UNIVERSITY OF SOUTHAMPTON

FACULTY OF BUSINESS, LAW AND ART

School of Business

Repertory Grid Technique: A Pragmatic Approach to Evaluating User Experience in Visualisation Navigation

by

Azira Ab Aziz

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ABSTRACT

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REPERTORY GRID TECHNIQUE: A PRAGMATIC APPROACH TO EVALUATING USER EXPERIENCE IN VISUALISATION NAVIGATION

Azira Ab Aziz

The aim of this study is to evaluate user experience of visualisation navigation by adopting a pragmatic approach. A pragmatic approach with the adoption of Repertory Grid Technique (RGT) reveals a different side of visualisation evaluation. Visualisation in past research has been studied through different theoretical lenses, discussed here under four headings: human cognition; technology interventions; data and information; and evaluation behaviours. From these four headings emerge objective and subjective user experience measurements. These insights have been used to demonstrate the implications of RGT and how it can generate valid data for analysing user experience. The findings elicited from 48 users demonstrate the contributions of the study specifically to evaluation approaches. The implications of RGT explored uncommon research paradigms in visualisation research, improvement in the elicitation method and extensions to the RGT, enhancing the research credibility. The outcomes derived from RGT were used as indicators to uncover user experience. These outcomes were: (1) the list of the hierarchical factors to evaluate user experience; (2) the potential implications for practice when designing visualisation navigation; and (3) the richness of the classification of visualisation navigation features generated by user experience. A comparison between the generated data and previous studies was used to demonstrate the impact on the research context. The main contributions of this research are fourfold. First, the research followed a pragmatic paradigm and adopted RGT, which is uncommon for visualisation research exploring users' perceptions towards visualisation, and constitutes a methodological innovation. Second, it fills a gap in the theoretical basis of evaluating visualisation navigation based on user experience. It also articulates four lenses of past research: human cognition, technology interventions, data and information, and evaluation behaviours. Third, it determines the important elements of user experience towards visualisation. Fourth, the research bridges the gap between designers, users and academicians by exploring the visualisation phenomenon.

Keywords: visualisation, navigation, pragmatic, repertory grid techniques, mixed method.

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DECLARATION OF AUTHORSHIP

I,AZIRA AB AZIZ

declare that this thesis and the work presented in it is my own and has been generated by me as the result of my own original research.

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Visualisation Navigation

I confirm that:

1. This work was done wholly or mainly while in candidature for a research degree at this University;
2. Where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated;
3. Where I have consulted the published work of others, this is always clearly attributed;
4. Where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work;
5. I have acknowledged all main sources of help;
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Signed: ....

Date:...

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Definitions and Abbreviations

RGT	Repertory Grid Technique
UE	User Experience
KV	Knowledge Visualisation
HE	Higher Education
PCT	Personal Construct Theory
PCA	Principal Component Analysis

Chapter 1: Introduction

1.1 Visualisation, Evaluation and User Experience

Visualisation is a rapidly growing field of study that has become increasingly important over several decades. The continuous development of technology has enabled visualisation to become an important subject for developing applications, such as graphic design, financial data representation and computer modelling (Tufte, 1997). Due to this rapid development, many visualisation studies have been conducted, aimed at producing enhanced visualisation. For example, a Visualisation Lab which uses Virtual Reality (VR) was launched to promote innovation and solve problems in the UK's transport network (Moon, 2015). This thesis will evaluate the concept of visualisation and consider its significance in the context of evaluation and user experience within the domain of navigation, using various visualisation maps. The thesis will argue that visualisation is indeed a major issue in both theory and practice. Repertory Grid Technique (RGT) following a pragmatic approach was adopted to evaluate user experience towards visualisation of navigation.

There are numerous methods conducted by scholars on visualisation. These methods can be divided into two: subjective evaluation and objective evaluation. Subjective evaluation seeks to understand user perception and motivation by adopting such methods as: field experiments and structured interviews (Abubakar *et al.*, 2014); experimental game setting (Borkin *et al.*, 2013); informal evaluation, usability test, field observation, or laboratory questionnaire (Lam *et al.*, 2012); workplace based evaluation (Slingsby and Dykes, 2012) and thinking aloud, summative questioning and observation (Lloyd and Dykes, 2011). Objective evaluation focuses on examining visualisation frameworks perceived by users to identify their effectiveness, such as online surveys of users' experiences (Vande Moere *et al.*, 2012); reaction cards (Merčun, 2014) and online experiments, with a series of stimulus response tests or online task scenarios (Wood *et al.*, 2012). These approaches effectively evaluate user experience of visualisation. However, conducting a subjective and objective evaluation collectively will explore the complexity and diversity of user experience. These approaches will also reveal other aspects of user experience.

User experience is well known for its complexity and diversity. These challenges have led the study to explore an alternative approach that consists of in-depth evaluation of user experience. User experience is governed by various theories with different focal points, such as colour, information, perceptual theory, visual cognition and visual communication. These theories sometimes overlap and complement one another. The richness of user experience usually relates to its subjectivity, and does not normally appear in a guideline format to help designers. As designers are often unable to see the findings in a guideline format, this can limit the contribution of user experience on a practical level. Hence, a guideline for designers is important in eliciting user experience. A comparison between subjective and objective user experience measurements with findings revealed in the study has been used to provide the guidelines. Similarities with previous studies will provide empirical evidence about visualisation concepts and differences, and will be used as additional guidelines for designers.

The adoption of RGT may reveal several possibilities, including the implications and ability to elicit data for analysing user experience to complement other visualisation evaluations (Faisal *et al.*, 2007; Hsieh *et al.*, 2008; Lloyd and Dykes, 2011; Slingsby and Dykes, 2012; Vande Moere *et al.*, 2012; Wood *et al.*, 2012; Abubakar *et al.*, 2014; Merčun, 2014). These findings will contribute on methodological, theoretical, conceptual and practical levels. The proposed method could reduce the limitations of current methods and is easy to replicate in another domain.

1.2 Focus of the Research

The motivation for this study was to provide an alternative methodological approach to evaluate user experience by exploring visualisation of navigation. Hence, two objectives were formulated to address the methodological gap:

a) To position the study on a pragmatic approach, using RGT in evaluating user experience
b) To explore the use of a high and low task approach of RGT in visualisation research

This study aims to address the following research questions:

a) What is the impact of a pragmatic approach with the adoption of RGT in evaluating user experience for visualisation of navigation?
b) How can the use of RGT be demonstrated to elicit user experience using a high and low task approach in visualisation research?

Section 1.3 will briefly describe the overall structure and layout of this study in order to achieve the research objectives.

1.3 Thesis Outline

The overall structure of the study takes the form of six chapters, including the introductory chapter.

Chapter 2, the Literature Review, begins by presenting the three foci in visualisation research. The review examines visualisation features for the three relevant classifications: heuristic sketch, conceptual diagram and knowledge maps. A discussion of visualisation research that produces four lenses of past research, including human cognition, technology intervention, data and information visualisation, and evaluation behaviours was presented. The discussion revealed shortcomings in visualisation related to evaluation which identifies a methodological gap in the research. The methodological gap led this study to identify theories related to user experience in visualisation, including objective and subjective measurements. In bridging this gap, the study based on RGT methods was used to elicit users' subjective factors, explore the relationship between those factors and construct the classification of features which were established.

Chapter 3, Methodology, concerns the method used for the study. This chapter begins with the current practice of the research paradigm used in visualisation study. The chosen paradigm underpinning this study, known as pragmatic research design, suggests applying a personal construct theory. This theory, in association with RGT, elicits the features of visualisation methods. The exact processes of collecting data that fulfil ethical considerations are reported. This chapter also demonstrates some of the challenges encountered when conducting the research.

Chapter 4, Data Analysis, analyses the results from interviews and open-ended questionnaires obtained during data collections. Justification of the data analysis techniques based on current practice is presented. Results are reported in three sections: (1) Quantitative: Principal Component Analysis (PCA); (2) Qualitative: Aggregation of Thematic Analysis and Three Layer Classification Scheme; (3) Mixed-method Matrix: Quantitative and Qualitative.

Chapter 5, the Discussion, presents a brief summary and critique of the findings, divided into two sections: (1) Implications of RGT; (2) Generating data for analysing user experience. Implications of RGT focus on the impact of adopting uncommon paradigm and techniques, improvement and extension to the RGT and enhancing research credibility. Generating data for analysing user experience examines three possibilities, which were the list of the hierarchical factors to evaluate user experience, their potential implication for practice and the richness of the classification of visualisation navigation features constructed by user experience. A critical comparison between these findings and previous research frameworks is discussed to derive some conclusions.

Chapter 6, Conclusion, provides a summary of the findings in two sections: 1) the implications of RGT, and 2) generating data for analyzing user experience. The discussion is followed by limitations of the study. The contributions of the study are set out and discussed based on a methodological, theoretical, contextual and practical level. This chapter concludes with some recommendations for future studies.

Chapter 2: Literature Review

2.1 Introduction

This chapter critiques the relevant literature underpinning the study. The first section introduces the type of visualisation research. The second section discusses visualisation features for the three relevant classifications. The review continues by discussing previous studies of visualisation research, producing four lenses of past research. The third section highlights one shortcoming in visualisation, which is the evaluation. Hence several types of evaluation, including their methods, are reviewed. The fourth section presents the theories related to user experience in visualisation, followed by a list of objective and subjective measurements of user experience. In this section, the discussion will provide an in-depth evaluation of user experience. Finally, a summary of the chapter includes the research gap, which identifies the limitations in the current evaluation, and proposes the conceptual framework of the study based on RGT methods.

According to Ware (2008a), there are three major foci in visualisation research. First is the power of visualisation algorithm to solve unfamiliar problems that arise in a rapidly changing field. Visualisation studies that build an algorithm to enhance visualisation capabilities have been successfully demonstrated in several disciplines, such as geography, automotive, aerospace, engineering, business and architecture. For example, visualisation can be used to locate places through navigational tools, to simulate a major construction, to interpret massive data for decision making and the representation of ideas through sketching. The development of algorithms has been divided into several phases, such as development, execution and testing them to optimise different visualisation techniques. Therefore, scholars (Henderson, 1999; Haase *et al.*, 2000; Perini, 2005b; Goodwin, 2009; Afzal and Maurer, 2011; Comi and Eppler, 2011; El-Sadi and Roberts, 2012; Turkay *et al.*, 2014) have been keen to understand the principles and techniques needed to solve unfamiliar problems through the development of graphic visualisation. Recent developments in graphic visualisation, specifically on real-time navigation, are the 3D map on mobile devices (Abubakar *et al.*, 2014), online geographic map (Wong *et al.*, 2014) and virtual landscape using 3D geovisualisation (Papakonstantinou *et al.*, 2015).

Second, the development of theory is needed to provide an understanding of subjects and adopt an appropriate approach. Although theories that govern visualisation studies may differ, depending on the research aim, there are several related theories, such as visual cognition, information and perceptual theory. The interest lies in examining theories that may be used as a basis to explain the visualisation phenomenon. For instance, Ware (2008a) explains a perceptual theory of flow visualisation.

Third, the development of design guidelines may have a huge implication for designers and users in education, arts, graphic design and advertising disciplines. There are several design guidelines that can be employed specifically for websites (Hassenzahl and Wessler, 2000), legends (Dykes *et al.*, 2010), and graphical user interface (Marcus, 2014). These design guidelines may be adapted to most of the contexts. For example, developing websites in business and academic contexts may apply similar rules. Considering the adaptability of guidelines, designers may ignore the need to evaluate visualisation from the user's perception. For example, in a business context, customers may encounter real difficulties when purchasing through a website that does not match their preferences. They may require some additional information that could help them perform their tasks.

2.2 Visualisation

There are numerous, but similar definitions given by scholars. According to Zhou *et al.* (2011, p. 6235) visualisation means "*visible, pictorial and clearly present*". The term, *visualisation* used by Marchese and Banissi (2012) also relates to visual perception, which refers to the process of creating a mental image. According to Keller and Tergan (2005), visualisation is "*to enhance processing ability by visualizing abstract relationships between visualized elements and may serve as a basis for externalized cognition*" (p. 5). Both Spence (2007) and Card *et al.* (1999) emphasize a mental image, which, with the support of media (computer or paper), allows critical insights. The emphasis on critical insights gives a comprehensive definition of visualisation for the purpose of this study. Critical insight referring to knowledge has not yet been widely discussed in visualisation research.

Visualising knowledge has several foci based on its definition. According to Xiaoyan *et al.* (2012, p.1), visualising knowledge is a "*process of designing, implementing and applying appropriate visual representations to create, transform and communicate knowledge".* A similar definition by Lengler and Eppler (2007, p.1) refers to visualization as *"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".* Tergan *et al.* (2006, p. 168) mention that visual format aims at *"supporting* *cognitive processes in generating, representing, structuring, retrieving, sharing and using knowledge"*. These definitions show the progress of the knowledge process, such as creating, acquiring, capturing, sharing and using it (Jimenez-Jimenez and Sanz-Valle, 2012). While not all knowledge process is facilitated by visualisation, it clearly provides a significant contribution.

Another different perspective of visualising knowledge is communication. Wang and Jacobson (2011) claim that visual representations aim to communicate knowledge. A brief definition by Burkhard (2004, p.520) states that *"the use of visual representations is to improve the transfer and creation of knowledge between at least two persons".* Burkhard (2004) claims that a minimum of two people are required in the knowledge transfer process. In relation to his claims, Bodrow and Magalashvili (2008) refer to those who are involved in the transfer process as experts. However, there may be situations where only a single person can transfer the knowledge, facilitated by technology. For example, Roberts (2000) explains how ICT may aid the transfer of knowledge without the existence of other people. ICT tools such as video-conferencing and emails facilitate knowledge transfer through the 'knowledge-information-data' transformation process (Jasimuddin *et al.*, 2012). Hence, computer technology becomes an enabler for communication through visual representation.

The definition of visualising knowledge also focuses on graphical perspectives. Knowledge visualisation may be described as a set of *"graphical entities used to transfer knowledge from an expert to a person (or group of persons), which clarifies its complexity and explains the meaning and the purpose of the relevant interdependencies"* (Bodrow and Magalashvili, 2008, p.347). According to Lengler and Eppler (2007), visual representation may be referred to as 'graphic formats'. Davies and Goel (2001, p. 377) define visual representation as *"both high-level symbolic representations and low level bitmap representations".* The high-low level bitmap represents the level of visibility of the objects. These authors describe visual as purely graphic; however, it can be argued that any types of movement or processes can be defined as visual. For example, an audience in a theatre could see a visual representation in a stage performance as a series of movements. This movement captures the audience's attention and could be perceived by them as meaningful information.

These definitions raise an argument about what constitutes knowledge in the context of visualisation. According to Lengler and Eppler (2007), the term 'knowledge' refers to an insight, experience, contact or skill embedded in the human mind. Burkhard (2004) defines knowledge as complex insights that require visual support. Blair (2002) believes that knowledge is mainly concerned with expertise, and is impossible to separate from the owner. Although knowledge is subjective, intangible, unstructured and difficult to visualise, there is a way to make it visible. It can be made visible through a transformation process deriving from information. For example, when identifying the patterns and meaning of datasets, knowledge will be created (Bertschi et al., 2011). Hence, a meaningful structure of information can be disseminated (Drosdol and Frank, 2005).

Throughout this paper, the term of *knowledge visualisation* is used which refers to

"*a graphical representation which depicts insights, creates understanding and supports the communication of knowledge*".

By discussing the elements of knowledge in visualisation, the role of visualisation becomes visible. The role of visualisation to represent knowledge is demonstrated by adopting several methods of representation. These methods could bring benefits to both designers and users in understanding the context. Users' interpretations are varied and subjective, but the general idea of visualisation is similar. Hence, further discussion of methods to evaluate visualisation from the user's perception is essential. The discussion of methods is within the scope of knowledge visualisation literature.

2.2.1 Features of visualisation methods

A question concerning classification has been raised regarding the terms 'classification' and 'categorization'. These two terms are widely used to refer to the same meaning, but there is a significant difference in terms of structure. Jacob (2004) points out the difference between classification and categorisation as follows: classification refers to hierarchical structure, whereas categorisation refers to clusters of entities. However, both are acknowledged as representational tools in the organising of resources (Jacob, 2004). Throughout this thesis, the term 'classification' will be used to refer to the structure of the features of visualisation format. Scholars such as Bailey (1994) and Jacob (2004) generally define 'classification' as the organizing of entities into groups based on the similarities of the entities' features. The term has been applied to situations where the organizing process is lawful and systematic (Jacob, 2004). It is lawful because there are certain principles that manage the process, and systematic because the application of those principles is consistent. However, Eppler (2008) suggests that the process of organising is not just based on a single classification principle, and proposes several alternative criteria.

These should include at least some logical and pragmatic elements (Eppler, 2008). The various criteria are important to ensure that the classification is not just theory based, and each should reflect the behaviour of the items. The criteria can thus be used as an assessment of visualisation features. A comprehensive list of criteria is offered by Eppler (2008), based on research conducted by several scholars (Bailey, 1994; Minto, 1995; Wurman, 2000). The summary of classification properties is as follows:

a) Mutually exclusive categories
b) Comprehensive
c) Firm features
d) Consistent level of abstraction
e) Self-explanatory labels
f) Explicit, consistent and informative classification principle
g) Well-defined domain
h) A list of commonly used items
i) Adequate amount of groups
j) Understandable and usable for the users.

As stated above, the criteria are non-overlapping and mutually exclusive, such distinction allowing recognition of the items. The classification is also comprehensive, because all items in the domain are not supposed to be separate from the classification. Furthermore, a classification should have firm features to avoid ambiguous items. In fact the label for each classification should be self-explanatory and consistent within the same level of abstraction. Hence, the classification principle should be explicit, consistent and informative. A well-defined domain should provide a list of commonly used items in each classification. A well-organised system should provide an adequate amount of manageable groups, and the classification should be easy to understand and useful for the users.

Visualisation classification depends on discipline, context and application. In generating classifications, there should always be a list of key features to define each classification (Eppler, 2008). However, there is no standard procedure to identify these features (Bailey, 1994). One suggested way is by looking at certain classifications that display similarity in context and disciplines.

Based on the classification provided by Lakoff (1987), there are four different types of principles:

a) Purposive : categorizing by intended use
b) Perceptual : categorizing by common format/look
c) Functional: categorizing by use and type of content

d) Motor-activity: based on physical interaction with the content

These classification principles can also be found in Blackwell and Engelhardt (2002), Lohse *et al.* (1994) and Shneiderman (1996), as reviewed by Eppler (2008). Their preference in applying classification principles shows both a similarity and a distinction. For example, Lohse *et al.* (1994) and Shneiderman (1996) both suggest that functionality is an important principle, even though other principles may differ in content, structure and graphic form. However, Blackwell and Engelhardt (2002) point to totally different principles, such as social context and cognitive processes. Even though there are discrepancies, these classification principles have become the guidelines for further classification of visualisation features. This study adopts Lakoff (1987)'s suggestion, emphasizing purposive, perceptual and functional principles. Motor-activity was excluded because the study focuses on visualisation perception only.

Several studies have produced different types of visualisation classification focusing on knowledge (Jonassen, 1991; Eppler and Burkhard, 2007; Cyras, 2009; Zhong and Zhang, 2009; Meyer, 2010). These existing classifications and distinctions are relevant, but may be limiting the potential of visualisation to specific perspectives. An example of the shortcomings of such perspectives is shown in research conducted by Zhou *et al.* (2011), who compare three classification methods. They claim that there is a cross-section of different perspectives in visualization focus. Eppler focuses on the visual method, Burkhard focuses on visual methods for specific knowledge types, and Jonassen focuses on assistance to promote cognitive understanding. However, in the absence of any empirical evidence, it is difficult to assess the validity and reliability of the claims.

