandwich and show to the panel that it's installed. Before I just have two wheels with its backs to each other. So unless you look through,

you wouldn't know it's matched. So if I don't do something in hardware, whatever I've done already in software is enough.

Interviewer: Wouldn't just fitting the first wheel to the sandwich be enough already?

Participant: I can't find out the position of the cords using Kinect™ because it is so small. You remember how I got the five positions of the holes? It is because I placed this really close to the Kinect™. I can't detect these holes and I can't detect the cords at working distance. It is so small, Kinect™ can't resolve that there's a whole there. The first wheel I detect is by keeping it really close to Kinect™. So it doesn't detect my wheel at all, but it detects the background to my holes. What Kinect™ sees is the background to the holes. Everything else is black which pixel value is zero. Everything in this hole pixel values the depth. If I have no holes, I can't detect anything.

In the actual version, I can detect the wholes, it is about 19mm, but here the wholes are about 4 mm in diameter.

Interviewer: How do you plan to turn it, manually?

Participant: No, I will make a gripper, to turn it. I have already ordered the components.

Interviewer: Any problems you've encountered? You've mentioned that two shape appears when you put the wheel really close to Kinect™.

Participant: Yes, I mean that's something strange that the Kinect™ does. But that doesn't affect me, in fact it is really good for me that it gives me that shadow. Only in that shadow I can see the 5 holes.

Interviewer: Is it possible to do what the depth map does with the RGB camera?

Participant: It is possible, but I've done this for my pen assembly, but it is not very reliable. Because if you change your light, or if the shadow falls on the wheel for example, then whatever was previously gray value (200), would become a grey value (190). It is very subjective to the environmental conditions, which is

very bad when you are doing a demo. In the cave it might not work but it will work in the meeting room. Otherwise I would do it in RGB, because no matter what the distance is RGB can always see it.

Interviewer: It would be good if you could use a combination of both.

Participant: That's what I did in my pen assembly demo, because I couldn't find the depth of the gap between the two parts of the pen. Kinect™ was unable to resolve it. The gap was black in colour so I could do it by tracking the black there, but a lot of problems. I set up the demo in my room here, it took me three days to set it up in the room below. I had to then change the colour value from the rooms and which lights where on and off so It wasn't very easy to program. But, yes, it could be done, if you could guarantee everything remains the same. But it is really risky.

Interviewer: Anything else you could use this application for?

Participant: You could use it to install a dashboard on a car. A dashboard has a few points where it goes in and clicks. I mean those points inside a car are pretty constant based on the design, which can be feed into our system. The gripper would grip the dashboard based on the points where the fitting would happen, go and install it in the car. There are multiple possibilities. If you look at the system, the only unique thing is the rotation for alignment, but with the dashboard it would not be rotation but translation. We should call it assembly in motion.

Interviewer: To briefly summaries it all, what does this system do?

Participant: The system allows you to automatically install components on a moving target. This may not be automotive at all, it could be something else. I think that's the pitch. A lot of the things done manually today, because the target is moving, could now be automated by using the Kinect™.

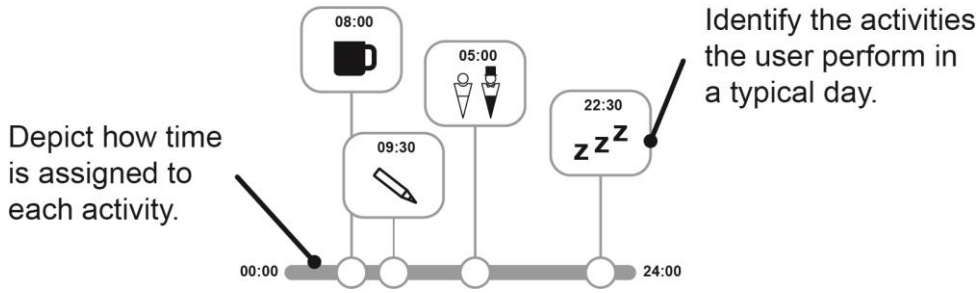
Interviewer: Why are you doing it? You could do it manually but it just takes a long time.

Participant: In the end its productivity. If you need a human to do it, it would be 4 times slower. Although it is accurate almost 100% of the time. But you also

have side effects like work-related Musculoskeletal Disorder. I mean the fellow is now lifting the wheel. When the guy is standing up and installing the wheel, this hub is not in his eye line, the hub is below, even if it was in his eye line, he would be able to lift up the whole wheel and look at the hub, look at the wheel and aligns. So what he does is he feels the alignment. He doesn't look at the alignment. So he brings the wheel to the car, tries to put it in, it does go, then it tries to turn and push to install the wheel. That is what we're going to take out of the system.

Appendix F – Procedures to Employ a Visualisation Method

F.1 A Day in the Life Methodology



1 Identify Problem

Determine the user group and the type interaction (product or service related) you would to investigate.

2 Technique Selection

A Day in the Life can be created using two different format: as a diagram, or a video. Decide on the format you would like to use:

Diagram

Typically produced as a result of interviews or observations.

Video

This involves filming the subject throughout a day.

3 Recruit Participants

Identify and recruit the type participants you want to study.

4 Create Artefact

Create the visual artefact based on the tool you selected in Step 1:

Diagram

Identify and depict the activities the subject encounters in a typical day. The diagram shows a composition of how this visual artefact can be structured.

Video

Select and compile footages of the key activities.

5 Next Step

Once the artefact is created consider to:

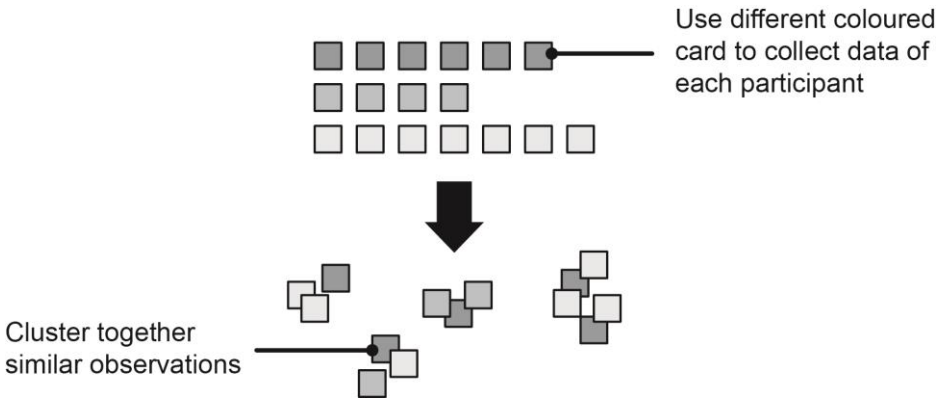
Interview Participant

This is to gain further insight into why participants perform certain activities.