Most authors use similar names to acknowledge the categories, such as heuristic sketches, conceptual diagrams, visual metaphors, knowledge maps and knowledge animations. However, there are additional categories that are not covered by most authors, such as semantic networks, concept maps, cognitive maps and thinking maps. These discrepancies point to the need for more research to define the features which constitute these categories.

Although extensive research has been carried out on visualisation, with the exception of Eppler (2006) work, which compares concept maps, mind maps, conceptual diagrams and visual metaphors, to the author's knowledge, no single study exists which adequately covers the features of each classification. The parameters used to distinguish these four classifications vary from functionality to graphic elements and application. Eppler (2006) study achieves its purpose in providing guidelines for the features through experimentation. However, the results are limited to the learning environment, and require further investigation about the effectiveness of the four visualisation formats.

Two years later, Eppler (2008) published a paper in which he used guidelines recommended by Lakoff (1987) to classify a knowledge map. The research conducted by Eppler (2008) is based on five types of question:

a) By intended purpose (why?)
b) By content (what?)
c) By application level (who?)
d) By graphic form (how?)
e) By creation method (how? / who?)

This is valuable in providing the features of a knowledge map specifically in graphic form. Eppler (2008) suggests that the graphic form be divided into four groups:

a) Table-based format
b) Diagrammatic format
c) Cartographic format
d) Metaphoric format.

He also proposes an example of a different application for each group, such as a Venn diagram and a Gantt chart. However, the author relies only on an example from an online knowledge map and does not provide adequate empirical evidence to validate the classification. Hence, a potential contribution could be derived from filling this research gap. The potential to validate Eppler (2006) classification empirically is therefore the main focus of this study.

In order to find valid evidence, the literature concerning the features of visualisation is reviewed. The first step is to compare visualisation classification for similarities and differences. Hence, a matrix of visualisation classification is shown in Table 2.1.

Table 2.1 A matrix of visualisation classification

	Burkhard et al. (2005)	Cyras (2009)	Eppler and Burkhard (2007)	Zhong and Zhang (2009)
Heuristic sketch				
Conceptual diagram				
Visual metaphor				
Knowledge map				
Structured text and tables				
Mental image/vision and stories				
Interactive visualisation				
Knowledge animations				
Domain structures				
Objects				

Literature on visualisation classification shows that three of the classification's formats (Heuristic sketch, Conceptual diagram and Knowledge Map) are commonly used by most authors (Burkhard *et al.*, 2005; Eppler and Burkhard, 2007; Cyras, 2009; Zhong and Zhang, 2009), and only a few authors use the other seven categories. Comparing these authors' classifications shows that their background study has a similar focus. Although their studies are based on various different domains, such as education, architecture and legal informatics, they all examine how visualisation plays a role in representing knowledge.

The classification of visualisation features remains inadequate, because there is little evidence of why and how these classifications have been formed. Features associated with each classification are essential to guide designers in choosing appropriate methods, but this has not been mentioned in previous studies. Therefore, the lack of empirical evidence to validate these classifications leads this thesis to provide a comprehensive classification of visualisation features. The thesis will contribute to conceptualising the features for these three classifications (heuristic sketch, conceptual diagram and knowledge map) that could assist users performing a specific task, and proposes guidelines for the development of visualisation across wider domains. The other seven categories are not included in this study, because validating conceptual features does not require all ten categories. Furthermore, some of the categories may overlap, for example, to what extent interactive visualisation and knowledge animation may differ. Only three common classifications are extensively discussed to prove the concept. The following section explains the three main categories, which are: heuristic sketch, conceptual diagram and knowledge map.

2.2.1.1 Heuristic sketch

'Heuristic sketch' is a term introduced by Eppler and Burkhard (2007) which is frequently used in knowledge management literature. The term has been commonly accepted by knowledge visualisation scholars, but to date there is no consensus as to the reason why it is different from 'normal sketch'. To explain the features of heuristic sketch requires a basic understanding about what constitutes the sketch.

Basically, the term 'sketch' is generally understood to mean rough drawings before an idea is precise. There are several definitions of sketch. For example, Pfister and Eppler (2012) define sketch as a "*tool of thought that enables the mind to capture things which are in flux and iteratively refine them*" (p. 373). Encyclopaedia Britannica (1998) offers a more in-depth explanation, that sketching can be considered as "*a rough drawing or painting in which an artist notes down his preliminary ideas for a work that will eventually be realized with greater precision and detail*" (p. 863).

Both definitions suggest that the sketch is the initial process of visualising an idea. This is supported by Tversky (2011), who emphasizes that sketches are usually used in the early phases of design. She points out sketches are appropriate at this stage because they are more "*tentative and vague than a diagram*" (p. 523). There is a particular process proposed by scholars such as Schon (1983) and Ware (2008). Schon (1983) identifies that designers normally follow this process: sketch, re-examine the sketch and revise. As explained by Ware (2008b), the process starts with the externalisation stage, which involves a scribbling down of the concepts or ideas. The next step is critiquing the sketches, based on the imaginary ideas. This stage is to evaluate whether the scribble is correctly represented. Finally there is the extension stage, which requires a modification of certain aspects, such as adding a new line. This all suggests that the sketch phase is a critical process for example artists, designers, and students.

A sketch can be identified through certain features. According to Tversky (2011), these frequently appear as glyphs, lines and blobs. Glyphs are a kind of symbol which consists of lines, dots, boxes and arrows, and is used to represent information. Similarly, lines consist of a series of dots to indicate that the entities are related. However, blobs are considered to be incomplete objects (Tversky and Suwa, 2009). Supported by Tversky *et al.* (2000), they identify that a sketch consists of stylized figures, lines, curves and blobs. Full or partial combinations of these features are able to represent the sketches in various formats, for example paper-based sketches or computer-aided sketching. Examples of glyphs, lines and blobs that are relevant as visualisation components are shown in Figure 2.1.

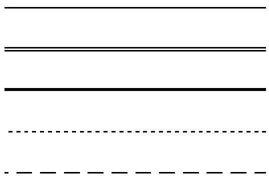
Glyphs (Visual Alphabet)	***Lines***	***Blobs***
 ***©Rapid E-Learning Blog***	 ***©MsWord***	 ***© Autodesk® Maya®***

Figure 2.1 The examples of glyphs, lines and blobs

Goel (1995) and Schon (1983) describe sketches as having no specific shapes, sizes or distance. An example of the sketch as a rough drawing is shown in Figure 2.2.

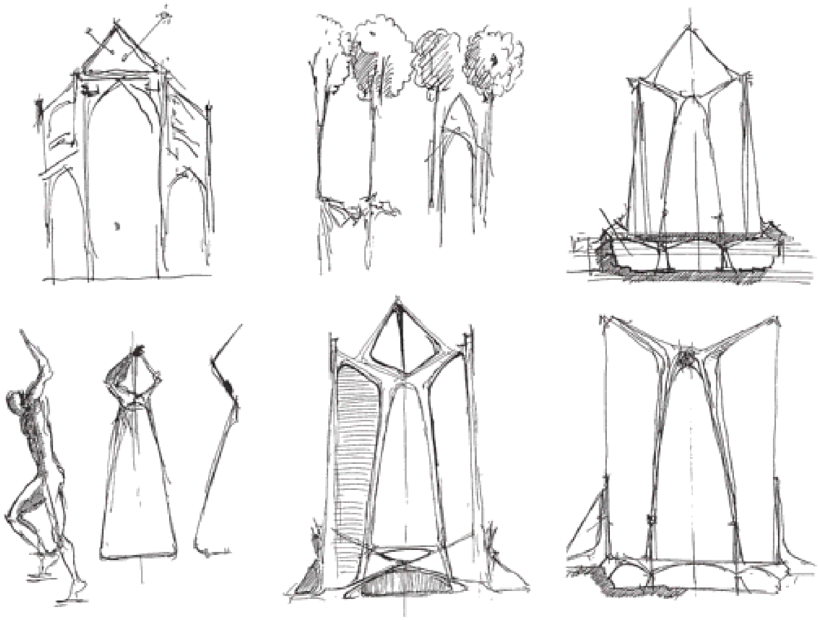


Figure 2.2 Samples of very basic sketching (Ware, 2008b)

Sketches often consist of depictive and symbolic elements. Tversky (2002) carried out a survey of sketch maps, and claims that depictive elements, such as boundaries and arrows, do not exist in reality. Symbolic elements refer to names, populations and distances. It seems that the nature of sketches influences the knowledge creation process. Pfister and Eppler (2012) reviewed the literature about the benefits of knowledge creation sketching for knowledge management, and found evidence for this claim. Because of its benefits, the sketch has become a vital element in many disciplines, such as engineering and architecture. For further understanding of such benefits, several roles of the sketch are reviewed.

The first role is that sketches facilitate in eliciting thoughts. Maryam *et al.* (2006) demonstrate in their study that sketching has an impact on organizing thoughts. They conducted an experiment to develop a new design and, with valid testing, the result shows unexpected ideas. Similar to Maryam *et al.* (2006) findings, several authors (Eppler and Pfister, 2011; Tversky, 2011) claim that sketches represent the designer's imagination. For example, they will initiate new ideas through various sketches, and make new inferences until the ideas are accepted. Thus, the sketch influences the designer to think beyond his or her normal imagination boundaries.

The second role of the sketch is ambiguous, and can lead to multiple meanings. Tversky et al. (2003) point out that ambiguity can stimulate creativity and generate more ideas. Supported by Majchrzak et al. (2000), they suggest that the sketch is suitable for ambiguous tasks that require multiple interpretations. Therefore, the ambiguity in sketches promotes innovation (Tversky and Suwa, 2009). For example, the drawings shown in Figure 2.3 are considered to be ambiguous sketches.

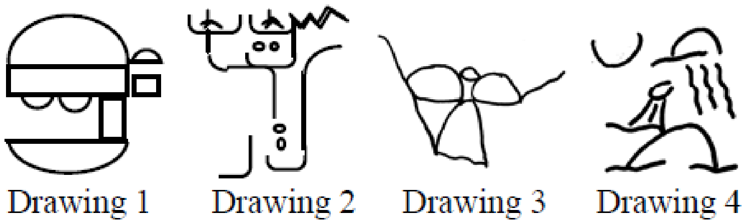


Figure 2.3 Ambiguous drawing (Tversky and Suwa, 2009)

Finally, there is evidence that sketches are related to communication, as demonstrated by (Eppler and Pfister, 2011; Wood *et al.*, 2012). Wood *et al.* (2012) claim that ideas of narrative and aesthetics depicted through sketch offers communication ability. Similarly, Eppler and Pfister (2011) state that sketches are able to improve communication by sharing ideas verbally and visually. Other authors (Lane and Seery, 2011) have examined the impact of sketches in teaching and learning through a series of experiments. Their findings show significant evidence that sketches act as a tool to communicate concepts and ideas. Hence, these studies reveal an opportunity to focus on the quality of communication, rather than the existence of communication.

One question that needs to be asked regarding all of the above, is whether the use of heuristics terms in knowledge management literature best represents the original concepts. Furthermore, the reason why it is called ‘heuristics sketch’ is reviewed for further understanding. To begin with, it is necessary to clarify exactly what is meant by the term ‘heuristic’.

The term ‘heuristics’ is referred to by Gigerenzer and Gaissmaier (2011) as “*a strategy that ignores part of the information, with the goal of making decisions more quickly, frugally, and/or accurately than more complex methods*” (p. 454). A concise definition of heuristic is: “ *a program, rule, piece of knowledge, which one is not entirely confident will be useful in providing a practical solution, but which one has reason to believe will be useful, and which is added to a problem-solving system in expectation that on average the performance will improve*” (Romanyci and Pelletier, 1985, p. 57). This definition highlights the element of problem-solving capability. Heuristics highlight different ways to find new insights into problems. For a comprehensive understanding about these arguments, several examples in various disciplines are given.

In knowledge management, the concept of heuristic sketch is claimed to have a different focus from other disciplines. Eppler and Burkhard (2006) claim that the term ‘heuristic sketch’ is far more suitable to support reasoning which helps to identify potential solutions. However, the relationship between problem-solving and heuristics has been widely investigated in other disciplines (Chamizo, 2011; Gigerenzer and Gaissmaier, 2011). For instance, Chamizo (2011) demonstrates the use of heuristic diagram as a tool in teaching. The approach here is to embed the problem-solving activities in the heuristic diagram. Gigerenzer and Gaissmaier (2011) discuss the challenges and strategies for promoting heuristic concepts in psychology. They state that heuristics are “*embodied and situated in the sense that they exploit capacities of the brain and their success depends on the structure of the environment*” (p. 474). For example, heuristics offer an option to explain complex human behaviour, such as personalities, preferences and attitudes.

Such explanations and reasons given by Eppler and Burkhard (2007) of the use of heuristics in reference to sketch require further justification. The authors offer no explanation for the distinction between heuristic sketch and normal sketch.

As part of the input to these studies, there are a few features that can be used to define heuristic sketch. These items will used in the framework to recognize the nature of sketch with heuristic criteria. The items are:

a) Depictive elements (boundaries and arrows)
b) Symbolic elements (names, populations and distances)
c) Do not exist in reality
d) No specific shapes, sizes or distance
e) Incomplete objects
f) Represented by glyphs, lines and blobs

2.2.1.2 Conceptual diagram

One of the most widely used formats in visualisation is a conceptual diagram. Managers use a conceptual diagram in creating a business flow chart, educators teach students a statistics chart and designers shows the process in a system architecture diagram. These examples are using part of a conceptual diagram application for completing a task. Conceptual diagram generally refers to a form of concept that is represented in a visual form. A comprehensive definition proposed by Eppler (2006) is that a conceptual diagram is "*a systematic depiction of an abstract concept in pre-defined category boxes with specified relationships, typically based on a theory or model*" (p. 203). This is similar to the definition given by Paradies and Stevens (2005), of "*a diagram of proposed relationships among a set of concepts, factors or variables about a particular hypothesis, question, context, problem or topic*" (p. 1012). Garland (1979) defines a diagram as a visual language sign to represent functions and relations. Zhong and Zhang (2009) refer to conceptual diagrams as "*the outline descriptions of abstract point of standardized shapes used to represent the relationship of information*" (p. 716). These definitions show the important criteria in the conceptual diagram, which are entities and relationships of entities/concepts. However, the challenge is to determine what constitutes a diagram. Identifying the features of the conceptual diagram will contribute to achieving clarification.

A conceptual diagram can be identified through several features relating to its physical features and its data formats. It is evident that a conceptual diagram will have specific physical features. A number of studies have found that conceptual diagrams consist of shapes (pyramids, matrices or boxes), lines, dots, items, or arrows (Eppler, 2006; Zhong and Zhang, 2009). According to Tax (2012), it is essential to understand the visual properties, known as aesthetic perspectives, in diagrams. Examples of visual properties are symmetry and the number of lines crossing in a diagram (Tax, 2012). An illustration of the most commonly used diagrams in business is shown by Eppler and Burkhard (2007) in Figure 2.4.

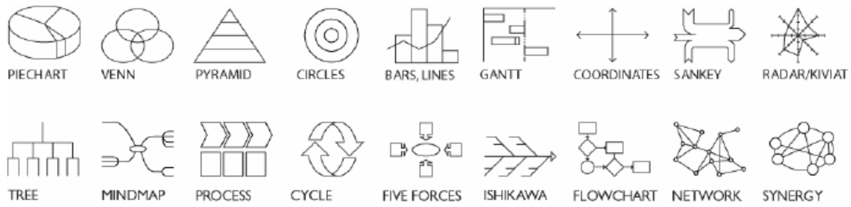


Figure 2.4 A sample of diagrams commonly used in business (Eppler and Burkhard, 2007)

Another feature is the data type. Eppler (2006) indicates that the data in a conceptual diagram is analytical and the format is systematic. The analytical data is structured into systematic building blocks, such as labelled boxes with embedded text. Labelled boxes are also known as entities and embedded text represents their relationship (Tax, 2012). Thus, based on the explanation of several features of the conceptual diagram, it is essential to review the literature concerning its usefulness.

There are several benefits of the conceptual diagram, which is acknowledged to be an appropriate tool for making abstract concepts accessible (Meyer, 2010). Similarly, according to Aktamıs (2012), it is sometimes difficult to make abstract concepts in science education comprehensible. He conducted a study with the use of an alternative teaching model known as a FAR guide (Focus, Action and Reflection) to teach an *Energy* chapter in *Physics*. His findings concluded that students were able to configure such an abstract concept in their minds with the assistance of this model. Hence, it is proven that the use of conceptual diagrams helps to minimize the complexity of abstract concepts.

Several studies also indicate that conceptual diagrams can be used to organize information (Eppler, 2006; Meyer, 2010). Eppler (2006) provides an explanation of how structured information is able to give a concise overview of every aspect of a concept. For example, processes or relationships can be illustrated through graphs in bars or line format to represent the level of data performance.

It is clear that diagrams can fulfil communication needs. Garland (1979) suggests that diagrams can be used to communicate between the object and the recipient. Furthermore, Burkhard (2004) explains that diagram helps in the transfer of knowledge. However, several studies (Perini, 2005a; Dix, 2011) have raised concerns about misleading information in representations that may convey an incorrect message.

There are a few features that can be used to define the conceptual diagram. The following four items will be used in a framework to recognize the conceptual diagram:

a) Recognizable through pre-defined shapes (pyramids, matrices or boxes), lines, dots, items, arrows
b) Consists of analytical data – labelled boxes with embedded text known as entities and relationships
c) Minimizes the complexity of the abstract concepts
d) A concise overview through structured information.

2.2.1.3 Knowledge maps

Recent developments in knowledge maps have amplified the need for structured visualisation. Hence, a considerable amount of literature has been published on the knowledge map (Wexler, 2001; Renukappa and Egbu, 2004; Eppler, 2008; Cavalic and Ilguen, 2012).

Most literature establishes its own definitions of knowledge maps. For instance, Davenport and Prusak (1998, p. 72) state that "*a knowledge map whether it is an actual map, knowledge yellow pages or a cleverly constructed database points to knowledge but does not contain it. It is a guide not a repository*". However, Wexler (2001) considers the knowledge map as "*one feasible method of coordinating, simplifying, highlighting and navigating through complex silos of information*" (p. 249). Other definitions are "*graphic formats that follow cartographic conventions to reference relevant knowledge*" (Eppler and Burkhard, 2004, p. 17) and "*a navigation aid to explicit and tacit knowledge, illustrating how sustainability knowledge flows within and across organisations*" (Renukappa and Egbu, 2004, p. 908). The most practical definition, however, is "*a diagrammatic representation of corporate knowledge, having nodes as knowledge and links as the relationships between knowledge, and knowledge specification or profile*" (Kim *et al.*, 2003, p. 36). Thus, based on these definitions, there are various application of knowledge map which need to be explored.

Practically knowledge map consists of two layers (Eppler and Burkhard, 2004). The first layer is called the ground layer and is used for context mapping, whereas the second layer consists of individual elements that are mapped within the context. The example in Figure 2.5 shows the knowledge map divided into layers (Kim *et al.*, 2003). This figure depicts a conceptual model of a knowledge map which consists of two components:

a) Diagram which is comprised of nodes and linkage to represent the knowledge
b) Specification which provides a description of the knowledge.

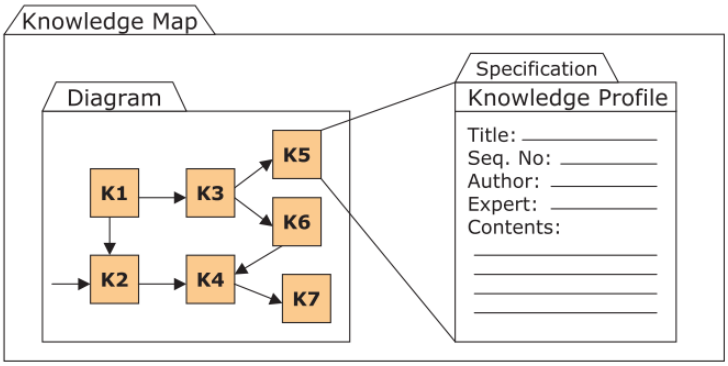


Figure 2.5 An example of a knowledge map

These features reduce the complexity of information to be displayed. Moreover, the simplicity elements can amplify human cognition to process only relevant information. To illustrate the importance of the knowledge map, the implementation takes place in healthcare, business and education (Wexler, 2001).

For example, in education, scholars (Mohd *et al.*, 2010) adopt knowledge map principles when designing a system. The system focuses on three layers, consisting of general information down to the specific. Since the illustration of the system is well-structured, it will ease the process of understanding the flow to retrieve information. The system is developed to enable users to access selected information, based on their preferences. Figure 2.6 shows the dashboard system, adapting a knowledge map concept.

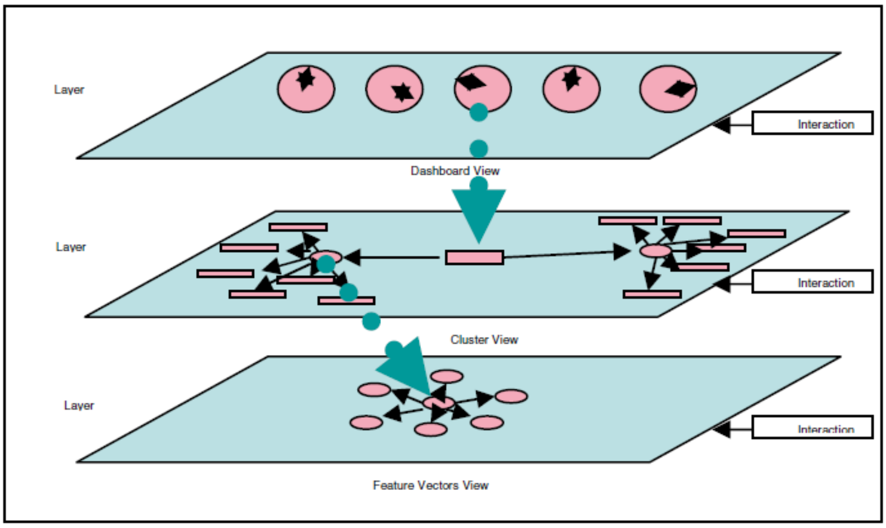
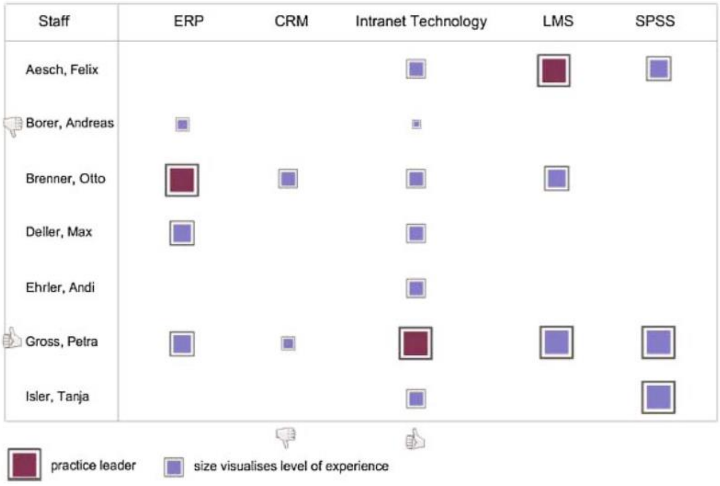


Figure 2.6 A framework of a dashboard system using knowledge map concepts (Mohd *et al.*, 2010)

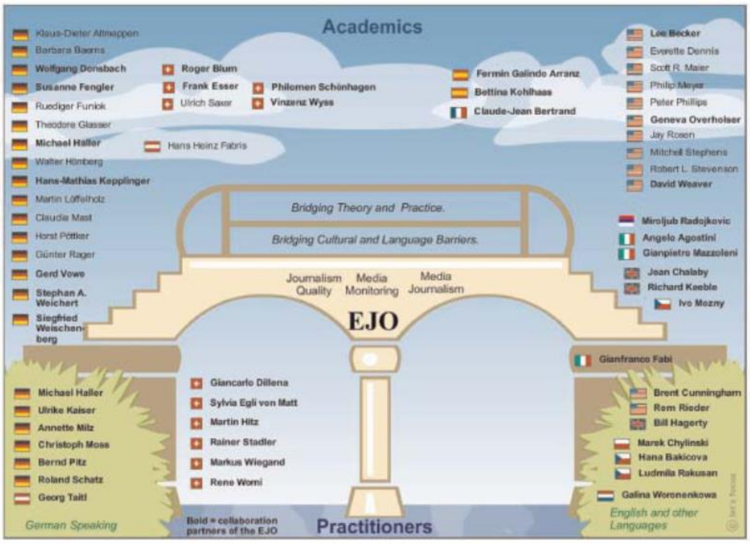
Other function of knowledge map is to capture business knowledge, particularly practical knowledge, or ‘know-how’, for example the skill to do things, or expertise in making decisions (Yusoff *et al.*, 2011). A knowledge map acts as a directory of sources (Eppler and Burkhard, 2007) to understand the relationships and dynamics between knowledge stores (Renukappa and Egbu, 2004). This view is supported by Meyer (2010) and highlights the capability of the knowledge map to give relationships between entities.

The fundamental features of knowledge maps are table format, metaphoric format, cartographic format and diagrammatic format (Eppler, 2008), as shown in Figure 2.7. It is known that these four forms are the most widely used in organisations. Examples of metaphoric format are the natural world (tree, iceberg, mountain) or man-made artefacts (house, bridge), whereas cartographic format is illustrated by various techniques, such as geographic map and informational map (Cavalic and Ilguen, 2012). Diagrammatic form is divided into two formats, such as structure (examples being the Venn diagram, matrix and mind map) and process diagrams (examples being timelines and flow charts) (Cavalic and Ilguen, 2012). A combination of these forms of graphic elements has given distinction to what constitutes the knowledge map.

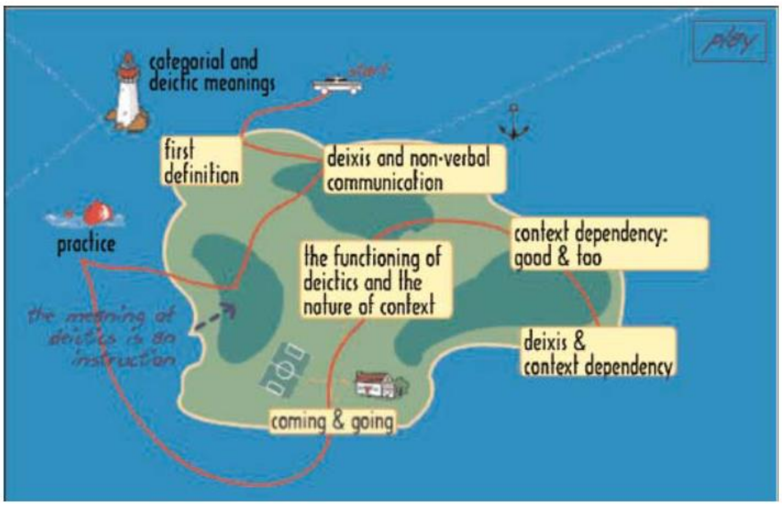
Table format



Metaphoric



Cartographic



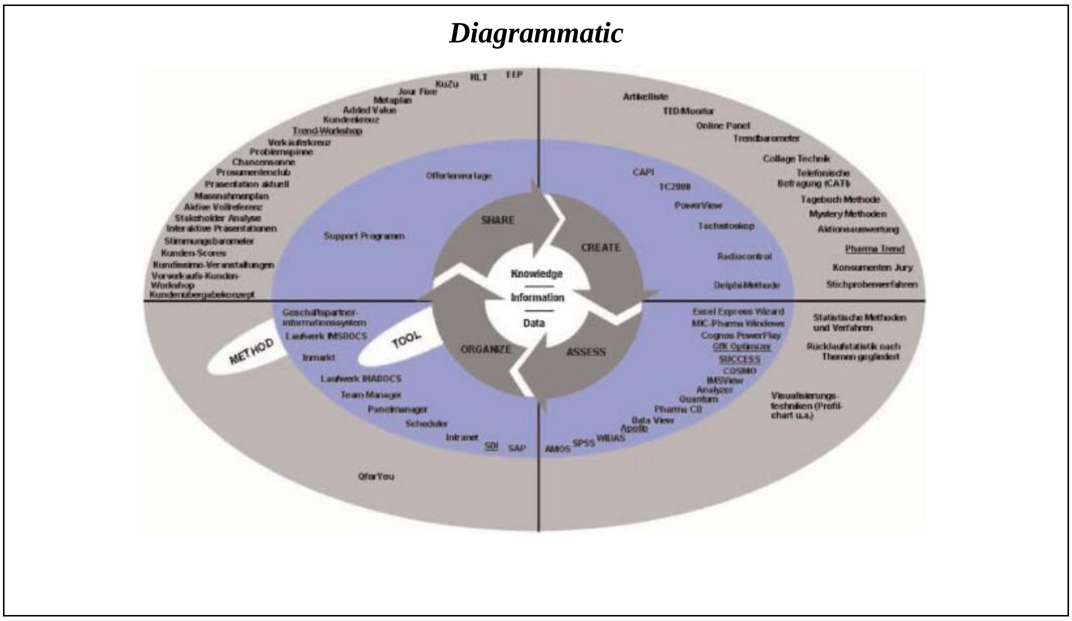


Figure 2.7 Example of Knowledge Maps (Eppler, 2008)

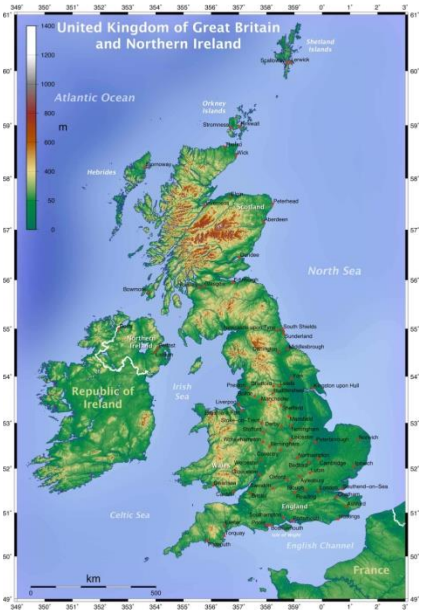
Among the four formats of knowledge maps, cartographic conventions have been widely used to visualise pertinent knowledge (Burkhard, 2005). Pertinent knowledge, referring to conceptual, competency and procedural knowledge (Handzic, 2005) is much demanded from users and mapmakers in emerging technology. However, procedural knowledge is mostly reflected, because maps act as navigational aids that represent relations between objects (Slater, 2009). For example, navigational knowledge, such as locating a place, becomes feasible for users when technology, such as GPS, supports the real time application. These new tools were designed based on their understanding of the domain of cartography.

Cartography, or the study of maps, refers to the rules that need to be applied to make it universally understandable. Labels, title, scale, legend and coordinates are all examples of those rules (Robinson *et al.*, 1995). Although it is not necessary to apply every single rule, they are mostly adaptable to any context and depend on the purpose of cartographic conventions. For example, symbols are used to simplify a complicated concept, and are further explained through legends. Most cartographic conventions prefer to use universal symbols to avoid confusion. As explained by Lobben (2015), users do not have to refer to legends if the symbols used adopt a universal colour, such as blue to represent water.

In comparing cartographic conventions with the actual cartographic map, there are some differences in terms of visualisation. First, the actual cartographic map prioritizes a rigid standard to have such a scale systematically designed. By comparison, a cartographic convention has an additional aesthetic value which evolved practically from current trends.

The current trend, which is pragmatic, is adapted to enhance the visualisation. For example, the trend in drawings includes additional shades of colour to represent the density of population in certain areas. Second, Lobben (2015) stated that the differences between an actual cartographic map and cartographic conventions is semantic. Semantics is concerned with meaning, and maps can lead to a subjective interpretation, because humans perceive things differently. These two differences offer an important input for designers to avoid any dramatic changes in cartographic conventions. To avoid any difficulty in interpreting a cartographic map with an aesthetic value, the basic rules of cartography are essential. A map with aesthetic value has become more acceptable, without ignoring the meaning and purpose of cartography. Examples of an actual cartographic map (known as topographic) and a cartographic conventions map (known as thematic) are shown in Figure 2.8.

Topographic Map of UK
(Maps, n.d)



Thematic : The Guardian-UK Election Results Map(Neckles, 2010)

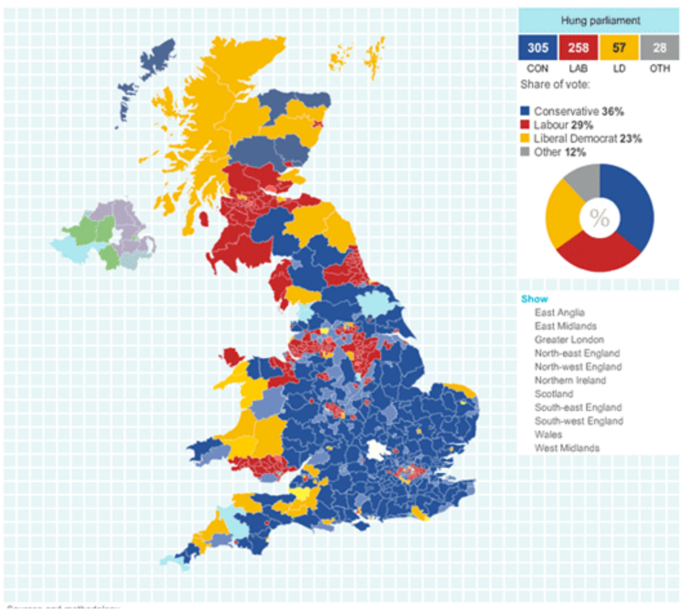


Figure 2.8 Samples of Topographic and Thematic Map

Evaluation of map design for navigation using established cartographic practice is a challenge. However, generally maps, both topographic or thematic, should follow principles such as neatness, labels, title, scale, north arrow, legend, coordinate system, map frame or border and map projection (Robinson *et al.*, 1995; Wilson, 2007; Slater, 2009; Freelan, 2015; Lobben, 2015). The details of the common principles are explained in Table 2.2.

Table 2.2 Descriptions of each principle

Design Principles	Descriptions
Neatness	Pleasing to the eye, readable, balanced
Labels	Correctly labelled, consistent
Title	A clear indication about the purpose of the map
Scale	Connect the map reader to the real world
North arrow	True north, magnetic north and declination north
Legend	Simplicity, colours and symbols
Coordinate system	Longitude and latitude
Map frame/border	All information must be contained within a frame
Map projection	Size, shape or conformality

While focusing on design principles that are crucial for maps, their functionality for audiences in maximising the positive benefits is essential too. Scholars (Pfister and Eppler, 2012; Borkin *et al.*, 2013) have been interested in identifying methods that could make visualisation memorable. Their results showed that familiarity helped to reduce cognitive load and to understand knowledge. However, their studies excluded user engagement when using a static visualisation. These topics will be discussed further in Section 2.4.

To conclude, there are certain features that can be used to define a knowledge map. The following six items will be used as a framework to recognize the knowledge diagram:

a) A guide, rather than a repository, that points to knowledge
b) Acts as knowledge navigation aid
c) Structured in table format
d) Represented by metaphoric format
e) Illustrated by cartographic format, either informational or geographical
f) A diagrammatic form of structure or process.

2.2.2 Prior studies in Visualisation

Visualisation has been discussed widely in previous studies, so the focus of this study is within the scope of knowledge visualisation literature. There is some inconsistency concerning visualisation amongst disciplines that are prominent and highly relevant to knowledge visualisation. For example, Eppler and Burkhard (2004) claim that knowledge visualisation emerges from visual cognition and perception, visual communication, and information visualisation. However, Zhou *et al.* (2011) point out that scientific computing visualisation, data visualisation and information visualisation provide the basis for knowledge visualisation. These claims appear to be inconsistent, and require further justification to validate them. Narrowing down the list of scholars concerned with knowledge visualisation can allow a brief explanation of the related disciplines. Evidence relating to knowledge visualisation is clearly being assessed, as shown in Figure 2.9. Eppler and Milani (n.d) have simplified the list of scholars focusing on four interrelated concepts of visualisation: (1) knowledge visualisation; (2) information visualisation; (3) software visualisation; and (4) perception, design and visual communication.

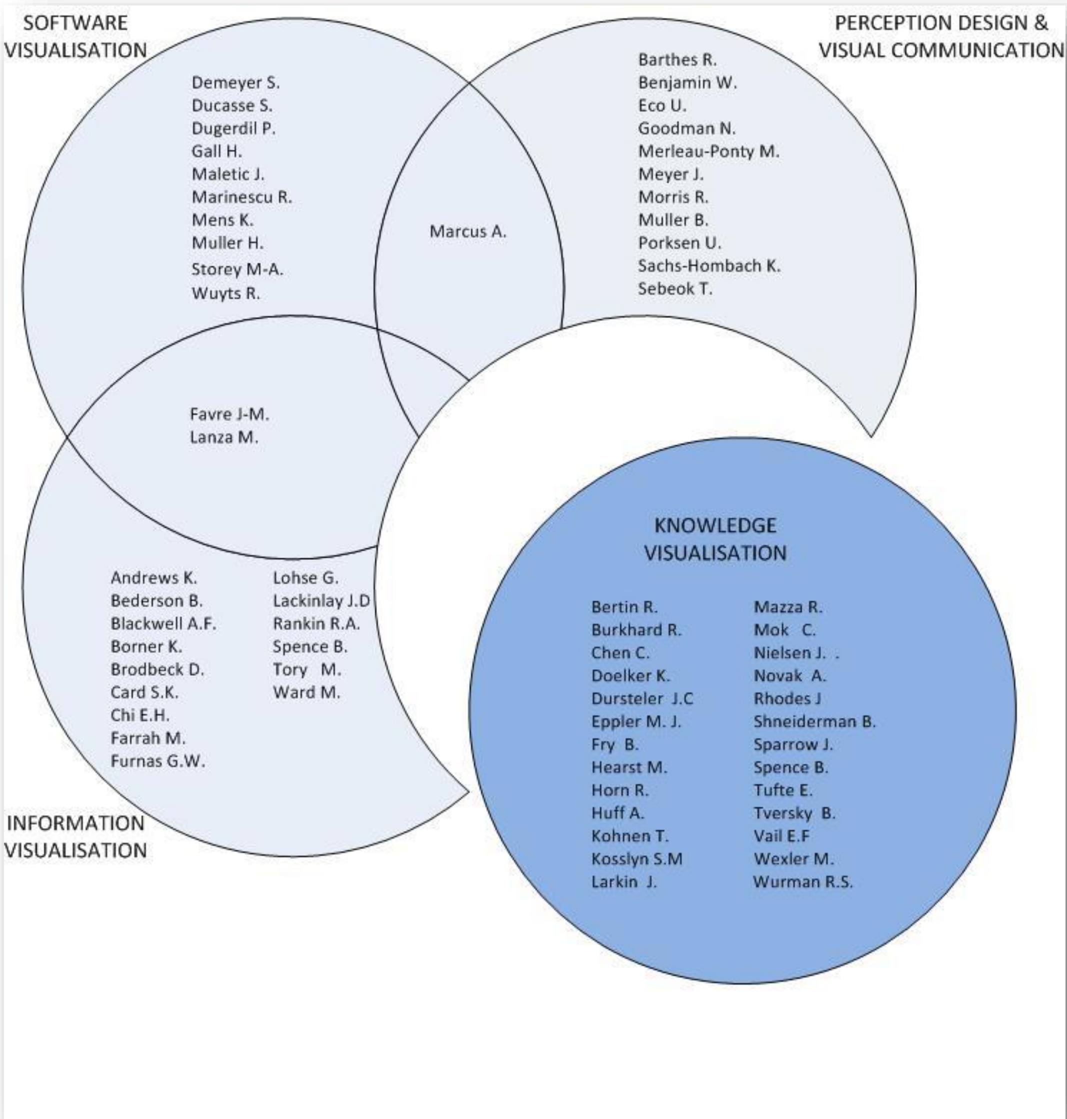


Figure 2.9 A list of scholars concerned with visualisation (Eppler and Milani, n.d)

The list of studies conducted by visualisation scholars is summarized in Table 2.3.