Discuss in Team

Discuss the finding within the design team so each member have a clear understanding of the target user.

F.2 Affinity Diagram Methodology



1 Identify Problem

Determine the design problem.

2 Recruit Participants

Recruit 4-6 relevant participants (Martin and Hanington, 2012), and collect data through:

Contextual Inquiry

Interview the participants based on a pre-determined set of questions. Attempt to record 50-100 observations for each participant. Write each observation on its own card or sticky note (Holtzblatt et al., 2005; Martin and Hanington, 2012).

Usability Testing

Ask the participant to talk through how they would perform a task and write down each observation and quotes on separate card or sticky notes (Martin and Hanington, 2012). Use different colour cards or sticky note for each participant so that the frequency of similar observations can be revealed in Step 3.

3 Create Artefact

Work in a team and cluster together similar observations to reveal patterns (Kolko, 2011; Martin and Hanington, 2012).

4 Next Step

Affinity Diagrams can reveal patterns to further the design development:

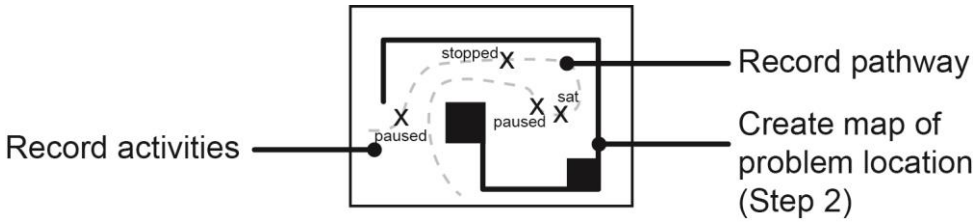
Contextual Inquiry

The resulting clusters reveal the nature of the problem (Martin and Hanington, 2012).

Usability Testing

The resulting clusters reveal the usability issues (Martin and Hanington, 2012).

F.3 Behaviour Mapping Methodology



1 Identify Problem

Determine the task to be performed and problem location.

2 Create Props

Create the follow props to help with the mapping:

Create Map

Generate a map of the problem location. Include key features (furniture, interaction point etc.) (Martin and Hanington, 2012).

Establish Annotation

Come up with abbreviations for actions or activities (such as standing, sitting, looking around etc.) (Martin and Hanington, 2012).

3 Recruit Participants

Recruit representative users for the mapping.

4 Create Artefact

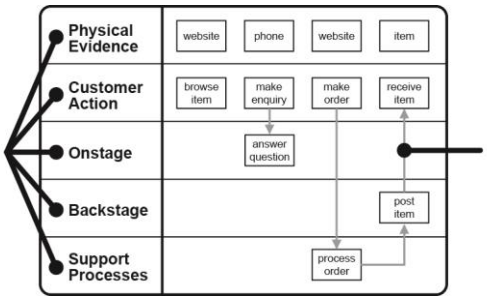
Ask participants to perform the task, and record their pathway and activities on the map (IDEO, 2003; Martin and Hanington, 2012), as shown in the diagram.

5 Next Step

This artefact depicts the pattern of user behaviour within an environment. It helps designer to identify if a particular feature is effecting how a user behave and how the design could be refined.

F.4 Blueprint Methodology

Complete each component of the *Blueprint*.



Link activities between the Customer Action, Onstage, Backstage, and Support Processes.

1 Identify Problem

Determine the service process that you would like to investigate.

Identify User

Select the user group to focus on (Bitner et al., 2008).

Identify the Service Scope

Determine from the user's perspective when the service starts and ends (Bitner et al., 2008).

2 Recruit Participants

Based on your scope and available resources, recruit participants for the blueprinting process. This could include the service providers, both front-end and back-end staff.

3 Create Artefact

Create the visual artefact, based on the diagram, in the following order:

Customer Action

Denote the customer actions within the service scope.

Onstage and Backstage

Identify actions of employee visible and invisible to customers.

Support Processes

Identify support functions.

Link Acitivities

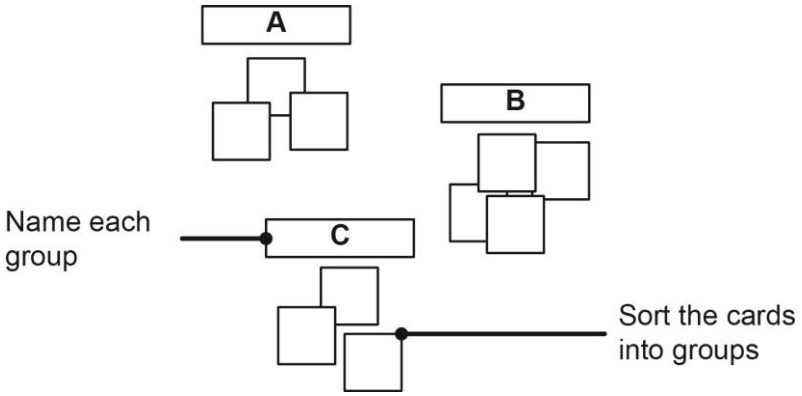
Add links between the Customer Action, Onstage, Backstage, and the Support Processes.

Identify tangible elements in the service delivery.

4

Blueprints allow team members to identify important elements, as well as an overlaps or repeated processes within a service design (Stickdorn and Schneider, 2010). Capture any area of disagreement in the creation of the *Blueprint* and revisit these areas to refine and clarify the design.

F.5 Card Sort Methodology



1 Identify Problem

Determine the list of items that you want to be categorised to uncover the hierarchical structure.

2 Create Props

Prepare the following props:

Create Cards

Write each item on an idividual card. Number the back of the cards (Usability Net, 2006) to help with the analysis process in Step 4.

Establish Categories

Identify the categories in which the items can be grouped.

Provide Blank Cards

Provide blanks cards for participants to add their own item (Martin and Hanington, 2012).

3 Recruit Participants

Recruit representatives of the user group you are designing for.

4 Create Artefact

Card Sort can be done individually or in small groups or 3-5 people (Martin and Hanington, 2012). Complete the following steps:

Arrange Cards

Ask the participant(s) to group the cards into relevant clusters, and provide a name for each cluster. If categories are provided, ask participant(s) to group the cards into the relevant category (Usability Net, 2006).

Record Findings

Ask the participant(s) to group the cards into relevant clusters, and provide a name for each cluster. If categories are provided, ask participant(s) to group the cards into the relevant category (Usability Net, 2006).