Table 2.3 Summary of related studies of visualisation

Authors	**Purpose**	**Key Findings or claims**
Eppler (2011)	Reviews the seminal concepts from different disciplines that help to explain how visualisations can effectively act as collaboration catalysts and knowledge integrators	The five principles (visual variety, unfreezing, discovery, playfulness and guidance) of seminal concepts can be used to assess or improve knowledge visualization templates used in knowledge sharing tasks of teams
Hearst (2009)	Explores the potential of information visualisation for text analysis from analytical points of view	There is evidence of visualising the text for various purposes such as text mining, word frequencies and citation relationships
Mazza (2009)	Focuses on the human aspects of the visualisation process	Provides a reference model for interactive visual representation, consisting of data transformations, visual mapping and view creation
Borst and Kosslyn (2008)	Examines the information representation similarities between visual mental imagery and visual perception conditions	The results prove that mental images and perceived stimuli are represented similarly and can be processed in the same way
Fry (2008)	Demonstrates various methods of representing data accurately on programming application	By using prototyping tools called 'Processing', the user is able to design interfaces of complex data sets.
Dursteler (2007)	Seeks the definition of information visualisation from various perspectives	The process of information visualisation requires two fundamental elements, which are information architecture and information design, in producing the mental image
Nielsen (2006)	Examines the user viewing behaviours on the web	Results show users' tendency to read in an "F" pattern. In addition, information presented in bulleted lists is the main focus while reading

Burkhard (2005)	Presents synergies between information visualisation and knowledge visualisation	Differ in regards to goals, means, background and roots
Chen (2005)	Identifies the problems in information visualisation	The major information visualisation problems including user-centred perspectives, technical challenges and various issues at disciplinary levels
Tversky (2005)	Explores the potential of images in expressing and promoting thought	People tend to use internal and external mental representation to facilitate judgement
Novak *et al.* (2004)	A model of personalized learning knowledge maps is presented as one possible way of addressing the problem of capturing, visualizing and sharing implicit knowledge of community users	Personalised knowledge learning map (document map and concept map)
Kohonen (2001)	Proposes a Self-Organizing Map (SOM) for data visualisation techniques	SOM algorithm facilitates the high dimensional data by reducing dimensions and displaying similarities
Wexler (2001)	Examines the knowledge mapping process and potential benefits of effective mapping	Effective knowledge mapping involves who, what and why of the knowledge mapping process
Spence (2000)	Provides an overview of information visualisation emphasis on computer applications	Explains the techniques of presenting information, increasing the usability and efficiency of computer systems
Vail (1999)	Investigates the possibilities of mapping the organisational knowledge	Outlines a process for a knowledge mapping project with different purposes
Horn (1998)	Focuses on the concepts of visual language; the integration of words and visual elements	Becomes a practical guide for the applications of visual language
Sparrow (1998)	Attempts to explain the importance of making knowledge visible, better accessed, valued or managed	Acknowledges the use of knowledge maps as cognitive tools to provide a view of knowledge

Doelker (1997)	Classifies different functions of images	These functions are "*registrative, mimetic, simulative, explicative, diegetic, appellative, decorative, phatic, ontic or energetic*"
Tufte (1997)	Explains the theory and practice in the design of data graphics.	Provides a practical application and examples, including statistical graphics, technical manuals, animations and scientific visualisations
Mok (1996)	Explores the website design environment purposely to give the users an ability to control the development process	Proposes method of DADI: Definition, Architecture, Design, Implementation to guide the interactive multimedia product development
Shneiderman (1996)	Proposes a guideline for designing advanced graphical user interfaces	Presents a task by data type taxonomy: overview first, zoom in and filter, then show details on demand
Rhodes (1994)	Describes the fundamental thinking activities and tools that can be applied in management	Introduces mapping, quality assurance thinking and conceptual learning and suggests that the future of organization belongs to conceptual manager
Huff (1990)	Focuses on the concept of cognitive mapping, its construct and techniques	Compilation of five methods to map cognitive structures
Wurman (1989)	Defines the concepts of information anxiety of too much information	Factors contributing towards information anxiety are misunderstanding information, information overload, knowing information exists, finding information and accessing information
Larkin and Simon (1987)	Explores the potential benefits of diagrammatic compared with sentential representation	Human familiarity with particular representation is important for the recognition process
Bertin (1967)	Provides guidelines for designing visual aids by considering human perceptions	Proposes reducing human cognitive processes by labelling each element in the graph directly

With reference to Table 2.2, these studies show the evolution and significant transition of knowledge visualisation. The transition of research interest reveals several lenses in past research which can guide further understanding of knowledge visualisation concepts. These lenses are discussed under four headings: human cognition, technology intervention, data and information, and evaluating visualisation behaviour. This study articulates these four lenses which can be used as a basis to evaluate visualisation methods. The four lenses are derived by analysing their purpose and key findings, as shown in Table 2.3.

2.2.2.1 Human cognition in visualisation (1967-1994)

Early work on knowledge visualisation is considered by many authors, such as Bertin (1967), Larkin and Simon (1987), Wurman (1989), Huff (1990) and Rhodes (1994). This research involves describing and quantifying human cognition towards visual representation. How visual representation can affect human thinking and learning was considered an interesting research topic in former years. For example, previous studies report that the human brain has the ability to process visuals better than words (Koffka, 1935; Miller, 1956; Kosslyn, 1980; Shepard and Cooper, 1982). Several attempts have been made by these scholars to compare human performance in remembering visual elements and identifying patterns. Based on their experiments, results show an active response from the human brain towards visual representation. In addition, Sweller and Chandler (1994) demonstrate how cognitive load can be reduced by visualizing abstract knowledge. The results of their analysis show that visual representation is easily recognized and memorable. However, these results could be biased towards those who prefer image to text.

Despite this, studies are gradually evolving with the assimilation of technology, which enables research to explore many technology-enabled features.

2.2.2.2 Technology intervention in visualisation (1996-1997)

Most studies in the field of visualisation during the past two years focus on graphical user interface (GUI) and human computer interaction (HCI), e.g. Shneiderman (1996), Mok (1996), Tufte (1997) and Doelker (1997). Their concern is the exploration of methods to apply in computer application. A lot of applications have been created to support the development of visualisation which encourages human interaction, known as Human Computer Interaction (HCI). HCI's motivation is towards increasing the effective interaction between human being and computer. The purpose of visual computing is to allow scientists to interact with data during its processing. This interaction, such as manipulating of visual representation, could encourage the exploration of the unknown and allows for such probability. The immediate effects of these changes are beneficial and provide interesting findings for the researcher.

Scholars have also proposed several means and methods to enable the development of graphic visualisation. Several applications have been developed to support graphic visualisation, which is widely used in many disciplines, such as natural sciences, geography, meteorology, applied sciences and engineering (Henderson, 1999; Haase *et al.*, 2000; Perini, 2005b; Goodwin, 2009; Afzal and Maurer, 2011; Comi and Eppler, 2011; El-Sadi and Roberts, 2012). Examples are the prediction of tsunamis and warnings of earthquakes. However, the exploration of applying visual representation may require further development and enhancement. Hence new technologies, with fully interactive features, are now contributing to the transformation of visualisation to allow it to become viable. The need for visualisation has increasingly demanded advanced applications such as 3D and virtual reality applications. Another example of technology intervention in visualisation is in product design. The support of computer software to create a 3D model, such as computer-aided design (CAD), has replaced the manual process in product design. The process of sketching and prototyping is normally time-consuming and involves having to deal with many constraints. The initial process has to be accurate and executable; otherwise it incurs high costs to reproduce the same product. Through visualisation, the product can be visualized and manipulated before production. Hence, the chances of minimizing any product faults are higher than in manual processes.

To conclude, all the examples show that technology intervention has been widely applied. In subsequent years, visualisation research has focused more on data and information lenses.

2.2.2.3 Data and information visualisation lenses (1998-2005)

It is essential to the practice that the content of visualisation is far more important than the visualisation technology itself. The aim to understand, facilitate and present data, information and knowledge have become the central focus. Authors such as Sparrow (1998), Horn (1998), Vail (1999), Spence (2000), Wexler (2001), Kohonen (2001), Novak *et al.* (2004), Tversky (2005), Chen (2005) and Burkhard (2005) explain the techniques, processes, synergies and problems of data, information and knowledge representation. These three elements are often regarded as a hierarchy, in which knowledge is derived from information and information is derived from data. Arguments tend to relate to what extent the concepts of data visualisation and knowledge visualisation are different from information visualisation (Burkhard, 2005; Zhou *et al.*, 2011). To avoid confusion, definitions of these three visualisations are essential. According to Alavi and Leidner (2001, p. 111), *"data is facts and raw numbers, information is processed or interpreted data and the knowledge is personalized information".* An established concept such as information visualisation is referred to as "*the use of computer-supported, interactive, visual representations of abstract data to amplify cognition*" (Card *et al.*, 1999, p. 7). In similar vein, Vande Moere *et al.* (2012) define information visualisation as "*exploiting the cognitive capabilities of human visual perception in order to convey meaningful patterns and trends hidden in abstract datasets"* (p. 2739). These two definitions show that the most important elements in visualisation are 'human' and 'data'. It is generally understood that information visualisation aims to foster the human cognitive ability to identify and recognize similar image characteristics. A further comparison of data, information and knowledge is shown in Table 2.3.

Table 2.4 Comparison of data visualisation, information visualisation and knowledge visualisation (Zhou *et al.*, 2011, p. 6236)

	Data Visualisation	**Information Visualisation**	**Knowledge Visualisation**
Visualisation objects	Spatial data	Non-spatial data	Human knowledge
Visualisation purpose	Representation of abstract data in intuitive way	Find new information from abstract data	Promote dissemination and innovation of group knowledge
Visualisation ways	Computer graphics, image	Computer graphics, image	Drawing sketches, knowledge chart, visual metaphors
Interactive types	Human-machine interaction	Human-machine interaction	Human-human interaction

Table 2.4 shows four parameters to distinguish data, information and knowledge visualisation. These are: objects, purpose, ways and types. The visualisation objects focus on spatial (e.g. geometric) or non-spatial data and human knowledge (e.g. insights). For visualisation purposes, data visualisation assists the viewer to see what the data is, information visualisation shows the contextual meaning of information and knowledge visualisation shows the implications of knowledge for action. These three visualisations may use a computerized format or traditional drawings to represent the content. The representation of content often requires interaction with either human or machine.

Informatic studies mostly attempt to demonstrate that visualisation is beneficial to understand large volumes of data. With the use of the database as storage, it requires a significant formula to extract the meaning of the data, Keller and Tergan (2005). The visualisation process can simplify the process of categorising, summarizing and detecting the pattern of data. This method can assist humans to make judgements by providing accurate predictions. Such interpretation, based on data or facts, will show little human interference, but it might be useful for a human to be able impart their own meaning to illustrate their way of thinking. This could create a far more advanced opportunity for understanding. This view is supported by Barat (2007), who believes that visual representation is a reflection of the human mind, rather than a representation of real objects.

Since the need for the development of automation for large data processing systems is increasing, scholars have begun to develop algorithms to visualise a meaningful interpretation of data. This is highlighted by Tufte (1997), often regarded as the father of information visualisation, concerning the use of visualisation in aeronautics, engineering and medicine. Examples of well established information visualisation applications are: Tree Maps (Johnson and Shneiderman, 1991; Shneiderman, 1992), Cone Trees (Robertson *et al.*, 1991), Table Lenses (Rao and Card, 1994) and Hyperbolic 3D (Munzner, 1998). This application allows users to explore a large amount of abstract data which supports an immediate response.

To conclude, the concept of data and information visualisation is the foundation of knowledge visualisation. Information visualisation focuses on the use of computer-supported tools to transfer of facts, whereas knowledge visualisation aims to further transfer user's insights and experiences. Hence, the recent focus on knowledge visualisation is related to evaluation behaviour of visualisation.

2.2.2.4 Evaluation behaviour of visualisation (2006-2011)

Early visualisation research was largely concerned with human cognition, technology, data and information. However, the focus of later studies has been more towards evaluating visualisation behaviour. Several studies investigating visualisation behaviour have been conducted by Nielsen (2006), Dursteler (2007), Fry (2008), Borst and Kosslyn (2008), Mazza (2009), Hearst (2009) and Eppler (2011). They focus on elements such as visualisation structure, functionality, effectiveness, accuracy and processing abilities.

Visualisation structure is related to the resemblance of the representation. As stated by Borst and Kosslyn (2008), the results prove that visualisation can be processed in the same way, if mental images and perceived stimuli are similarly represented.

Authors such as Hearst (2009) and Mazza (2009) focus on the functionality of visualisation, Hearst (2009) claiming that it can be used for textual data. For instance, visualisation for text mining is represented in a Word Tree. A word tree shows a relationship in the form of words linked to phrases. Another example is visualising text mentioned most frequently by users in the form of a graph. Similarly, Mazza (2009) provides evidence of how visualisation can be used effectively for data transformation, mapping and creation.

On the other hand, Eppler (2011) is more interested in measuring the effectiveness of visualisation. He suggests that the following five principles can be used: visual variety, unfreezing, discovery, playfulness and guidance. He provides evidence by conducting an experiment involving team knowledge-sharing tasks. Prior to this study, Fry (2008) claimed that visualisation should be measured by accuracy of representation. Fry (2008) demonstrates various methods of representing data accurately in programming applications and creates a tool to allow users to design interfaces of complex data sets.

Finally, the functionality of visualisation can be measured by its processing ability. The processing ability of visualisation is based on the user's reading pattern. According to Nielsen (2006), users have a tendency to read in an "F" pattern. Most users read horizontally for the first few lines and continue by reading vertically after this. In addition, users tend to focus on bulleted lists when reading information on a website.

To conclude, these four lenses show assimilation from different disciplines. The research conducted is influenced by human cognition, technology intervention, data and information visualisation, and evaluation behaviour. These arguments are similar to the claim proposed by Eppler and Burkhard (2004) and Zhou *et al.* (2011) about the origins of knowledge visualisation. The four lenses can be used as a basis to explore theories and literatures related to evaluation. The following section will review the challenges and different types of visualisation evaluation. The interest emerges from the evaluation behaviour lenses that led this thesis to further identify the importance of evaluation in visualisation research.

2.3 Visualisation evaluation

The current debate about visualisation evaluations has received much attention in the literature. The purpose of evaluation is to identify to what extent visualisation is useful in supporting a task and to elicit factors from a user's perception focusing on requirements and needs. To evaluate the user experience, it is necessary to clarify what is meant by '*useful*'. The term 'useful' can be said to refer to "*a situation when the user can actually achieve the task objectives supported by the specific items*"(Smith-Atakan, 2006, p. 8).

Evaluating users' experience could elicit a subjective opinion on visualisation. It is more personal, because users will provide their perceptions related to a specific visualisation problem. It is important to conduct this study because the empirical evidence could help designers to uncover gaps in visualisation perception. It should contribute to strengthening the development of visualisation in the future.

The challenges arise due to the complexity and diversity of visualisation related to various degrees of perception and evaluation factors. Firstly, research conducted on visualisation may use inappropriate experiments to evaluate it (Ellis and Dix, 2006; Bresciani and Eppler, 2010). For example, evaluating visualisation in the form of generative artefacts (Ellis and Dix, 2006) can generate results, but these may not prove their usability. There is considered to be a lack of empirical evidence in this area, which therefore needs more thorough evaluation.

Secondly, the uncertainty of the type of evaluation, being either summative or formative, is in dispute. Summative evaluation refers to evaluation based on end results, whereas formative evaluation refers to evaluation at every phase of design development (Forsell, 2014). Ellis and Dix (2006) suggest that explorative evaluation is able to provide a more in-depth method of evaluation. An in-depth evaluation can be used to test qualitative and quantitative data (Santos, 2005).

Therefore, challenges that need to be addressed relate to evaluation factors. Visualisation is currently measured according to those who intend to convey any type of message through visual formats. Such measures may therefore lead to a certain degree of bias, without giving appropriate or correct messages (Klein, 1994; Eppler and Burkhard, 2007; Steiger and Steiger, 2007; Cyras, 2009; Zhong and Zhang, 2009). For instance, the arguments relating to the visualisation evaluation mainly focus on its ability to convey thoughts, beliefs, ideas, arguments and processes (Steiger and Steiger, 2007) and to assist in communication (Klein, 1994). However, questions have been raised as to whether visualisation can truly represent real objects, or whether it is simply a metaphor of human beliefs. Answers to such questions are important to understand because visualisation could provide misleading information. Overall, these challenges highlight the importance of conducting appropriate evaluation techniques that could have an impact in developing design guidelines. Researchers have to aware that visualisation cannot always be evaluated easily and further improvement of evaluation techniques in practice is needed.

As written by Padda *et al.* (2007, p. 88),

"*This widespread proliferation [of visualization tools/techniques] has made it difficult for both the users and evaluators to select and evaluate effectively an appropriate visualization tool/technique respectively. In current literature, the evaluation of the visualization techniques is described on an ad hoc basis, without matching the applicability of the techniques to the available context*."

Hence, Padda *et al.* (2007)'s statement has created a potential opportunity for this thesis is to explore several methodologies and techniques in evaluating visualisation. Although several methods have been developed by scholars, a substantial gap still exists. Table 2.5 shows how researchers in the past have put effort into evaluating visualisation, including the processes involved and the shortcomings.