5 Next Step

Card Sorts can reveal the following:

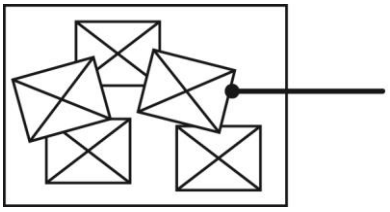
Suitability of Categories

If the categories were pre-defined, a consistent organisation reveals that our user will understand how you have structured the items. Inconsistent organisation revels that the categorises are poorly defined and should be renamed (Maguire, 2001).

Establish Categories

If the participants were asked to name the groups of cards, this approach helps to elicit the name of the categories as well as the item that should be placed in that category.

F.6 Collage Methodology



Ask participants to use a combination of images to convey their thoughts.

1 Identify Problem

Identify the topic you would like to investigate with a target user group.

2 Create Props

Brainstorm ideas and create a toolkit containing relevant graphics and photos for *Collage* creation (Sanders and William, 2003) surrounding your chosen topic.

3 Recruit Participants

Recruit representative participants of the user group you are designing for.

4 Create Artefact

Ask the participant to make use of the toolkit (from Step 2) to produce an image based on the topic you want to investigate. The diagram shows an example of how a *Collage* is formed.

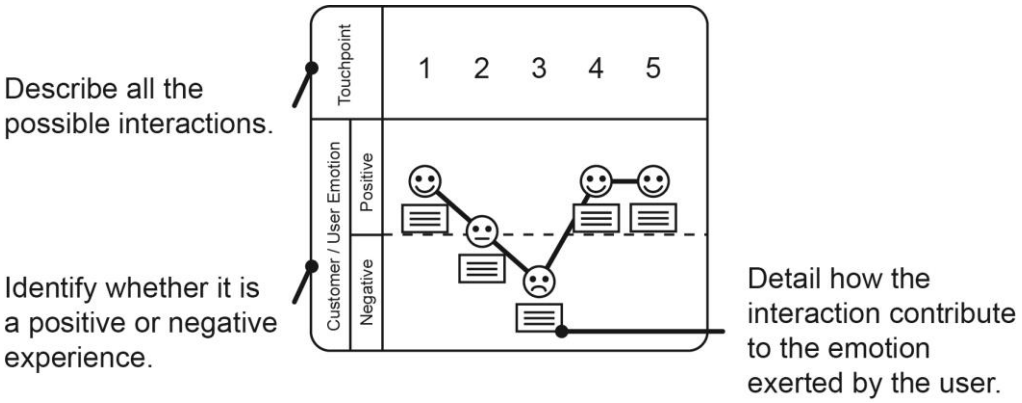
5 Next Step

Once the artefact is created consider to:

Interview Participant

Ask participants to explain how they have chosen and arranged the images to reveal ideas or issues related to your chosen topic (IDEO, 2003).

F.7 Customer / User Journey Methodology



1 Identify Problem

Determine the service interaction that you would like to investigate.

Determine Service Scope

Determine the scope of the service interaction. Consider using the *Scenario* method (Martin and Hanington, 2012).

Identify User

Determine the target end user. Consider using the *Persona* method (Martin and Hanington, 2012) to fully identify their wants and needs.

List Touchpoints

Compile a list of all the possible interactions the user will have with the service/product (Kolko, 2011).

2 Create Artefact

Create the visual artact. Consider the elements presented in the diagram. Make use of a timeline to show points of user interaction in the service (Kolko, 2011) and identify the emotions exerted at each point (Martin and Hanington, 2012).

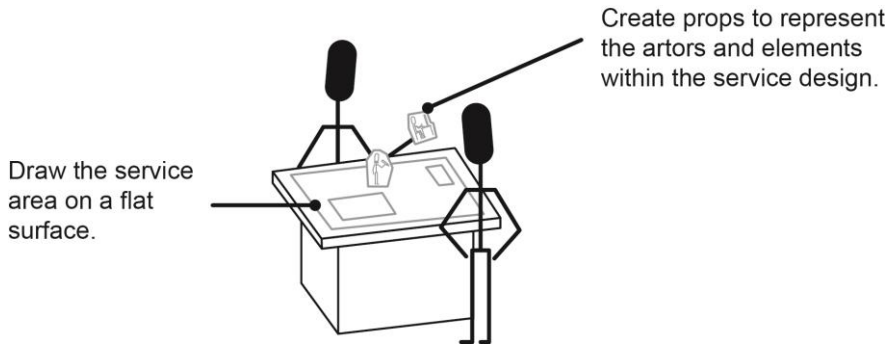
3 Next Step

Once the artefact is created consider to:

Discuss in Team

This artefact can be used in the design team to communicate the existing design and develop ideas for improvement (Martin and Hanington, 2012).

F.8 Desktop Walkthrough Methodology



1 **Identify Problem**

Determine the service system to be investigated.

Identify Scenario

Establish scenarios to be tested (Martin and Hanington, 2012). Consider using the *Scenario* method.

Identify Actors

Determine the actors involved in each scenario. Consider using the *Persona* method (Stickdorn and Schneider, 2010).

2 **Recruit Participants**

Recruit 4-6 participants to help with the artefact creation and scenario enactment. Try to include people from different background to gain a wider perspective of the service system under investigation (Martin and Hanington, 2012).

3 **Create Artefact**

Create the following items:

Define Service Area

Draw the service area on a flat surface.

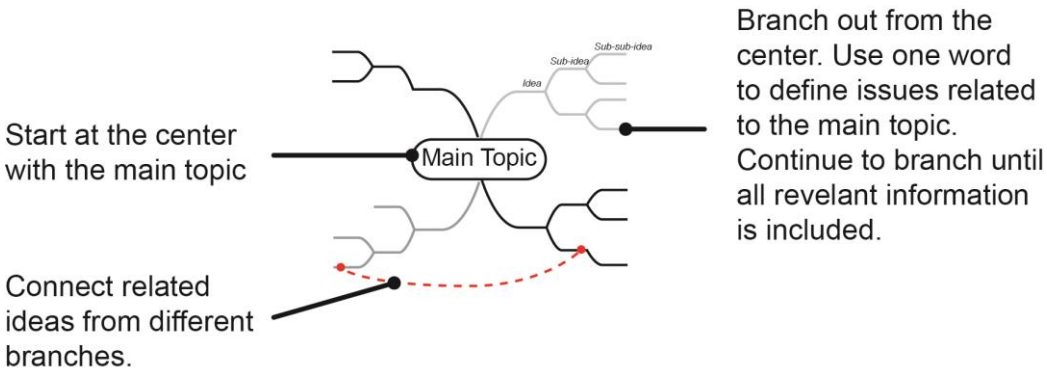
Create Service Elements

Create props to represent the service environment and the actors involved in its delivery. Use simple tools, such as Lego builds (Stickdorn and Schneider, 2010) or paper models (Martin and Hanington, 2012) to represent buildings and people.

4 **Next Step**

Enact each scenario identified in Step 1. Ask each participant to take up role of an actor within the service system, and enact the service using the items developed in Step 3. Note down any disagreement or problems identified and use these to refine the service delivery.

F.9 Mind Map Methodology



1 Identify Problem

Decide on the topic you are exploring.

2 Tool Selection

Select a suitable format to create the *Mind Map*:

Applications

A number of software (MindJet, 2015; MindMapper, n.d.) and web applications (WiseMapping, n.d.; Coggle, n.d.) are available for *Mind Map* creation. Digital *Mind Maps* can be easily modified and shared electronically.

Hand Drawn

The *Mind Map* is produced by hand on paper. This is a fast and inexpensive way to create a *Mind Map* but compared with digital version this artefact is more difficult to modify and shared.

3 Create Artefact

Create the visual artefact based on the diagram. Consider the following steps:

Define Problem at Centre

Use simple wording or an image to define the topic you are exploring.

Branch Out From Centre

Identify key ideas related to the central topic. Describe each idea with one key word on an individual branch. Create secondary branches linking to the first branch, and again use key word to describe how each idea link to that in the first branch. This process can be continued to create third and fourth level branches until all relevant information has been added to the map.

Link Relevant Branches

Draw a line to connect ideas on different branches to help reveal related ideas.

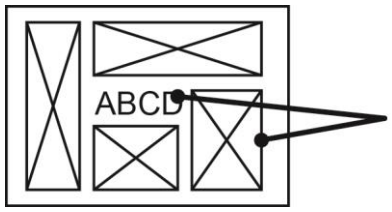
4 Next Step

Once the artefact is created consider to:

Discuss in Team

Discuss within the design team to help explain your understanding of the problem and how information are organised.

F.10 Mood Board Methodology



Use a combination of texts and images to convey the design atmosphere.

1 Identify Problem

Identify the topic you would like to investigate with a target user group.

2 Create Artefact

Locate images, texts, and photos that matches the atmosphere of the service or product design. Combine them onto a poster board to create the *Mood Board*.

Image Type

Pay attention to your choice of images. Abstract images can evoke greater emotion responses compared with literal images (McDonagh et al., 2002).

Digital Board

Digital *Mood Boards* has the advantages of including sound and movement (Saffer, 2010).

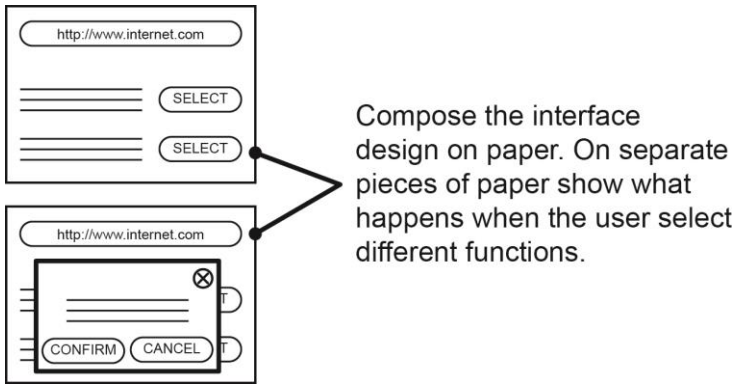
3 Next Step

Once the artefact is created consider to:

Discuss in Team

Discuss the artefact within the design team to agree upon the overall atmosphere of the service or product design (Moritz, 2005).

F.11 Paper and Interaction Prototype Methodology



1 Identify Problem

This methodology presents the *Low-Fidelity Prototyping* technique. First, determine the interface screen design and the tasks that must be performed in the software.

Other Techniques

Two other prototyping techniques are available for different stages of the design:

- **High-Fidelity Prototyping:** *High-Fidelity Prototyping* visualises the user interface with greater detail than *Low-Fidelity Prototyping*. They consists the behaviour of real systems, allowing users to directly interact with the prototype but are more expensive and difficult to make (Bailey et al., 2007).

- **Wizard-of-Oz:** In this technique, the user interacts with an interface that is changed a facilitator in the background. The interface would appear realistic for the user who will not be aware of the facilitator operating the prototype in the background.

2 Create Artefact

Compose the interface screens. Use one piece of paper for each screen. Check that each task is accommodated for and create additional screens if required.

3 Next Step

Once the artefact is created consider to:

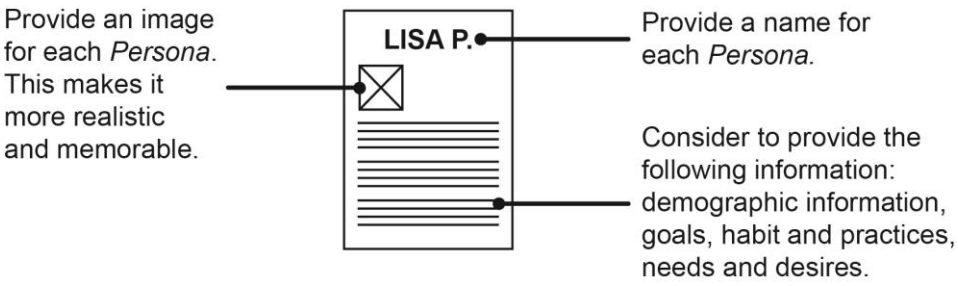
Recruit Participant

Recruit representative participants of the user group you are creating the design for to test the prototype. Ask the participants to perform the tasks using the prototype and record any difficulty they encounter and questions asked.

Discuss in Team

Use the prototype to present the interaction design concept (IDEO, 2003).

F.12 Persona Methodology



1 Identify Problem

Determine scope of product use.

Identify User Group

Decide upon the key user groups.

Define Research Scope

Decide upon the number of Personas to create based on your product and available resources (Vincent and Blandford, 2014). Typically 3-6 *Personas* should be generated (Pruitt and Grudin, 2003).

2 Recruit Participants

Recruit representative users for each user group (Holtzblatt et al., 2005).

Perform Research

Gather data of the representative users through *Focus Groups*, *Field Studies*, or *Interviews* (Pruitt and Grudin, 2003). Identify relevant information, including demographics, attitudes, and behavioural information (Mendel, 2012).

3 Create Artefact

Fused the data identified in Step 2 to create *Personas* based on the diagram.