Table 2.5 Evaluating user experience in visualisation

Author	Methods of Evaluation	Possible Shortcoming
Abubakar *et al.* (2014)	▪ Field Experiments ▪ Structured Interviews	Users' personal opinions may not be known if only measured variables were asked.
Merčun (2014)	▪ Reaction Cards	Limiting the user experience with predefined adjectives and ignoring their subjective view.
Borkin *et al.* (2013)	▪ Experimental –used a Game Setting	Risk of bias when measuring memorability in a game setting. A game setting could ignore personal abilities.
Lam *et al.* (2012)	▪ Informal Evaluation ▪ Usability Test ▪ Field Observation ▪ Laboratory Questionnaire	Problematic if scenario to evaluate user experience was not reflecting the real scenario. Hence, behaviour in laboratory may differ from behaviour in a real situation.
Wood *et al.* (2012)	▪ Online Experiments with a series of Stimulus Response Tests ▪ Online Task Scenario	Uncontrolled influence of the conditions and quite a complex task for inexperienced researchers.
Slingsby and Dykes (2012)	▪ Workplace based Evaluation	Time-consuming and requires a highly committed user.
Vande Moere *et al.* (2012)	▪ Online Survey of Users' Experiences	Inefficient for in-depth evaluation of user experience.
Lloyd and Dykes (2011)	▪ Thinking aloud ▪ Summative ▪ Questioning ▪ Observation	Time-consuming and complicated to implement. Researchers need to possess skills to avoid pitfalls.
Hsieh *et al.* (2008)	Experience Sampling Method (ESM) and Feedback	Low attention and compliance from users due to long commitment.
Barat (2007)	Document Analysis	Researcher opinions can lead to biased results.
Faisal *et al.* (2007)	Questionnaire of User Interface Satisfaction	Unable to capture user experience in evaluating Info Vis. limited to syntactic knowledge.
Ellis and Dix (2006)	Document Analysis	Incomplete evidence because methods of evaluation solely based on review.

To address the shortcomings of visualisation evaluation on user experience as stated in previous studies, the implications have been evaluated. The implications of not considering various aspects of evaluation could inform new research to consider an appropriate method to fit their studies. These implications are divided into two aspects: (1) methodological shortcomings; and (2) time, skills and tasks of the studies.

The first methodological shortcoming was related to users' personal opinions. Scholars (Faisal *et al.*, 2007; Vande Moere *et al.*, 2012; Abubakar *et al.*, 2014; Merčun, 2014) conducted their studies using several methods, such as field experiments, interviews, questionnaires and reaction cards. Their studies revealed a good impact in the body of knowledge, but there were aspects that could shed new light on future evaluation. The reason was that these methods ignored the users' personal opinions and their own subjective views. Users' personal opinions cannot be captured unless in-depth evaluation is conducted. In-depth evaluation not only contributes to collect syntactic knowledge, but also semantic knowledge. Therefore, these shortcomings suggested use of a method that could capture appropriate user experience.

The second methodological shortcoming was related to researchers' opinions. It is essential for researchers to be aware of bias, which occurs when research findings rely solely on the researcher's opinion (Ellis and Dix, 2006; Barat, 2007; Lam *et al.*, 2012; Borkin *et al.*, 2013). Research may be considered valid if it is supported with relevant data. An inductive method can be used to show a comprehensive technique that the researcher's judgement was based on user data. The use of reliable software or consulting of experts to validate the findings has to be considered by researchers in the early stages of a study.

The third factor in methodological shortcomings is the choice of simulation setting. Not representing a real scenario might occur when experimenting in a laboratory. Accuracy and reliability in the simulation setting are essential to predict the outcomes (Ellis and Dix, 2006). The outcomes should be able to reflect reality, if irrelevant factors, which often lead to the wrong sort of experiment, are reduced.

The fourth methodological shortcoming is related to a tendency to ignore users' personal abilities, such as skill in memorising words or numbers. Activities such as measuring memorability while playing games might increase the level of tension that differs for every person. This factor should become a limitation and provides an important reminder that the researcher needs to identify potential risks when evaluating visualisation.

Researchers wishing to conduct studies related to visualisation evaluation of user experience should identify the time taken, skills possessed and tasks involved. Identification prior to choosing the appropriate method should minimise any pitfalls in their studies. Indeed, the shortcomings in previous research correspond to these three factors (Hsieh *et al.*, 2008; Lloyd and Dykes, 2011; Slingsby and Dykes, 2012; Wood *et al.*, 2012). Methods such as workplace based evaluation, experience sampling method (ESM), thinking aloud, summative assessment, observation, online experiments with a series of stimuli response tests and online task scenarios can be a lengthy process. For researchers needing to be aware of time constraints, it is suggested avoiding the adoption of any of these methods. Another obstacle for the inexperienced researcher is the skills required to control the process of conducting their studies, especially when the task is quite complex. For example, observation requires researchers to be aware of the task given, as it will influence user behaviour. They must be knowledgeable when dealing with users who may face unexpected issues, such as lack of understanding of the given task. Researchers encountering this problem should plan to ensure they are able to minimize faults in the findings by giving an appropriate explanation. In relation to this study, the researcher has to be aware of his/her own ability to conduct such methods.

These implications may reveal research gaps. First, there may be a gap in the user's experience when scholars focus on a single paradigm approach - either Positivism or Interpretivism - which may limit exploring any user's experience. Hence, the adoption of a single paradigm that integrates both an objective and subjective position are suggested. A paradigm such as pragmatism was considered a more appropriate option for this study. The findings based on users' perceptions may help to strengthen visualisation concepts, and uncover a promising area in visualisation research.

Second, factors of time, skills and tasks can be reduced by adopting a technique that could solve these three issues. Over many years, RGT has been established as a psychological technique that demonstrates its ability to be conducted in short duration experiments, is a specific technique that is simple to follow and can be framed into a specific scenario. Having a specific scenario to evaluate user experience is also recommended by Lam *et al.* (2012). They mentioned that a scenario should provide a suitable match with the user's practical context when using visualisation. A well-defined technique, such as the use of reaction cards (Merčun, 2014), was considered similar to RGT, but limits users to construct their own adjectives in reflecting their experience. Therefore, eliciting subjective experience is not only limited to a low task approach but also includes a high task approach.

Third, to minimise bias, this study adopts a technique that offers quantitative and qualitative data. By combining inductive and deductive methods, the research findings were not solely based on the researcher's judgement, but were also supported by user data. To further validate those data, using reliable software should be a priority for any study. Hence, software designed specifically for RGT was an obvious option. Various personal abilities might be quite a challenge; therefore this study aims to reduce irrelevant factors, such as interference and stress, by giving more control to the users. RGT allows users to control the situation by giving them freedom to give an honest opinion at their convenience. Further discussion about RGT can be referred to in Section 3.4.

2.4 Users' Experience (UE) in Visualisation

An in-depth evaluation of users' experience was one of the shortcomings in evaluating visualisation. This shortcoming has become a focus in the study, and hence this section will discuss related theories, and objective and subjective measurements of users' experience in visualisation. The term 'user experience' has a similar meaning to human-centred approaches (Lloyd and Dykes, 2011; Slingsby and Dykes, 2012) and human perception (Barat, 2007).

2.4.1 Theories related to users' experience

This study offers theoretical debates of visualisation in the context of users' perceptions. A considerable number of theories related to visualisation have been discussed previously, such as Visual Cognition, Colour, Interaction, Information and Perceptual theory (Ziemkiewicz *et al.*, 2010) as summarized in Table 2.1. These theories are essential in providing a framework to explain the capability of visualisation to support tasks based on users' perceptions.

Table 2.6 Comparison of related visualisation theories

Visualisation theory	Focus	Principles	Applications
1. Colour theory (Marcus, 2014)	Invokes emotion and thoughts, both aesthetic and functional	Colour organisation (consistency), economy (simplicity), emphasis (strong contrast), communication (vibrations), interactions and symbolism (colour codes)	Application Design, Arts
2. Visual Cognition (Eppler and Burkhard, 2004; Purchase *et al.*, 2008; Cyras, 2009)	Relates to the human processing ability to translate the visual into thought and action	Recognise pattern, visual recall, promote communication and increase learning	Picture processing, Instructional design for E-learning
3. Information theory (Purchase *et al.*, 2008; Chen and Janicke, 2010)	Science of quantification, coding and communication of information	Selective, Descriptive and Semantic Information content	Statistical Inference, Pattern Recognition, Decision Theory
4. Perceptual theory (Ware, 2008a)	Perceive pattern of data for an effective flow of visualisation	Analytic task, Mapping between data and visual representation Testable hypothesis	Representation of vector sign
5. Visual Communication (Muller, 2007; Meyer, 2010)	Focus on a communication mode (image, word, music, body language), exploring visual meaning.	Information design (information), Information architecture (graphic interface, Human Computer Interaction (HCI)) Information art (aesthetic and emotional)	Bridging mass-media and interpersonal communication content

These theories play a significant role in explaining the visualisation phenomenon (Purchase *et al.*, 2008). A visualisation phenomenon that is related to human perception is very subjective. This subjectivity allows users to have their own understanding of visualisation concepts. Although their perceptions may differ, similar constructions of experience can provide a meaningful interpretation. Thus, an objective view was also required to assist this study in developing visualisation guidelines by aggregating knowledge perception. Navigational knowledge was tested to demonstrate this phenomenon.

The discussion of theories related to visualisation is divided into two focal points: theory that promotes visual elements and theory that promotes human insight. Although these theories explain visualisation from two different focal points, they sometimes overlap and complement one another.

Theories that promote the importance of visual elements are: colour, information, perceptual theory (Purchase *et al.*, 2008; Ware, 2008a; Chen and Janicke, 2010; Pohl *et al.*, 2012; Marcus, 2014). Colour theory basically focuses on the use of colours to invoke emotion, thoughts, aesthetics and functionality. Designers can develop visualisation to achieve these focuses by adapting colour design principles. One of the fundamental principles of colour theory is colour organisation and economy. According to these principles, adapting colour organisation and economy could promote consistency and simplicity in visualisation. Marcus (2014) suggests that designers should aware of using certain colours to represent similar content, such as red for alert signs and avoid exceeding the maximum number of colours. These principles can help users to understand visualisation and can avoid confusion.

Information theory emphasises a focus of visualisation towards quantification, coding and communication of information. Purchase *et al.* (2008) and Chen and Janicke (2010) explain how information theory can lead to a selective, descriptive and semantic information content. The selective and descriptive elements of information content are measurable, unlike semantic content. For instance, selective and descriptive elements can assist users to interpret content by presenting it in a clustered form and obvious pattern, whereas semantic content requires a more personalised response from users. Not all phenomena can be explained by this theory, but scholars agree that there is a strong connection between information theory and visualisation.

Perceptual theory emphasise the analytical data that users can translate into meaningful representation. Perceptual theory encourages mapping between data to represent a meaningful pattern such as vector signs (Ware, 2008a).

Theories that promote human insights are visual cognition and visual communication. Scholars (Eppler and Burkhard, 2004; Muller, 2007; Purchase *et al.*, 2008; Cyras, 2009; Meyer, 2010) suggest that visualisation is closely related to the human processing ability to translate the visual into thought and action. Studies in psychology and cognitive neuroscience have examined the human processing ability (Eppler and Burkhard, 2004). The findings demonstrate that the human brain can identify, store and recall visual patterns better than text. It can thus be concluded that visualisation helps to reduce the complexity in processing information. Also, visual patterns that have been processed can be communicated to others, improving understanding. The use of visualisation as a medium for understanding meaning has been increasingly acknowledged (Senaratne and Sexton, 2009). For instance, visual communication theory suggests that designers should focus on designing a visualisation based on several principles, such as information design, architecture and art. These principles can guide designers to think about explicit and implicit content to meet the needs of users. This demonstrates that both theories maintain that human insight is essential for visualisation.

In conclusion, it is important that a theory of visualisation emphasises both visual elements and human insight. Both elements are descriptive and constructive, and are used in this study as guidance to evaluate visualisation. Since visualisation is, by nature, a practical tool, visualisation evaluation should lead to a constructive approach and be pragmatically applied (Ware, 2008a).

The six theories are essential in explaining visualisation from various perspectives. Investigating the theoretical approaches involves the need for visual representation of knowledge. It is important to note the impact of visualisation in representing knowledge, such as procedural, navigational and architectural knowledge (Roda *et al.*, 2011), the reason being that proper representation can increase the benefits of visualisation. The representation process is initiated by cognitive needs, such as the human desire to explore or experience things around one for better understanding. The desire may go beyond semantic, or be limited to syntactic knowledge. Syntactic knowledge is associated with the way humans differentiate between what they perceive. This knowledge can be elicited from a low level task, such as identifying, locating or ranking a visualisation (Faisal *et al.*, 2007). Conversely, semantic knowledge is more related to an explanation or justification elicited from a high level task, for example comparing, correlating or generalising a visualisation (Faisal *et al.*, 2007). Therefore, visualisation acts as a scaffolding for cognitive needs, such as structuring text and visualising elements in a meaningful way, which aid the representation process (Bertschi et al., 2011). Scaffolding may be in the form of sketches, conceptual diagrams, images, objects, interactive visualisation, information visualisation, visual metaphors, or knowledge maps (Bertschi et al., 2011). For example, a mind map can be used to provide an outline of a particular subject, and is a good example of transmitting messages using a minimal amount of words, as suggested by Keller and Tergan (2005).

Knowledge that has been represented through visualisation also demands evaluation. The interest in evaluating knowledge has become possible with the assistance of a visualisation tool (Leinonen and Jarvela, 2006). Leinonen and Jarvela (2006) claim this visualisation tool assisted in evaluating their own knowledge, and designers may represent their navigational knowledge through maps, which can later be evaluated for usability. However, the motivation of this study was not to evaluate designers' knowledge, but rather the user's ability to interpret knowledge, which is vital. Therefore, navigational knowledge has been evaluated to discover the impact of visualisation in the HE sphere. The use of visualisation is not too crucial compared with other contexts, such as business, but has a huge impact in assisting students, educators and administrators in the learning process. For example, students may need to use visualisation in their routine, such as assisting them to navigate their way round a campus. It is one of the basic elements they require before they can become familiar with the campus.

Theoretical debates have raised concerns about the most relevant theories used to explain visualisation. Previous discussion has identified a gap in the literature that visualisation theories can be explained under two focal points, those that promote visual elements and those which promote human insights. Both focal points are important to explain the focus of this thesis. Therefore, it can be concluded that these six theories are the most relevant theories.

2.4.2 Objective and subjective user experience measurements

To clarify the evaluation, previous literature based on several empirical lenses from visualisation research has been extracted (refer to Section 2.3). Several databases, specifically Web of Science® and Scopus®, were used to search for articles in high-impact journals. A combination of keywords and related terminology such as "visualisation", and "evaluation" and "assessment" were used to widen the search. Results presented in Table 2.4 show a list of constructs used by scholars to evaluate visualisation. The list may not include all related research, but is a representative list of constructs. These constructs are classified using four lenses of past research, not according to hierarchy, and some are mentioned more than once.

Table 2.7 Major factors in evaluating visualisation in past literature

Objective and subjective user experience measurements classified by four lenses of past research	**Reference**
Human Cognition Organisation of Visual and Perceptual Components, Cognitive Mapping, Processing Ability, Familiarity, Mapping, Quality Assurance Thinking and Conceptual Learning, Memorable, Recognizable, Information Anxiety	Bertin (1967); Huff (1990); Koffka (1935); Kosslyn (1980); Larkin and Simon (1987); Miller (1956); Rhodes (1994); Shepard and Cooper (1982);Sweller and Chandler (1994); Wurman (1989)
Technology Intervention Graphical User Interface Colour Usage, Layout/Space Usage, Graphical Usage, Visual Appearance, Design, Formats and Functions, Human Computer Interface Manual and Automated Searching Abilities, Registrative, Mimetic, Simulative, Explicative, Diegetic, Appellative, Decorative, Phatic, Ontic or Energetic, Roles, Appealing Graphics, Understandable Information, Improved Products, Culture, Cognitive, Communication, Learning Outcome, Definition, Architecture, Implementation, Symbolic Features, Task and Data Type Taxonomy, Practical Application, Visual Deception, Measured For Utility, Problem Context, Purpose Context, Knowledge Worker Context, Effectiveness, Efficacy, Satisfaction, Accuracy, Repeatability and Robustness	Afzal and Maurer (2011); Comi and Eppler (2011); Doelker (1997); Goodwin (2009); Haase *et al.* (2000); Henderson (1999); El-Sadi and Roberts (2012); Mok (1996); Perini (2005b); Santos (2005); Shneiderman (1996);Tufte (1997); vanWijk (2005); Xiaoyan *et al.* (2012);
Data and Information Visualisation Productivity, Quality, Learning, Satisfaction and Participation, Data, Audience, Prevent Misinterpretation, Compress Knowledge, Present Overview and Details, Consistent, Avoid Decoration, Do Not Distract Audience, Natural Representations, Motivate Audience, Usability , Perceptual-Cognitive Tasks, Prior Knowledge, Perform Primitive Task (Identify), Perform Intermediate Task (Categorise), Perform Complex Task (Generalise), Functionality, Benefit, Application Context and Guidelines, Graphic Elements, Reading Direction, Design Rules and Guidelines, Macro Structure Adaptability, Difficulty Level, Extensibility, Memorability, Understandability, Words, Visual Elements, Task and Data Type Taxonomy, Fostering, Processing and Managing Knowledge, Schematization, Navigation,	Bresciani and Eppler (2009); Burkhard (2005); Chen (2005); Dykes *et al.* (2010); Eppler (2006); Horn (1998); Keller and Tergan (2005); Roda *et al.* (2011); Faisal *et al.* (2007); Shneiderman (1992); Tversky (2005); Tan *et al.* (2009); Tufte (1997); Vande Moere *et al.* (2012); Wexler (2001); Zhou *et al.* (2011); Zeiller and Edlinger (2008)

Content/Information, Categorization of Information, Presentation of information, Updates, Advertisements/Popups/Animation, Text Usage, Downloading Time, Headlines, Practical Application, Visual Deception, Objects, Purpose, Ways, Types, Style, Who, What and Why of the knowledge mapping process, Usefulness, Ease of use, Ease of learning and Satisfaction, Data type, Visual representation, Expressiveness, Effectiveness, Interaction and Implementation, Legends (Logical, Comprehensive, Clear, Elegance, Flexibility, Richness, Responsiveness, Aesthetic, Professional, Inspirational)	
Evaluation Behaviour Capture and Depict Knowledge, Insights, Visual, Support Process of Knowledge Integration, Revisable, Communicable, Leads to New Discoveries, Visual Variety, Visual Unfreezing, Visual Discovery, Visual Playfulness, Visual Guidance, Data Mining, Data Transformations, Mapping And Creation, Similarities, Reading Pattern, Visibility, Compactness, Frequency of Usage, Design Choices, Colour Design Principles (organization, economy, emphasis) Visual Media Print, Motion, Interactive Visual Language Layout, Colour, Typography, Texture, Imagery, Identity, Sequencing, Animation, Sound, Establishing Website's Identity, Navigation, Colour, Identity, Readability, GUI Principles (Communicate, Economical, Organize)	Agrawala *et al.* (2011); Eppler (2011); Hearst (2009); Borst and Kosslyn (2008); Marcus (2014); Mazza (2009); Nielsen (2006);Tan *et al.* (2009)

Notes: this is a representative list that may not include all related research

This section provides a summary of meaningful factors to evaluate the user experience of visualisation navigation. The summary was guided by four theoretical lenses mentioned previously in Section 2.2.2. However, having reflected upon the literature, the evaluation of visualisation according to user perception is still inadequate in providing guidelines for designers to develop appropriate visualisation for various groups of users. To address this gap, this thesis will make a comparison between factors discussed by scholars in several theoretical lenses, and factors elicited from users' perceptions. Any similarities and differences of findings can contribute on both a theoretical and practical level.

2.5 Research Gap (shortcoming in existing evaluation)

A review of the literature revealed substantial research gaps in the visualisation, evaluation and user experience, at both theoretical and methodological levels. With regards to previous studies in visualisation, a gap in producing a comprehensive list of past research has been recognised. This study fills a gap in the literature by producing a comprehensive list of past research, grouped into four lenses: (1) human cognition; (2) technology intervention; (3) data and information; and (4) evaluation behaviour. By discussing multiple theories related to users' experience, four theories (information, visual cognition, visual communication and colour) were considered the most relevant to this study. These theoretical and empirical lenses were used as a basis to reveal a list of objective and subjective user experience measurements (Table 2.7). The list is meaningful to explain the research findings, identifying similarities or differences of measurements in relation to previous research, and hence revealing two substantial gaps.