4 Next Step

Once the artefact is created consider to:

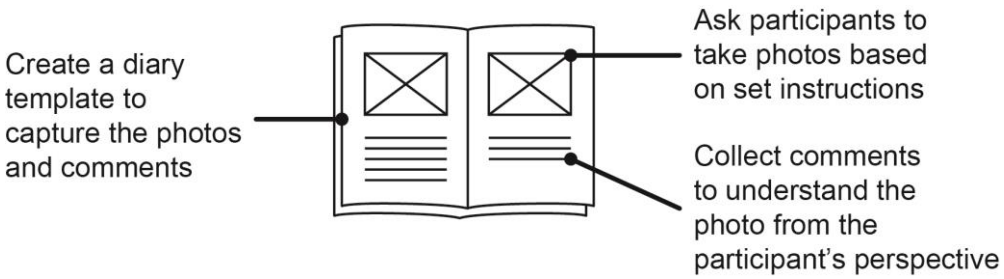
Validate Persona

Check *Persona* with the target user to confirm its validity (Pruitt and Grudin, 2003).

Use as Discussion Tool

The *Persona* contains information of the target user group. It can be used to support decisions throughout a design process (Vincent and Blandford, 2014).

F.13 Photo Studies Methodology



1 Identify Problem

Decide upon the topic you would like to study.

2 Create Props

Create the following props for the study:

Create Instructions

Set instructions for participants to take photos based on your chosen topic. This could be related to a particular time or event during a day (Sampanes et al., 2011). Create a diary template and ask participants to provide comments or answer set of questions for each photo.

Provide Equipment

Ensure that you can provide a camera for each participant to undertake this study. Alternatively, provide instructions for participants to use their own camera (Martin and Hanington, 2012).

3 Recruit Participants

Recruit representative participants of the user group you are designing for.

4 Create Artefact

Ask participant to follow your set instructions and provide them with a camera. The diagram depicts an exemplar format of *Photo Studies*.

5 Next Step

Once the artefact is created consider to:

Interview Participant

Interview the participants to gain greater understanding of the significance of each photo (Martin and Hanington, 2012).

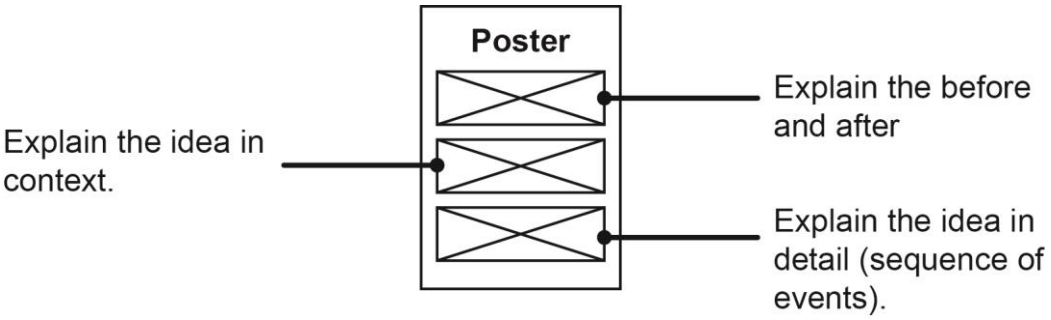
Sort Photos

Ask the participants to sort the photos in some way (such as positive and negative experiences, or time sequence in which the event in the photo occurs.

Identify Patterns

Analyse the photos for any patterns or themes (Martin and Hanington, 2012).

F.14 Poster Methodology



1 Identify Problem

Identify a challenging topic(s) you would like to investigate.

2 Create Props

Gather equipment to aid the Poster creation. Include markers, flipcharts, and magazines with images for cutting out etc.

3 Recruit Participants

Recruit team members to create the *Poster*.

4 Create Artefact

Ask participants to think of solution to the challenge you have identified in Step 1. Use the *Poster* as a format to respond to the challenge by describing the impact of their ideas. Consider to include elements presented in the diagram.

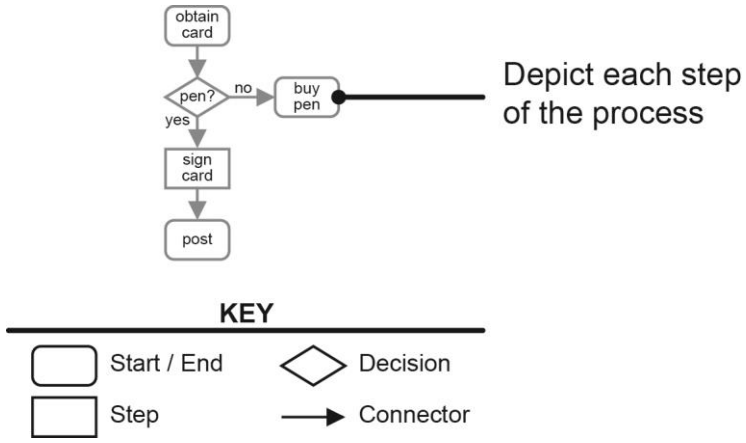
5 Next Step

Once the artefact is created consider to:

Identify Best Idea

Ask each participant to vote for the idea that should be further developed (Gray et al., 2010).

F.15 Process Model Methodology



1 Identify Problem

Determine the process you would like to investigate.

Identify Activities

Determine the activities that takes place through brainstorming (Tague, 2005), interviews, or observations (Royal College of Art, n.d.).

Determine Sequence

Identified the order in which the activities take place.

2 Create Artefact

Create the artefact based on the diagram.

Other Techniques

This methodology has shown the steps for modelling the *Process Model* using the *Flow Chart* technique. Many different process modelling techniques exists, such as *FMEA* (Royal College of Art, n.d.), *IDEF0*, and *Gantt Chart* (Aguilar-Savén, 2004).

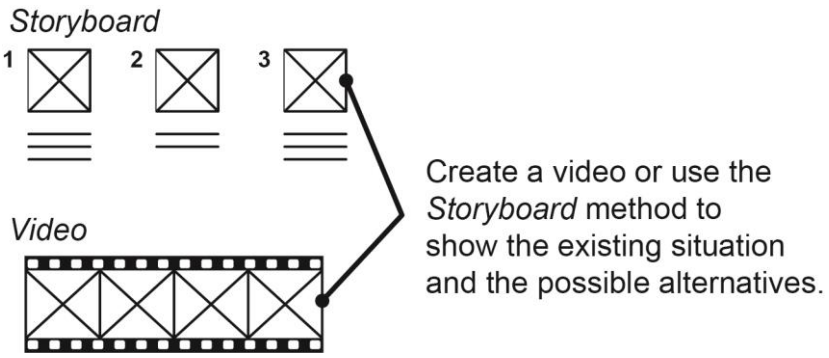
3 Next Step

Once the artefact is created consider to:

Validate Model

Validate the artefact with relevant stakeholders to ensure all the activities are included and are in the correct sequence.