The first gap is related to a lack of research having an objective and subjective approach to evaluate user experience when using visualisation of navigation. Most researchers (Vande Moere *et al.*, 2012; Borkin *et al.*, 2013; Abubakar *et al.*, 2014; Merčun, 2014) have focused on a single paradigm approach - either Positivism or Interpretivism. Eppler (2006) recommended including an experimental design with follow-up surveys to measure the effects of four visualisation methods (concept maps, mind maps, conceptual diagrams and visual metaphors). This recommendation was based on his previous limitation of using only a case study and seeking for a more in-depth approach to understand the impact of visualisation. Similarly, Bresciani and Eppler (2010) advised that an experimental approach should be employed in evaluating visualisation in an objective way. Other techniques, such as observation, document analysis, questionnaires on user interface satisfaction and online experiments are well-known techniques in both subjective and objective evaluation. Hence, the gap has created an opportunity to position this study in both areas.

Second is the inadequacy of eliciting subjective experience by using only a low task approach. Adopting only a low task approach in evaluating visualisation could restrict exploring users' experience (Eppler, 2006; Faisal *et al.*, 2007). A low task approach is the way humans differentiate between what they perceive (such as identifying, locating, or ranking a visualisation), while a high task approach is an explanation or justification (such as comparing, correlating, or generalising a visualisation). Thus, this gap reveals an opportunity to combine low and high approaches.

To address this methodological gap, the study has adopted a position with both objective and subjective elements, governed by a pragmatic approach. This position may help to strengthen visualisation concepts and uncover a promising area in visualisation research. The study has adopted a psychological technique known as RGT for eliciting user experience in evaluating visualisation of navigation. RGT has been proven to combine both high and low tasks to elicit user experience in other domains (Edwards *et al.*, 2009; Heine, 2009; Hinkle, 2009; Tan *et al.*, 2009; Alexander *et al.*, 2010; Berger and Hari, 2012). Although reaction cards (refer to Section 2.3) are considered quite similar to RGT, this method can restrict users in expressing themselves in their own words when reflecting on their experience.

To prove the value of RGT, this study proposes to elicit users' subjective factors, to explore the relationship between those factors and to construct a classification of features. These three analyses can demonstrate the benefits of RGT adoption in evaluating user experience, and may reveal a different side to visualisation evaluation. The next chapter describes the procedures and methods used in this study.

Chapter 3: Methodology

3.1 Introduction

In bridging the gaps in the literature, the primary objective of this chapter is to establish a link between the theory and practical application of visualisation. The discussion of literature associated with visualisation evaluation and user experience highlighted gaps in the knowledge. The first gap relates to a lack of research that has an objective and subjective approach to evaluate user experience when using visualisation of navigation. The technique is governed by personal construct theory (Kelly, 1955), integrating qualitative and quantitative methods by eliciting users' personal constructs and conducting an aggregation in an objective context. This objective informs the following research questions:

- What is the impact of a pragmatic approach with the adoption of RGT in evaluating user experience for visualisation of navigation?

The second gap is the inadequacy of eliciting subjective experience by using only a low task approach. This thesis sets out to address the gap by addressing the following research questions:

- How can the use of RGT be demonstrated to elicit users' experience using a high and low task approach in visualisation research?

The adopted method and a chosen paradigm underpinning this study are briefly explained in the next section.

3.2 Current practice of research paradigm

The discussion in this section aims to address the first research gap: ***lack of research that has an objective and subjective approach to evaluate user experience when using visualisation of navigation***. The discussion begins by identifying various research paradigms in visualisation studies, followed by the adoption of the pragmatic approach in this study.

There are two paradigms which explain how visualisation research is undertaken in practice: positivism and interpretivism. Before choosing the appropriate paradigm, the different methods employed in visualisation research will be compared. This comparison highlights the advantages and disadvantages of particular methods. Table 3.1 shows representative examples of the research approach that has been used in visualisation study.

Table 3.1 A comparison of various methods adopted in visualisation research

Methods	Description	Advantages	Disadvantages
Experimental design with follow-up surveys	Implemented in three groups (1) an optimal visualisation support; (2) a sub-optimal visualisation support; and (3) a control condition with no visualisation support. The task assigned aimed to address how different visualisation methods affect group collaboration (Bresciani and Eppler, 2009)	Provides an accurate measurement about the effect of different visualisation formats	The methods ignore possible personal preferences of the subjects. The authors acknowledge that they did not take into account the effect of other variables such as non-electronic context
Experimental design	Participants were divided into three groups and given a module which facilitated with (1) a static graphic with text; (2) a 2D graphic format; (3) a 3D graphic format. A questionnaire was given to test their capabilities to recall and solve a problem. This comparative study seeks to compare whether different types of visualisation could affect learning capability (Zaman and Rias, 2011)	The method quantifies the differences of visualisation types affecting learning. The evaluation is based on multimedia learning	Lack of validity in the questionnaire instruments. The method did not reflect the students' understanding of the subjects, which requires other methods such as interviews
Case study	An application design used in Communication and Interaction Design was reviewed to evaluate the need for interactive visualisation in corporate communication (Klein, 2005)	Provides a valid argument based on the real life example of practices used in designing an application	The findings could not be generalized to other subject areas
Discourse analysis with interviews	Used a course evaluation form and final exam to assess the	Provides an in-depth analysis to reflect the	The instruments used to compare four visualisation

	students' satisfaction in learning. Follow-up interviews were conducted to elicit their experience with the assignments (Eppler, 2006)	learning environment	methods can be contested

Table 3.1 shows the four methods conducted by scholars (Klein, 2005; Eppler, 2006; Bresciani and Eppler, 2009; Zaman and Rias, 2011) to provide empirical evidence used to assess the visualisation format. The method employed indicates the paradigm used to address the research gap. This review shows that scholars such as (Bresciani and Eppler, 2009; Zaman and Rias, 2011) believe that their studies lean towards positivism. They seek the truth and validity of the visualisation existence objectively. To prove their hypotheses, they collected empirical data using quantitative methods. The empirical data were collected through an experimental design consisting of three different groups. Each group was supported by various visualisation formats. This method provided advantages, such as the ability to quantify the findings with an accurate measurement.

However, there are scholars who have leaned towards an interpretivist paradigm when conducting their research (Klein, 2005; Eppler, 2006). The interpretivist paradigm emerged in visualisation research in response to criticism associated with the positivist paradigm (Marsden and Littler, 2000). Most positivist research has been criticised for ignoring the complexity and richness of the visualisation experience. In response to this criticism, interpretive researchers, such as Johnson (2004), began to systematically explore the nature and form of visualisation subjectivity. As Marsden and Littler (2000) state: "a *psychological similarity is founded on the similar construction of experience (experience equal to subjective interpretation), not on similarity of experience itself (experience equal to events)" (*p.819*)*. Researchers such as Klein (2005) adopted a case study, and Eppler (2006) an interview to elicit users' individual experiences of reality. This approach provides an in-depth analysis and valid arguments to support the researcher's assumption. However, the approach also shows some weakness, because the questions are not well-defined. The findings could not be generalized and only apply to specific population samples. Supported by other scholars (Zeiller and Edlinger, 2008; Comi and Eppler, 2011), they also recommend the use of an ethnographic method, such as participant observation (Comi and Eppler, 2011) and a case study approach (Zeiller and Edlinger, 2008) for evaluating the visualisation.

Issues generally arise when both paradigms (positivist and interpretivist) are shown to have advantages and disadvantages. As recommended by Marsden and Littler (2000), a multiparadigm approach could be used to minimize the disadvantages and maximize the advantages of each method. To exploit the advantage of both paradigms, the study adopts a pragmatic approach to offer philosophical assumptions on mixed methods. A gap in this study area highlights usability factors that relate to the pragmatic instead of positivist or interpretivist paradigms. Pragmatism is selected to explain the usability factors of visualisation. Visualisation is by nature the kind of subject that demands evaluation. Therefore, this study puts forward the idea of evaluating user experience by employing both quantitative and qualitative aspects of visualisation evaluation to maximise its advantage. This approach is considered more reliable and capable of providing valid evidence. This paradigm may lead to the exploration of new ideas and concepts of visualisation that might be useful for designers and users. A further explanation of pragmatism from an ontological, epistemological and methodological perspective is discussed in the next section.

3.3 Pragmatic Research Design

3.3.1 Philosophical assumptions

A pragmatic paradigm was chosen to evaluate visualisation navigation. The reason was a philosophical assumption that a pragmatic approach demonstrates how to conduct research within both positivist and interpretivist paradigms. A pragmatic paradigm can elicit an individual subjective view that lean towards interpretivism. This paradigm then invokes an objective context by aggregating personal constructs that lean towards positivism. The focus of this paradigm is on a practical approach that requires both positions to collect and analyse data (Saunders *et al.*, 2009). The discussion continues with assumptions based on ontology and epistemology to evaluate visualisation. Based on an ontological assumption, pragmatism is concerned with "*solving practical problems in the real world*" (Feilzer, 2010, p. 8). How a real world scenario is interpreted by an individual may be difficult to explain. To interpret its subjectivity, this concept often relates to visual cognition and visual communication theory (Eppler and Burkhard, 2004). Hence, the researcher believes that participants need to construct their own understanding of visualisation concepts. For example, it is essential to give the participants a task scenario to determine their perception through problem-solving skills. This assumption asserts that visualisation is focused on exploring how humans perceive different types of visualisation methods.

An epistemological perspective of pragmatism assumes that the knowledge embedded within a human being is know-how. Know-how or navigational knowledge was tested because it is considered to be closely related to evaluate visualisation. It is possible to demonstrate this type of knowledge through the way people solve a task. This study assumes that similar perception derives from similar construction of experience, or knowledge gathered from the same HE environment. There is no 'right or wrong' concerning knowledge, because it is meaningful to whoever is in possession of it. This assumption requires the interaction of both researcher and participants to gain a more in-depth investigation. The in-depth investigation can be demonstrated through the multiple data, and methods of collection used to support the validity of the claim. For example, this study could use mixed methods to gather various types of data. This assumption drives the choice of methods to be utilised. Scholars such as Shaw and Gaines (1993) use Personal Construct Theory (PCT) as a basis of knowledge acquisition and knowledge representation. They suggest PCT can be used to elicit their respondents' knowledge and represent it with a single framework. They conclude that PCT is used quite extensively to integrate human cognitive processes and computational knowledge representation.

3.3.2 Theoretical background for Pragmatic (Personal Construct Theory)

The theoretical background in this study is based on the Personal Construct Theory assumption that involves a subjective view of users' perceptions. The study then aggregates their personal constructs in a more general, objective context. These views are governed by a pragmatic paradigm as a methodological approach.

Personal Construct Theory, developed by Kelly (1955), is widely acknowledged (Banister *et al.*, 1994; Tindall, 1994; Fransella, 2005; Birdi, 2011) as a fundamental theory of personal psychology. His approach extends into various domains, such as clinical psychology, organisational development, education, cognitive science and business. Fransella (2005, p. 67) states that underpinning the personal construct theory according to Kelly (1955, p. 46) is that "*a person's processes are psychologically channelized by the ways in which he anticipates events*". The principle underpinning this research, therefore, is that human interpretation of experience is the influential aspect, rather than the event itself. This study explores the individual's construct systems and makes a judgement to explain situation. The study does not seek an absolute truth, which, it seems, does not exist. The theory focuses on individual use of knowledge to construct the meaning of subjects from different angles that are valid at a particular time (Kelly, 1955). It takes into account the different ways of seeing and interpreting the same event according to different people. The individual is hence considered as the creator of meaning (Banister *et al.*, 1994).

The construct of meaning is demonstrated by a person if they are able to identify any difference between subjects. In other words, respondents will show their analytical capability through identifying the similarities and differences of particular subjects. This theory also offers an analytical basis for both the nature and form of respondents' subjectivity. Thus, this study could contribute to an understanding of the individual respondent's perception of visual representation.

The current study makes the assumption that every person is different and unique in their construction of events. This assumption, known as individuality corollary (personal uniqueness), is the fundamental of RGT. RGT adopts the constructivist approach of Kelly (1955), which focuses on the way humans perceive or interpret the world. This approach asserts that the world is not simply an objective reality. Thus, the focus of RGT analysis rests on the individual. In order to resolve the conflict between the constructivist approach and aggregation of personal constructs, this study used a pragmatic decision to support the way the research was conducted. For example, in order to classify the collective visualisation method constructs, the analysis required the aggregation of individual constructs. To achieve this aim, an article by Birdi (2011) was used which demonstrates a convincing method of aggregating data to interpret a large number of responses. His method proves the significance of aggregation, as opposed to Cassell and Walsh (2004, p. 66), who state, "*aggregating responses to be able to say things about groups does deviate from Kelly's stance*".

3.3.3 Mixed Method Approach

This study has adopted a mixed method approach under one pragmatic paradigm, and differs from having a mixed method methodology which conducts research in two different paradigms. Pragmatism led this study to have a multiple data collection strategy for both qualitative and quantitative data. However, there are some arguments concerning the research approach using RGT, because of the chosen paradigm. One of the arguments is that RGT is dominated by a positivist framework, and is not commonly used for interpretive research (Marsden and Littler, 2000). However, according to a previous study, Birdi (2011) concludes that RGT is associated with both paradigms. Birdi (2011) demonstrates how Banister et al. (1994) use a quantitative approach, in comparison with Marsden and Littler (2000) who prefer a qualitative method. Comparing the two methods, it can be seen that RGT has the potential to follow an interpretive paradigm. For instance, scholars believe that positivists do not pay much attention to examining behavioural science (Edwards *et al.*, 2009). They hence follow an interpretive paradigm and personal construct theory to examine the human and organisational aspects of software engineering. This argument shows that the use of mixed method is relevant to RGT, because of insufficient and restricted quantitative measures in evaluating visualisation. This method, used to quantify or qualify the construct known as triangulation, can provide a far greater depth of subject. For instance, pragmatism in RGT can be used to elicit users' perceptions of visualisation by emphasising a high and low level task (interpretive) and to aggregate individual constructs (positivist). Since a RGT contains both types of data (Fransella, 2005), it is employed in this study, and is structured qualitatively and quantitatively as follows:

(1) Qualitatively: during the laddering and pyramiding process, an open-ended questionnaire and a semi-structured interview were conducted purposely to explore the constructs and the respondents' perceptions of those constructs. The respondents were encouraged to express their perceptions with little interference from the researcher.

(2) Quantitatively: some constructs gathered were quantified during analysis. Unlike the other methods, the construct from the open-ended questionnaire and semi-structured interview was measured through particular rating.

Parallel to the aim of this study is the exploration and evaluation of the respondents' perceptions, opinions and understanding in relation to the particular visualisation navigation. The respondents were asked to reflect upon the visualisation navigation thus: how they perceived the visual representation methods, which visualisation methods they would use to solve the particular task and why they decided to use those particular visualisations. This data gathered from respondents could be summarized into strong factors. These factors will explain groups of visualisation features in detail. There is evidence that the appropriate methods to be applied in conducting visualisation research are surveys, experiments and case studies (refer to Table 3.1). Instead of adopting these methods, this study seeks to use the method of RGT, which is commonly used to elicit the individual construct (Kelly, 1955). The reason for adopting this technique is to conduct a more in-depth investigation of visualisation navigation methods. RGT is known as a powerful tool to quantify people's perceptions. People's perceptions of a situation can be determined by their actions. A grid works as a "*cognitive map charting a particular aspect of a person's world*" (Easterby-Smith *et al.*, 1996, p. 4). Although the technique is simple, it is considered to be materially rich.

RGT has been used in a variety of domains, specifically in studies of design (Hassenzahl and Wessler, 2000), human computer interaction (Ashleigh and Nandhakumar, 2007) and information retrieval (Dillon and McKnight, 1990; Zhang and Chignell, 2001). For example, a study of design was undertaken by Hassenzahl and Trautmann (2001) when evaluating website design. The eliciting process began with the respondents producing the constructs, and then rating them based on the most appealing design. The results show that website design is related to style, structure, interaction and usability. A similar study was conducted by Crudge and Johnson (2004) to evaluate the search engine through RGT analysis. Several criteria were applied in determining user perception of the search engine. With the objective being to obtain meaningful user evaluation criteria for an information-seeking task, these state that user perception was related to ease of use, usability of features, task success and aesthetics. The findings were then used to prove the claim by the researcher in examining the characteristics and perceptions of search engines. Both studies thus prove that RGT analysis is able to evaluate the perception of design and human-computer interaction.

RGT consists of systematic methodology that integrates both qualitative and quantitative analysis (Tan *et al.*, 2009). Hence, this study has applied personal construct theory and associated RGT to a mixed method study involving 48 RGT interviews, conducted with students at Southampton University. It is a challenge to use RGT in problem-solving, so; this study introduced a task scenario to frame the context and allow the respondents to apply their knowledge to the given task.

3.4 Repertory Grid Technique (RGT)

This section addresses the second research gap: ***the inadequacy of eliciting subjective experience by using only a low task approach.*** This section focuses on the elaboration of RGT as a methodological approach to elicit user experience that combines both a high and low task approach when using visualisation navigation.

RGT is a way to reconstruct reality by allowing humans to create a simple grouping based on similarity and differences of visualisation. This technique also assists researchers to identify how users arrive at their perception position. RGT has informed this study at both the conceptual and method levels. At the conceptual level, there is less empirical evidence, and current research is more focused on the design principles of visualisation, rather than the benefits to users. The perspective of users is often excluded in research, because it is rather subjective and does not offer any meaningful interpretation. RGT has guided this study to elicit this subjective thought by implementing both low-level and high-level tasks. A low-level task is associated with the way humans differentiate between things, whereas a high-level task is more related to an explanation of things. Both tasks provide a data type, for example research conducted by Faisal *et al.* (2007) demonstrates that syntactic knowledge is elicited from a low-level task, whereas semantic knowledge is elicited from a high-level task. Following methods governed by RGT, this study uses both qualitative and quantitative approaches. It differs from most previous research that measures visualisation based on either quantitative or qualitative approaches. Quantitative method involves questionnaires, while qualitative uses interviews or experiments. By using only one of these methods, the potential to explore specific aspects of visualisation is limited.

Since this study is concerned with three visualisation methods (heuristic sketch, conceptual diagram and knowledge map), the process of eliciting its usability requires a task scenario. In this case, instead of asking their preferences by just looking at the campus map, the respondents were given a particular task to solve. The reason is that they may have had different opinions when actually using the campus map, compared with those who just looked at it. The interaction helped them develop some familiarity with each visualisation method. However, the respondents were not informed about the visualisation classification during the process. This bottom up approach allowed the respondents to construct their own meaning of visualisation classification empirically.

To implement a RGT requires four research stages: element selection, construct elicitation (such as triading or laddering), element comparison (relating the constructs to elements) and data analysis (Marsden and Littler, 2000). During this investigation, RGT not only analyses individuals, but aims to create classifications of constructs from individual grids (Alexander et al., 2010). These classifications provide a better understanding of current classifications of visualisation features, based on the constructs provided by respondents. To analyse the perception of visual representation of knowledge, elements were provided representing visualisation methods. The sampling characteristics of how this research was conducted are briefly explained in the next section.

Three values were formulated to demonstrate the adoption of RGT. These are:

(1) Eliciting factors in evaluating visualisation navigation in the minds of the users.

Their personal constructs are represented as a list of factors that users perceived when using visualisation.