F.16 Scenario Methodology



1 Identify Problem

Determine the problem area that you want to improve.

Identify Actors

Determine the actors involved in the current environment (Martin and Hanington, 2012; Suri and Marsh, 2000). Consider using the *Persona* method (Stickdorn and Schneider, 2010).

Identify Actions

Determine the tasks the actors must perform to reach the goal. *Field Observation*, *Contextual Inquiry*, and *Interviews* (Suri and Marsh, 2000) can be performed to identified problems with the current environment.

Identify Solutions

Based on the problem identified, think of possible solutions.

2 Technique Selection

Decide how you would like to present problem area, actors involved, and the possible solution to overcome the problem:

Storyboard

Use the *Storyboard* method to communicate the findings (Carroll, 2000; Stickdorn and Schneider, 2010).

Video

Create a video to show the existing situation and possible alternatives (Carroll, 2000; Stickdorn and Schneider, 2010).

3 Create Artefact

Create the visual artefact based on the format you have chosen in Step 2. The variations of format for this visual artefact are shown in the diagram.

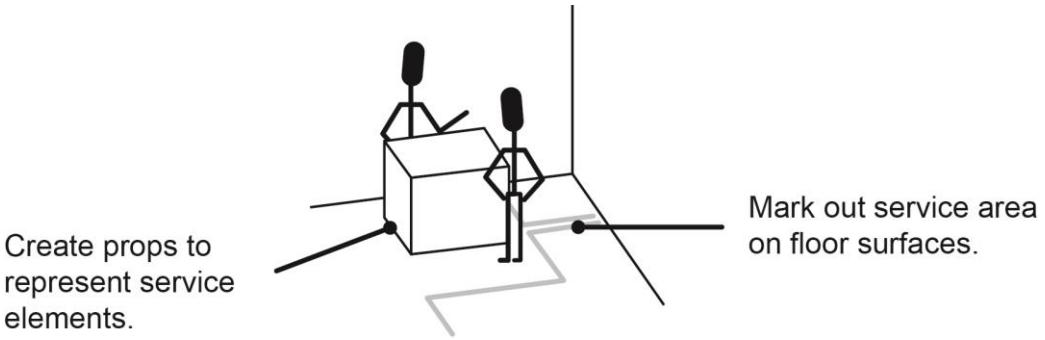
4 Next Step

Once the artefact is created consider to:

Use as Discussion Tool

The artefact can be used as a disccusion tool to gain feedback on the suggested solutions and to develop alternative solutions.

F.17 Service Prototype Methodology



1 **Identify Problem**

Determine which part of the service is being evaluated.

Create Script

Make a script detailing the people involved (users, service employees etc.) and the steps of the service delivery (Saffer, 2010).

2 **Create Artefact**

Create the following items in order to enact the service delivery:

Create Environment

Mark out the service area on floor surfaces (Saffer, 2010).

Create Objects

Use foams, pictures, or other materials to represent service elements (Saffer, 2010).

3 **Next Step**

Use the artefacts to enact the service delivery.

Recruit Participants

Ask clients and stakeholders to partake in the enactment.

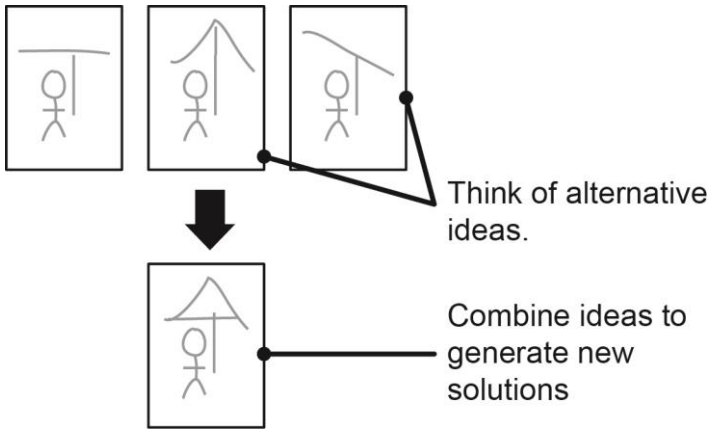
Assign Roles

Assign each participant with a role (such as the customer, or the service employee).

Enact Service Delivery

Record any problems identified in the enactment and refine the service design. Modify the prototype and re-enact the scene to see if the problem persists (Stickdorn and Schneider, 2010).

F.18 Sketching Methodology



1 Identify Problem

Identify key parts of the design problem.

2 Create Props

Create templates to help with the sketch, for example use templates for devices.

3 Recruit Participant

Work in a group to quickly come up with a number of ideas.

4 Create Artefact

Sketch out your ideas. Consider the following:

Think of Alternatives

Think of different ways in which you can design a particular feature.

Mix and Match Ideas

Combine ideas to generate new solutions.

5 Next Step

Once the artefact is created consider to:

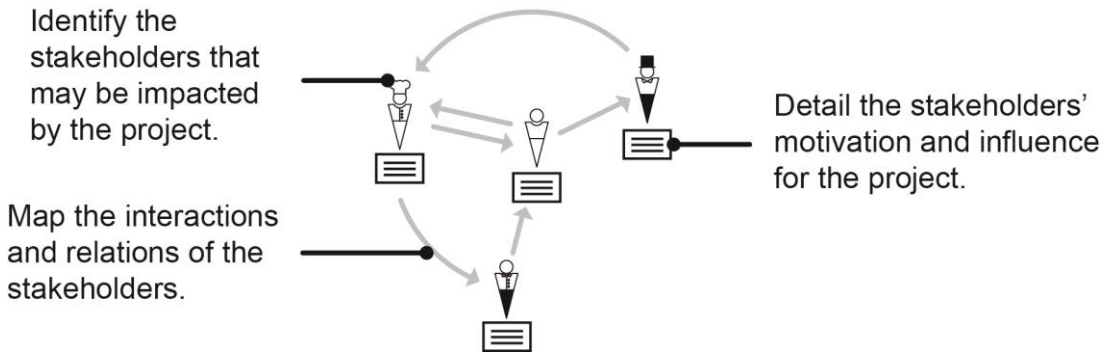
Discuss in Team

Use the sketches to communicate your ideas. Refine your idea based on feedback given.

Identify Best Idea

Select the best concept for further development.

F.19 Stakeholder Map Methodology



1 Identify Problem

Decide on the scope of the design project.

Identify Stakeholders

Identify the relevant stakeholders by considering a) who can be impacted by the project and b) who is responsible for the project (Gray et al., 2010).