(2) Exploring the importance of the relationship between the elicited factors.

A list of factors elicited from users could give meaningful interpretation to the study if their relationships were explored.

(3) Construct a classification of features related to visualisation navigation based on users' perceptions.

A grouping based on similarity and differences of visualisation was not widely implemented. The reason for having groupings could help to define the specific task from the user's perception. For example, users who are less familiar with the content might require a comprehensive visualisation, compared with those who are more familiar. Indeed, groupings can be used as a guideline to help designers understand various users' needs. A grouping with a hierarchy of users' perceptions contributes to providing a classification of visualisation features. The need for a rule to list features was advocated by Eppler (2008) and Zhou *et al.* (2011). They claimed that reasons of how and why visualisation features are classified were still lacking. The study allows users to create a simple grouping based on similarity and differences of visualisation.

3.4.1 Research Context

There was potential to examine visualisation classification methods by using the HE environment as the knowledge domain. The use of a visualisation sample of the university, such as the campus map, had an impact on this study. The need for visualisation of the campus map is vital, because the map is the first guideline for students searching for certain locations. The campus map is a good example of visualisation, as it appears in most university websites. For this purpose, a task scenario to frame the context was given to students, who could then demonstrate how they perceived the university campus map in several visualisation methods. As a result, research in an HE environment contributes in bringing different perspectives of visualisation based on users' perceptions.

3.4.2 The Characteristics of the Sample

A purposive sample of students studying at undergraduate and postgraduate level was selected to participate in this study. Purposive sampling was chosen because it is appropriate to obtain the most relevant population sample. The respondents were targeted across disciplines, and amounted to approximately 50 students in total, from three different schools, being Computer Science, Management and Psychology. These three disciplines were selected on the basis of their ability to represent several lenses in previous visualisation research. The three disciplines also include a discussion about knowledge visualisation in their syllabus. Hence, these students were considered to have high awareness of this topic compared with others.

The purposive sample gave the researcher a manageable sample of respondents. The University of Southampton has a total of 24,040 students (Source from Higher Education Statistics Agency: https://www.hesa.ac.uk/. Based on mailing lists gathered from https://all.soton.ac.uk/, it appeared that the three schools consisted of 12,414 students (undergraduate and postgraduate), divided into Computer Science (2,483 students), Management (4,946 students), and Psychology (4,983 students). These schools had such a large number of students that it was impossible to include the remaining faculties in this study as well. Focusing only on freshers, the samples gathered were not equally spread between the three disciplines. However, failure to achieve a population spread between the three disciplines did not affect the aim of the study. Since it was focusing on users' unique personal constructs, their disciplines were considered less relevant than their perceptions. Any comparison between disciplines may limit the wealth of data. Thus the samples gathered were considered adequate for this study.

There were several reasons for selecting students as a research sample. They are easily accessible, homogeneous and share similar characteristics. Students are more accessible than working people in terms of time, location and willingness. Hence, they were selected to participate in this study.

The students also represented a homogeneous sample because they were from a similar background regarding level of education. They were first year students of Southampton University who had enrolled in September 2013. These students (undergraduate and postgraduate) were varied from across continents, with various age profiles.

Freshers were deliberately selected, because they were most likely to be using visualisations of the campus map to identify locations. These students shared the similar characteristic of possessing a 2D campus map received during induction week. They admitted that they had seen, but were not yet familiar with the campus map. They might have developed a tacit knowledge within a few weeks embedded in the context, but were still experiencing difficulties with the campus map. Since this study only required a little knowledge of the campus map, these were the groups who could create a real impact on the study by providing an insight into visualisation techniques. These reasons show the importance of selecting appropriate research samples, as demonstrated by previous visualisation studies (Ellis and Dix, 2006; Roda *et al.*, 2011).

A small sample was chosen because it was sufficient to provide a meaning of the concept, and the eliciting technique itself was very time- consuming. According to Tan and Hunter (2002, p. 9), as cited by Dunn et al. (1986) and Ginsberg (1989), the sample size of "*15 to 25 within a population will frequently generate sufficient construct to approximate the universe meaning regarding a given domain of discourse*".

For the purpose of the recruiting the sample, publicity about the study was used to attract participants. Posters in A2 size were used to capture their attention. The posters were visible at several strategic locations, such as bus stops, shops etc. Those who were interested in participating could contact the researcher through given contact details. The advertisements had a specific time-frame of 4 weeks to achieve the target number of respondents and gather feedback.

Another way of recruiting respondents was advertising via email. Emails requesting for participants were circulated to a mailing list gathered from https://all.soton.ac.uk/faculties/, by selecting specific addresses from within the schools of Management, Computer Science and Psychology. For example, an email was sent to "*fpse-ug-cs-1*", targeted at first year undergraduate students studying computer science only.

Those who were interested and agreed to participate were sent a participant information sheet as an email attachment. Having confirmed, they were required to complete the consent form before the process of data collection could begin. Once the process of collecting data was completed, the participants were given a debriefing form (feeding back the findings of the study to the participants).

As compensation for their time and effort in participating in this study, a £4 lunch voucher at SUSU cafe in Southampton University was given to all participants.

3.4.3 Preliminary Stages (Pilot Study)

Prior to the data collection process, a pilot study was conducted to improve the validity of the research instruments, consisting of open-ended questionnaires, interview questions and visual representations. The need to conduct a pilot study is essential in social science research. According to Thabane et al. (2010), pilot studies can be conducted in both quantitative and qualitative research. There are two different ways to apply a pilot study, for feasibility or for pre-testing. Feasibility study refers to "*small scale versions, or trial runs, done in preparation for the major study*" (Polit *et al.*, 2001, p. 467). Pre-testing, on the other hand, refers to the trying out of a particular research instrument (Baker, 1994).

In order to improve the validity of the research instruments, a series of tasks was performed in the pilot study. To determine whether the research instruments produced the projected data, they were managed in exactly the same way as the main study. This process included open-ended questionnaires (triading), semi-structured interviews (laddering) and Likert scale (rating form). To maintain the consistency of questionnaires and interviews, any ambiguities were recorded. Several ambiguities were eliminated in the given examples and instructions in the questionnaire. To identify whether the time taken to complete the whole process was reasonable, the time for each pilot study was recorded. The time taken to complete the first pilot was more than one hour, which decreased once the process was revised. Some questions had to be rephrased to make sure that respondents were able to understand their meaning. For example, the use of the word 'construct' was avoided when giving the instructions to respondents. To facilitate the data collection process, some instruments were shortened, revised and re-configured with other respondents. The questionnaires were revised by reducing the number of open-ended questions from 15 to 10. This reduction did not reduce the potential of obtaining valuable construct, as these 10 questions proved to be more than sufficient.

Regarding qualitative research, scholars such as Van Teijlingen and Hundley (2001) have different perceptions towards pilot studies. They believe that instruments such as interviews are progressive, and the researcher will improve their technique by asking questions. Hence, the knowledge gathered from first interview can be analysed and used as guidance in subsequent interviews. Holloway (1997) is also of the opinion that it is not necessary to have a separate pilot study in qualitative research, unless the researchers do not have adequate knowledge of interview technique.

According to these arguments, a pilot study is believed to be of benefit to the researcher, so one was conducted here with four respondents, to gain some insights into data collection techniques. Frankland and Bloor (1999) also advocate the benefits of a pilot study in helping to clarify the focus and scale of projected analytical topics.

3.4.4 The Experiment and Tasks involved in RGT

The first task before starting the RGT was to obtain the full consent of each participant. Those who agreed to participate had received participant information sheets which provided a summary of the study, the conduct procedure, the risk involved, confidentiality, benefits and other information. If they were satisfied and decided to take part in the research, they had to sign a consent form before the experiment started. The participant consent form is attached in Appendix A.

All participants were asked to book a time slot based on their availability. The time-span for the survey was from *4th November to 13th December 2013*, Monday to Friday from 9am to 6pm. Each slot was allocated up to 1 hour, including preparation time before and after the survey. The actual study took 45 minutes, and consisted of two stages: construct elicitation and element comparison. Construct elicitation is basically comprised of triading, pyramiding and laddering. Element comparison is the process or rating of the construct towards the elements. A brief instruction was given by the researcher to help the participants understand the expected response.

The room used for the survey was Room 6047, a meeting room located on Level 6 in Building 2 (School of Management). The size of the room was 120 square feet. The room contained a computer, a projector, a table and several chairs. The distance between the projector and the participant was approximately 2.5 metres. The layout of the room is shown in Figure 3.1.

Figure 3.1 The room layout used for the survey

Only a participant and a researcher were in the room, and no other person was allowed to interfere. When the participant was ready to begin the survey process, the researcher distributed the survey form and switched on the projector to display the three images, together with the voice recorder to record the whole process. The three images shown to the participant were essential components in RGT used for construct elicitation. The elements are briefly explained in the next section.

3.4.4.1 Elements: Map of Southampton University Campus

In generating the elements, several techniques are recommended in RGT. The elements can either be provided by the researcher, or gathered from respondents, the most common approach being where the researcher identifies the most likely known items. These items can be identified solely by the researcher, or experts could be asked to name the elements. The experts need not be subsequently involved in the study. The other approach requires the respondents to choose from a provided list of named elements. A fixed number of elements was chosen to ensure that the study able to represent a homogeneous visualisation navigation. Homogeneous visualisation navigation includes a variety of visual representations (Dillon and McKnight, 1990) and identical elements across the subjects. These two recommendations were important in the process of eliciting and classifying the features of visualisation navigation.

With regard to the number of elements, there is still lack of consensus among researchers. Researchers have different opinions on the minimum and maximum number of elements. Researchers such as Easterby-Smith *et al.* (1996) and Tindall (1994) advise that the maximum number should not exceed ten, because it is difficult to manage more. However, Jankowicz (2004) and Scheer (1993) suggest a range of elements, between five and twelve, or six and 25 in number. Tan and Hunter (2002), on the other hand, claim that a sufficient triad can be derived with a minimum of six elements, and Perner (2012) uses just six elements to understand the ontology for a visual task to describe visual content. Another study by Hassenzahl and Wessler (2000) uses seven design prototypes to explore the relevant information about design space. Due to an inconsistency in researchers' opinions, therefore, seven common visualisations of Southampton University campus map were selected. These seven visualisations were navigation types of visual representation relevant to this study, based on the following criteria:

(1) a common visualisation method of University map, specifically 2D and 3D;

(2) an advanced visualisation method of University map, specifically satellite map, GPS navigation map and augmented reality;

(3) an uncommon visualisation method of University map, specifically sketch and open data format.

The representation of the campus map ignored the three different visualisation methods - heuristic sketch, conceptual diagram and knowledge map. The elements were not represented according to previous classifications and remained Uncategorized. However, the inspected elements generally consisted of features suggested by the literature and shown in Figure 3.2. Figure 3.2 shows that the list of features for visualisation methods (refer to Table 2.6) are reflected in the seven campus maps. For example a 2D map of the Highfield Campus consists of most of the characteristics from all three categories - hence, the way in which respondents' self-organised framework was explored, because this may differ from current visualisation classifications.

VISUALISATION METHODS

CONCEPTUAL DIAGRAM
- ❑ Recognisable through the pre-defined shapes (pyramids, matrices or boxes), lines, dots, items, arrows
- ❑ Consist of analytical data – labelled boxes with embedded text known as entities and relationships
- ❑ Minimizes the complexity of the abstract concepts
- ❑ A concise overview through structured information

KNOWLEDGE MAPS
- ❑ Represented by metaphoric
- ❑ Illustrated by cartographic format, either informational or geographical

HEURISTIC SKETCH
- ❑ Symbolic elements (names, populations and distances)

→ A 2D map of Highfield Campus (M1)

CONCEPTUAL DIAGRAM
- ❑ Recognisable through the pre-defined shapes (pyramids, matrices or boxes), lines, dots, items, arrows
- ❑ Consist of analytical data – labelled boxes with embedded text known as entities and relationships
- ❑ Minimizes the complexity of the abstract concepts
- ❑ A concise overview through structured information

KNOWLEDGE MAPS
- ❑ Illustrated by cartographic format, either informational or geographical

→ A 3D map of Highfield Campus (M2)

CONCEPTUAL DIAGRAM
- ❑ Recognisable through the pre-defined shapes (pyramids, matrices or boxes), lines, dots, items, arrows
- ❑ Consist of analytical data – labelled boxes with embedded text known as entities and relationships
- ❑ Minimizes the complexity of the abstract concepts
- ❑ A concise overview through structured information

KNOWLEDGE MAPS
- ❑ Structured in table format
- ❑ Represented by metaphoric
- ❑ Illustrated by cartographic format, either informational or geographical

HEURISTIC SKETCH
- ❑ Symbolic elements (names, populations and distances)

→ An Open Data format of Highfield Campus (M3)

CONCEPTUAL DIAGRAM
- ❑ Consist of analytical data – labelled boxes with embedded text known as entities and relationships
- ❑ A concise overview through structured information

KNOWLEDGE MAPS
- ❑ Structured in table format
- ❑ Represented by metaphoric
- ❑ Illustrated by cartographic format, either informational or geographical

HEURISTIC SKETCH
- ❑ Symbolic elements (names, populations and distances)

→ A Satellite format of Highfield Campus (M4)

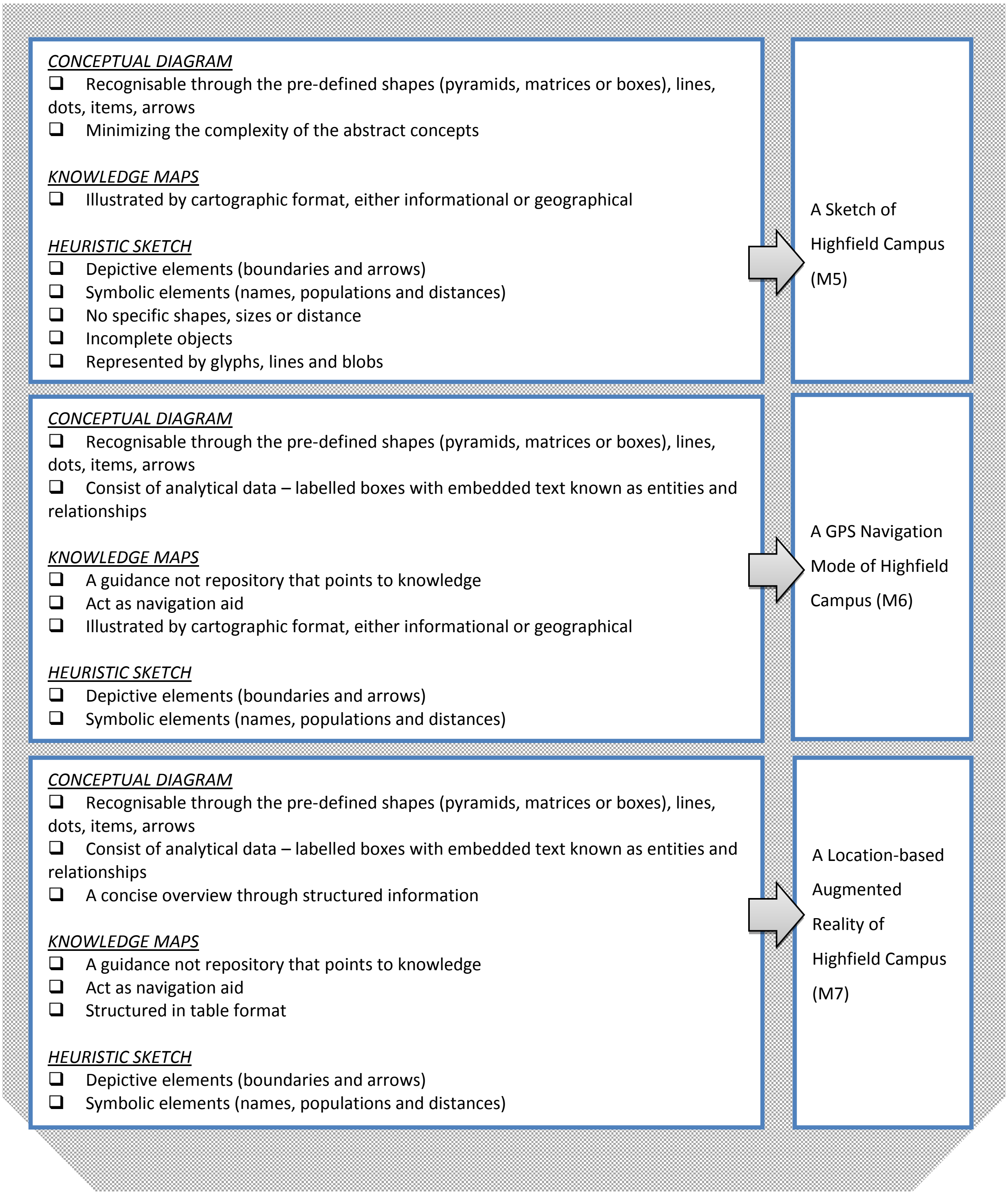


Figure 3.2 List of characteristics of visualisation methods that relate to all seven campus maps

These samples of the Southampton University campus map were mostly gathered from the website **http://maps.southampton.ac.uk/** and were created to fulfil the requirements of varieties. A sample of the campus map can be found in Appendix B.

The maps were presented in standard SmartBoard screen size and labelled with alphanumerics (e.g "*M1*"). The maps of the instrument were presented with no labels to identify their categories. Labels were removed to avoid any prior mindset about current visualisation method classifications.

3.4.4.2 Construct Elicitation

The process of eliciting the construct looks at the way individuals interpret visual representations, and involves questions such as: what type of information did they contain and how useful were they? By applying RGT, potential answers (referred to as constructs) to those questions were elicited at different levels of psychological abstraction (Banister et al., 1994). This technique was essentially made up of interviews and questionnaires. There were three interviewing methods:

a) Triading - the process to elicit the construct by asking respondents to describe a way in which two out of three elements were alike in some way, but different from the third. The respondents were asked to provide a bipolar construct. Instead of interviewing the respondents, an open-ended questionnaire was used to simplify the questions and allow the respondents to elicit the constructs without any interference from the researcher.
b) Laddering - the process of clarifying the constructs given by the respondents in a triading process. This process was conducted using a semi-structured interview.
c) Pyramiding (also known as laddering down) - to elaborate the constructs with more specific characteristics.

A brief explanation of these three methods is given in the following sections and illustrated in an Experimental Flow Chart (see Appendix C).

Triading

The first step in RGT is to provide respondents with triads (Kelly, 1955). In triading, each participant is given three images simultaneously. These images were selected randomly and presented to the respondents through a specific website called *Image Randomizer*.

This website was developed using a Javascript™ platform to randomise the images. A screenshot of *Image Randomizer* is shown in Figure 3.3.

Figure 3.3 A screenshot of Image Randomizer (© GoogleMap and © GPS Navigation)

A particular task scenario was given to the respondents beforehand. They were required to read and understand the task before the first triad was displayed to them. Their responses were based on their preferences in solving the task. The task scenario was as follows:

Isolutions is a department known as the University of Southampton IT Professional Service. The department plays a major role in providing technology and infrastructure for students and staff, such as the internet, email, printing, and other resources. It is possible to contact the department through various online applications and receive a prompt reply. However, for urgent matters such as hardware problems, you are required to access their office. Sometimes it is difficult to find the location because their department is scattered across various university buildings, and Isolutions have offices in several departments. Hence, you have to find different locations of the Isolutions Department through a given campus map.