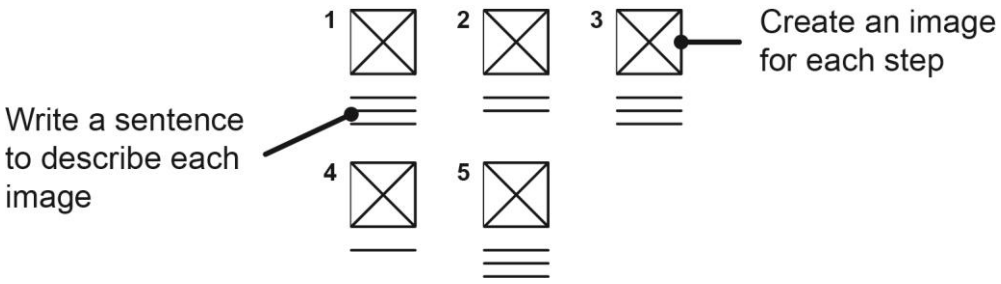
2 Create Artefact

Identify and map the interaction and relation of the stakeholder and reveal their influence, interest, or motivations for the project (Stickdorn and Schneider, 2010). Use a combination of text, images, and photos to support the communication of the different roles (Martin and Hanington, 2012).

3 Next Step

This map can be modified once the roles are more clearly defined (Martin and Hanington, 2012).

F.20 Storyboard Methodology



1 Identify Problem

Define the scope of your *Storyboard*.

Identify Story

Determine the story. Consider using the *Scenario* method.

Identify User

Identify the main character(s) in the story. Consider using the *Persona* method.

2 Create Artefact

Create the visual artefact based on the diagram. Consider the following:

Breakdown Story

Dissect the scenario into around 5 individual steps (Rogers et al., 2011). Each step should show a key interaction involving the character(s). If more than 5 steps are required, consider breaking your story into several storyboards.

Create Images

Create an image for each step.

Describe Each Frame

Write a sentence to describe each image.

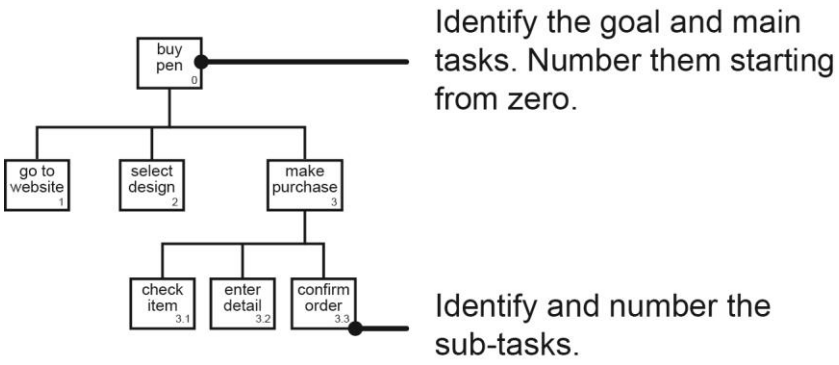
3 Next Step

Once the artefact is created consider to:

Ask for Feedback

Discuss in team to gain feedback.

F.21 Task Analysis Methodology



1 Identify Problem

To create a *Task Analysis*:

Identify Goal

Determine the goal of the design.

Identify Main Tasks

From the goal, determine what the main tasks are to complete the goal.

Identify Sub-Tasks

Break down the main task into sub-tasks.

2 Create Artefact

Create the visual artefact based on the diagram.

Other Techniques

This methodology has shown the steps for a *Hierarchical Task Analysis (HTA)*. Other *Task Analysis* techniques include: *GOM*, *CTA*, and *Activity Theory* (Crystal and Ellington, 2004).

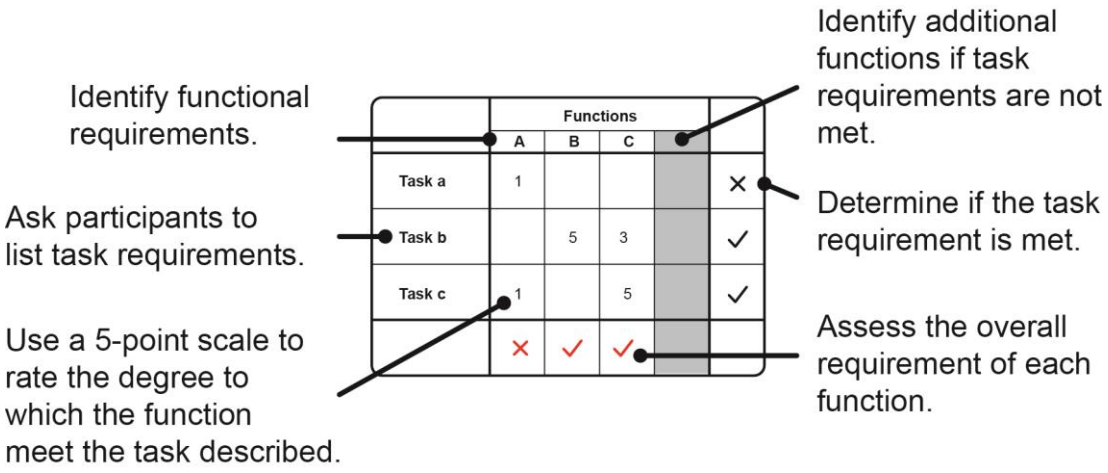
3 Next Step

Once the artefact is created, consider to:

Compare Alternative Designs

Use this visual artefact to compare the activities in different designs (Rogers et al., 2011).

F.22 Task Mapping Methodology



1 Identify Problem

Identify the system that you would like to explore.

Identify User

Determine the type of users who will be using this system.

Identify Functions

Identify all the possible functions of the system.

2 Create Props

Create the following prop:

Matrix Table

Create a table template and list all the possible functions (identified in Step 1) in the columns.

3 Recruit Participants

Recruit representative users from the user group you have identified in Step 1.

4 Create Artefact

Ask participants to complete the table by:

List Tasks

Listing their task requirements.

Rate Function

Use a 5-point scale to rate the functions against each task (Catterall, 1990).

Assess Tasks

Assess if each task requirement is met.

Identify Additional Functions

Identify additional functions for any task requirements not met. Rate the additional functions against each task and re-assess to see if each task requirement is met.

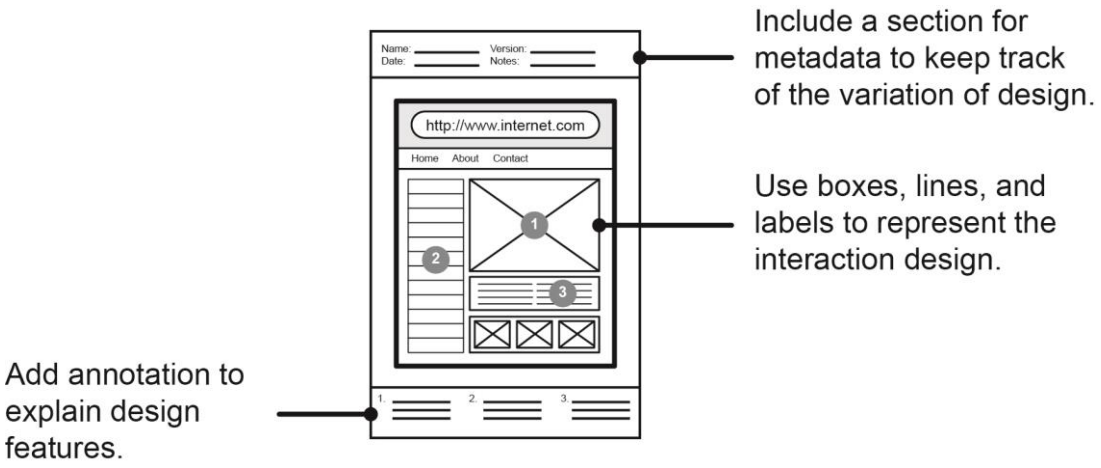
5 Next Step

Once the artefact is created consider to:

Assess Functions

Assess the functions based on how critical they are for each task. This is to help the designer to identify the more importance functions to focus on.

F.23 Wireframe Methodology



1 Identify Problem

Make a list of *Wireframes* you are creating.

Sketch out Each Frame

Sketch out the design so you know what will be in each frame.

2 Tool Selection

Select a suitable software. This can be any software that can be any drawing software (Adobe Illustrator, Microsoft Powerpoint), or specialised tools (Axure, Balsmiq, Omnigraffle).

3 Create Props

Create a template to define the structure and style for the *Wireframe*.

4 Create Artefact

Create the *Wireframes* based on the features presented in the diagram.

5 Next Step

Once the artefact is created consider to:

Discuss in Team

Present the visual artefact to team members and ask for feedback.

Appendix G – Demographic Questionnaire

1. What is your age?

2. What is your gender?

☐ Male ☐ Female

3. How fluent is your English?

☐ Basic ☐ Proficient ☐ Fluent

4. How much manufacturing assembly experience do you have?

☐ None ☐ Minimal ☐ Moderate ☐ Extensive

(less than 1 year) *(1-3 years)* *(3 Years or more)*

5. What is your comfort level with a desktop computer?

☐ Novice ☐ Beginner ☐ Competent ☐ Proficient ☐ Expert

6. How often do you use a desktop computer?

☐ Daily ☐ Weekly ☐ Monthly ☐ Occasionally ☐ Never

(less than once a month)

7. How often do you play video games?

☐ Daily ☐ Weekly ☐ Monthly ☐ Occasionally ☐ Never

(less than once a month)

8. On average, how many hours per week do you spend playing video games?

☐ 0 ☐ 1-5 ☐ 6-10 ☐ 11-15 ☐ 15-20 ☐ 20+

Appendix H – Knowledge Retention Test

1. How would you know what personal protective equipment (PPE) you will need?
    - ☐ Look up the xxx list.
    - ☐ Look up the xxx instruction protective equipment (xxx) list.
    - ☐ Look up the xxx Bill of xxx.
    - ☐ Ask your team leader or a qualified technician.

2. What personal protective equipment (PPE) do you need to wear?
    - ☐ No PPE is required.
    - ☐ xxx and xxx.
    - ☐ xxx, xxx, xxx, xxx, and xxx.
    - ☐ xxx, xxx, xxx, xxx, and xxx.

3. Where would you find the necessary parts in the Qxxx manual?
    - ☐ Collect parts from the xxx.
    - ☐ Look up the xxx list.
    - ☐ Look up the xxx Bill xxx.
    - ☐ Collect parts from the component rack.

4. How would you know what to do and use to xxx the jig?
    - ☐ Ask your team leader or a qualified technician.
    - ☐ Look up the xxx list.
    - ☐ Look up the xxx list.
    - ☐ Ask for the correct tools in the store.

5. What do you need to ensure during the xxx of the jig operation?
    - ☐ Ensure all the xxx xxx fit into the xxx correctly.
    - ☐ Ensure all the parts are cleaned to a good standard.
    - ☐ Ensure all the parts are moving and free from interference.
    - ☐ Ensure all the parts are cleaned to xxx and are free from interference.

6. What material do you need to collect from the store?
    - ☐ No materials were needed for this work manual.
    - ☐ Cleaning xxx and xxx.
    - ☐ xxx door xxx.
    - ☐ xxx non xxx agent.

7. What do you need to do after collecting the xxx from the store?
    - ☐ xxx the xxx before xxx the door to the jig.
    - ☐ xxx the xxx before fitting to the jig and xxx.
    - ☐ xxx xxx xxx and xxx for damage.
    - ☐ Check that the xxxx is xxxx and xxx for damage.

8. If a part comes with an xxx, what would you do?
    - ☐ Check that xxx match with the xxx and inform the xxx.
    - ☐ Give the xxx to the xxx inspector.
    - ☐ Attach the xxx to the xxx form.
    - ☐ Attach the xxx onto the part

9. To prepare the jig to xxx, what do you need to xxx?
    - ☐ The xxx and the xxx.
    - ☐ The xxx and the templates.
    - ☐ The xxx and the hinges.
    - ☐ There is nothing to xxx; the door xxx is xxx.

10. How many xxx are needed to secure the xxx?
    - ☐ Two.
    - ☐ Four.
    - ☐ Six.
    - ☐ Eight.

11. How many xxx are needed to secure the xxx?
    - ☐ Two.
    - ☐ Four.
    - ☐ Six.
    - ☐ Eight.

12. How would you perform the quality check operation?
    - ☐ Check over the work yourself to make sure it is correct.
    - ☐ Ask xxx to check.
    - ☐ Ask xxx to check.
    - ☐ Ask xxx to check.

13. What do you have to do before xxx?
    - ☐ Check that the xxx on the xxx is xxx.
    - ☐ Inspect the xxx according to the Axxx before xxx.
    - ☐ Rotate xxx with the xxx on the upside.
    - ☐ Rotate xxx with the xxx on the downside.

14. How do you fit the xxx?
    - ☐ Claw clamped through xxx in according to the Axxx.
    - ☐ Fit the xxx and xxx.
    - ☐ Manual Clamped with xxxx.
    - ☐ Pinned with xxx according to the Axxx.