They were asked "*in what way is one of these maps different from the other two? (specify according to its usefulness to you in finding locations of the Isolutions Department*)". The *usefulness* was referring to the ability to complete the given scenario. The respondents were then required to write down their first opinion (bipolar constructs) by completing the sentence as shown in the questionnaire (see Appendix A). Their opinions of similarity and differences were described in adjective form. For example, one respondent stated:

Example:

Map ***M4*** is ***too crowded and complex*** and Maps ***M5*** & ***M6*** are

(map number) *(different)* *(map number)*

(i)

simple enough to make out the routes/roads/lanes

(similar)

(ii)

The respondents had a tendency to provide an antonym to complete the sentence. But it is important to know that bipolar constructs are not necessarily opposites (Ashleigh and Meyer, 2011). Normally generating a contrast for a bipolar constructs rather than literal opposites could gain more information about visualisation (Hinkle, 2009). This process was repeated with a new set of triads (another combination of three images), until no more constructs were elicited. The triads were presented according to an algorithm arranged to avoid a repetition of the same pairing elements. Respondents were required to produce bipolar constructs per triad. However, in practice there were possibly more constructs, and no construct was produced from a given thread. The respondents were given an option to receive a new triad. The process was to stop when no constructs were produced. Hereafter, the process continued with laddering methods.

Laddering

In the laddering technique, respondents were asked to elaborate on each of their constructs written in the questionnaires. This technique involved a semi-structured interview to clarify the constructs, and participants were asked for more explanation about their constructs. Marsden and Littler (2000) propose the use of the laddering method to elicit more abstract values of the high order construct. In this study, high order constructs refers to the ability of respondents to analyse the visual representation of the campus map thoroughly by giving precise and concise answers. Since it was a participant-driven process, no clues were given to participants and it was expected that answers would be received based on their understanding. Questions were asked such as:

a) Considering the construct of … *(e.g. Too crowded and complex / simple)*, which would you prefer?
b) Why would you prefer the particular constructs?

The laddering methods continued up to three levels of abstraction. These methods could generate more specific constructs, as shown in Figure 3.4.

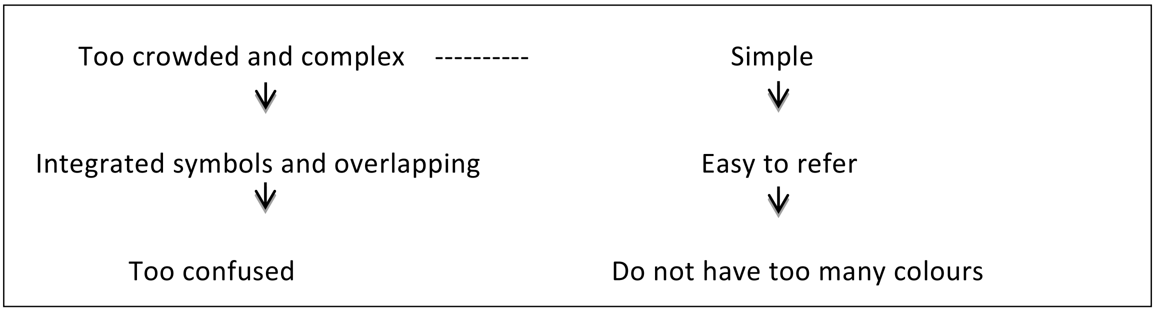


Figure 3.4 Example of laddering method

Another method used to elicit more specific constructs was pyramiding.

Pyramiding

The pyramiding method (also known as laddering down) was conducted to elicit the abstract values of the construct (Marsden and Littler, 2000). For example, the aim in pyramiding was to identify the characteristics that both elements shared. It is different from the laddering method, which asks more 'why' and 'what' questions. In this method, questions were asked such as:

a) Can you give examples for each of these constructs *(e.g. Too crowded and complex / simple)*?
b) Did the examples assist you in getting directions to the Isolution Department?

The pyramiding technique allowed respondents to elaborate the constructs with more specific characteristics, as shown in Figure 3.5.

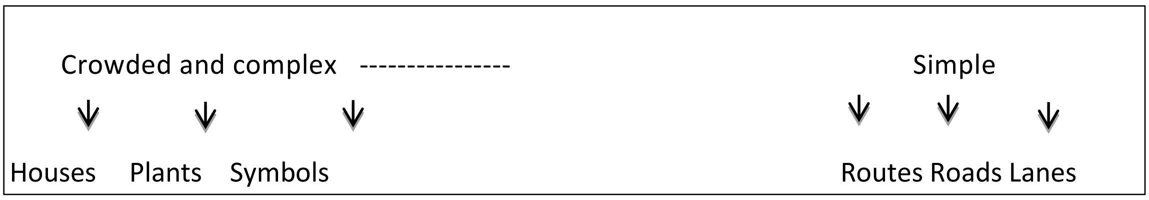


Figure 3.5 Example of pyramiding method

The construct eliciting process stopped when respondents completed the open-ended questionnaires, or gave a signal such as "*I cannot think of anything else to say*". To conclude, all three methods - triading, laddering and pyramiding - were employed in this study (Marsden and Littler, 2000). This elicitation process aimed for numerous adjectives relating to the visualisation of the campus map that were difficult to obtain from other methods. This systematic approach assisted the study in identifying whether constructs attached to particular visualisation methods were different from the classification studies mentioned in the literature. These two processes (laddering and pyramiding) were recorded and transcribed into written form in QSR NVIVO version 10. The written form was essential for conducting a content analysis. The next stage was to quantify the constructs through the rating process.

3.4.4.3 Element Comparison / Rating

In the final stage, each of the constructs had to be rated across all seven campus maps. This process was important to link the constructs to elements. Marsden and Littler (2000) emphasize that the similarities and differences elicited from respondents are important to provide the analytical basis, which in this study was used to identify visualisation classifications.

The respondents were required to rate each construct according to a five point scale. Evidence shows that rating figures do not reflect the inherent meaning in themselves, but "*provide a way in which respondents can position the elements in relative terms on each of their constructs dimensions*" (Marsden and Littler, 2000, p. 821). In this study, the rating was also based on the respondents' preferences in terms of usefulness. This process was recorded in a rating form (Figure 3.6), and respondents were given the opportunity to refer to all seven campus maps (Figure 3.7).

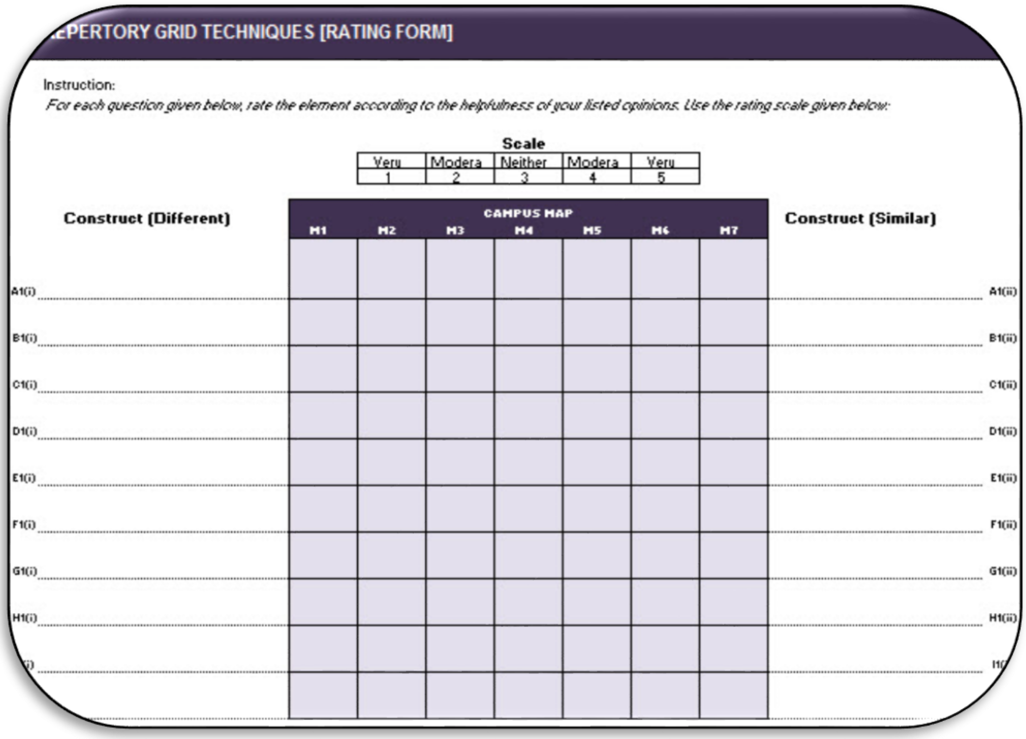


Figure 3.6 The rating form

Figure 3.7 Screenshot of all images

In conclusion, this study has demonstrated several methodological contributions to evaluate visualisation from the user's perception. Firstly, a pragmatic paradigm was uncommon for visualisation research, but clearly had a position in both subjective and objective contexts. A subjective context, known as personal construct was aggregated to provide an objective interpretation. Secondly, this study explains the adoption of a mixed method approach. The integration of qualitative and quantitative analyses was conducted to identify users' perception in visualisation. Finally, this study explored the use of RGT with software application. The software application has shown its practicability within an experimental environment.

3.5 Research Credibility

To confirm research credibility, it is important to examine whether this study has complied with mixed-method principles. Having both quantitative and qualitative methods allowed the study to have a combined validation. Positivism suggests that internal and external validity is the main validation in a quantitative approach (Campbell and Stanley, 1963; Venkatesh *et al.*, 2013) . In contrast, interpretivism focuses on the ability of research to demonstrate three important criteria: trustworthiness, utility and dependability (Lincoln and Guba, 1986; Venkatesh *et al.*, 2013; Zohrabi, 2013). From a pragmatic position, the researcher has followed these rules to examine every phase of the research, including data collection and analysis. These rules are discussed under two headings, described as validity and reliability of research (Zohrabi, 2013).

3.5.1 Validity

In mixed method research, Zohrabi (2013) provides criteria to make sure that the research has been accurately evaluated. Accuracy is measured based on the ability to achieve a purpose to evaluate. The discussion of validity is divided into two elements: internal and external validity.

A. Internal Validity

Internal validity is attained according to how the researcher observes and measures the procedure in conducting a research. Internal validity in mixed methods emphasises two methods of checking, known as triangulation and peer examination.

Triangulation involves the collection of data from multiple techniques, such as questionnaire and interviews. Adopting a RGT allowed this study to use multiple techniques in collecting data. The procedure of collecting involved an open-ended questionnaires, known as triading and rating, whereas the interviews were described as laddering and pyramiding. The data were in both quantitative and qualitative form. Then, constructs elicited from users (qualitative data) were triangulated with components derived from Principal Component Analysis (quantitative data). Triangulation was used to prove the results were not just based on the researcher's own judgement. These steps ruled out any other possible flaws on the obtained results.

Peer examination in this study was demonstrated during a preliminary stage (pilot study). A pilot study is conducted in exactly the same way as the main study. The reason was to produce the projected data and instruments that could be understood by respondents. At the end of the pilot study session, peers commented on the process and instruments. They highlighted any ambiguities in the questionnaires, especially in some examples and instructions. Questions were rephrased to avoid confusion, and ambiguous instructions were removed from the questionnaires. They suggested that the time taken to complete the whole process was not reasonable, and that the questionnaires should be shortened to avoid dissatisfied respondents. The number of questionnaires was reduced to ten, which proved to be more than sufficient. Therefore, peer examination helped to confirm that this construct had a strong validity (Roda *et al.*, 2011).

Zohrabi (2013) suggested that peer examination is also important to validate research findings, and hence it was used in this study. Several non-participants were asked to review and comment on 13 factors derived from a qualitative analysis and three major classifications of visualisation methods features. They had been briefed on the process and data were shown to gain their comments. Their comments were mostly on the broad categories (known as factors) and were more reflective about the sub-categories (themes and groups of words). There were some cases that required changes because the sub-categories were considered redundant. Changes were made according to their comments, and as a result the peers tremendously increased the validity of the research findings.

The findings from this study (13 factors and features of visualisation methods based on users' perceptions) was validated in the IEEE 9th International Conference on Research Challenges in Information Science 2015 by practitioners and academia in visualisation. They are experts in the field, were familiar with the subject and were not directly involved in the study. Those who were interested in the study had the opportunity to ask questions and offer comments face-to-face based on presentations supported by a poster. They agreed that these factors were derived from a thorough process, and showed a meaningful interpretation. Although there were some suggestions that several factors should become sub-factors, after discussion they agreed that the 13 factors and three major classifications of visualisation features were best reflected as they were.

B. External validity

Research with high external validity can be achieved if the findings can be generalised or transferred to other contexts or subjects (Venkatesh *et al.*, 2013). In a mixed methods study, quantitative findings can be generalised in the form of visualisation guidelines. Guidelines such as classifications of visualisation can be adapted to other contexts, such as business or social context. On the contrary, qualitative findings are related to transferability. Providing users' insights makes transferability possible in term of understanding the nature of users, as discussed in Section 3.4.2.

In conclusion, this section has discussed the two aspects of validity. Both internal and external validity was used to validate the research procedure, increasing the credibility of this research. Further discussion on research credibility will focus on reliability.

3.5.2 Reliability

Reliability in research concerned with consistency, dependability and replicability (Zohrabi, 2013). Several techniques have been suggested to improve reliability, but, only triangulation and audit trial techniques were conducted in this study. Triangulation was conducted by collecting data from multiple techniques, which were questionnaires and interviews. Questionnaires were represented in a triading and rating form, where respondents had to complete a sentence, followed by an interview. The triangulations were able to strengthen responses by clarifying all the given answers. Whereas audit trials were explicitly explained, a comprehensive procedure about data collection and analysis is shown in Section 3.4 (Repertory Grid Technique). A comprehensive explanation was useful for other researchers to replicate this study, although replicability can be related to most quantitative research. The two techniques described above contribute to increase the reliability of this study. In mixed method research, the two criteria of consistency and dependability are important to discuss.

A. Internal reliability

Generally, internal reliability is related to how consistent the research was in conducting the collecting, analysing and interpreting of data. Reliability is measured by how reliably the adopted methods produce similar results in other situations. A few strategies suggested by Zohrabi (2013) ensure that the method used has a low inference descriptor. A low inference descriptor indicates the ability to easily replicate by asking a specific question. This study follows a RGT that consists of three construct elicitation techniques. Each technique has a pre-defined question that allows replication easily. The first technique asked respondents to describe how two out of three elements were alike in some way, but different from the third. This technique was facilitated by an application known as *Image randomizer* that can be replicated in other contexts. A second technique, clarifying the constructs given by the respondents in a semi-structured interview, consisted of laddering and pyramiding to elaborate the constructs with more specific characteristics. The third technique asked respondents to give a rating for each of the constructs across all seven campus maps. The next strategy indicates that an interview can be recorded. During a semi-structured interview, all responses were recorded in a structured way, based on written answers. By using a RGT, this study has confirmed its internal reliability because the technique has been adapted by most disciplines. Thus, the study has shown its level of consistency and potential for transferability.

A. External reliability

The external reliability of this study was described based on five important criteria. These criteria were: researcher, respondents, context, instruments and data collection methods. The first criterion indicates that the researcher needed to have a position which, in this case, was towards a pragmatism to specifically study the subjective factors objectively. The second criterion was related to the choice of respondents. Respondents were chosen based on availability, homogeneity in age and education level, willingness to participate and being a cheaper resource. They were a cheaper resource because it mostly only required a small amount of money to encourage respondents to participate. The third criterion refers to the HE context, which was uniform for respondents. A manageable sample from three schools was chosen. The responses derived in the experimental process were gathered from the same sample group. Although the sample gathered was small, it had a large impact in filling the research gap (Roda *et al.*, 2011). The fourth criterion was about instruments that should be defined explicitly. This study defines instruments explicitly by adopting a RGT that consisted of a pre-defined question. This technique allows replication of the study. The final criterion was the data collection method. The experimental tasks involved in RGT were explained, starting with construct elicitation (triading, laddering, pyramiding) and element comparison (rating). This RGT data was managed by realistic software known as Idiogrid version 2.4. The method used demonstrated that adopting a RGT can produce reliable results.

To conclude, this section has explained validity and credibility. From a pragmatic point of view, the credibility of this study has been proven through these two measurements.

3.6 Ethical Consideration

This study was obliged to comply with the requirements established by the Data Protection Act in the areas of consent, anonymity and confidentiality when collecting and analysing personal data for the research purposes. If there were questions that respondents found distressing, they were free to not answer those questions, or to withdraw from participating. Withdrawing at any time would not cause any penalty, even after having given consent to participate. This study could not guarantee total anonymity, because it involved interviews. However, the researcher did not exploit the information given by respondents for other purposes. The findings gathered from the analysis did not indicate who provided particular data. This study does not intend to publish participant information with another party, and the participants remain anonymous in public. Only the researcher has access to the participants' personal details. All documentation has been labelled and kept in a folder in the researcher's cabinet. Once the documentation was ready for analysis, it was transformed into digital format, with password required to access the data.

A risk assessment was conducted before the interviews began. In order to comply with Health and Safety regulations, a specific room within the School of Management was booked and used for the whole interview process.

3.7 Limitations

Although this study followed a thorough experimental procedure as planned, it still faced a few limitations, namely the sample size and lack of prior research studies on the topic. These limitations have been acknowledged in the study, and their impact briefly assessed.

The sample size was appropriate for the study but still considered as small to represent the population. The duration of the experimental procedure was considered too long by some respondents, and this limited the number of participants. Not many respondents were willing to give up an hour of their time. Although this study did not provide a large sample, those who participated gave it their full attention, and highly valuable data was gained during the study.

Another limitation was lack of prior research studies focused on evaluating visualisation navigation based on users' perception. The researcher was aware of the scarcity of literature to provide a guideline in choosing a method that could reflect the results. However, by adopting uncommon paradigms, this study offers a methodological contribution to visualisation studies.

Chapter 4: Data Analysis

4.1 Introduction

This chapter provides evidence to support the adoption of RGT in evaluating user experience when using visualisation navigation. The RGT presented in this chapter demonstrates how these values were accomplished

- To elicit factors in evaluating visualisation navigation in the minds of the users
- To explore the importance of the relationship between the elicited factors
- To construct a classification of features related to visualisation navigation based on users' perceptions

The chapter begins by presenting a demographic distribution of respondents, as shown in Table 4.l. 48 respondents were recruited for the experimental procedures. They were first year students of Southampton University (undergraduate and postgraduate) from three disciplines, Management, Psychology and Computer Science. These three disciplines were important to represent several lenses in previous visualisation research. A knowledge visualisation topic is part of the syllabus, so awareness of the topic was probably greater than normal. 21 males and 27 females participated in the study. The participant age range was from 21 to 25 years old. Respondents possessed a 2D campus map received during induction week, but admitted that they were not yet familiar with it. Samples gathered were not equally spread between the three disciplines and could not truly represent their populations. Since no comparison between disciplines was made, the distribution of respondents' discipline was not included in the Table 4.1.

Table 4.1 Demographic information

	Gender		Total
Age	Male	Female	
20 and below	3	4	7
21-25	9	14	23
26-30	4	6	10
31-35	3	3	6
36 and above	2	0	2
Total	21	27	48

The information in Table 4.1 was later analysed to identify significant differences of gender and age in defining the usefulness of visualisation. The next section explains data analysis techniques for RGT.

4.2 Data Analysis Techniques for RGT

Data analysis techniques and application software for RGT used by several scholars was examined. Eight articles, as summarized in Table 4.2, present the list of data analysis techniques and application software used in the analysis process. Scholars have usually adopted either quantitative or qualitative techniques in past studies. For instance, a principal component analysis and cluster analysis are used to analyse quantitative data. Some quantitative analysis is supported by applications such as SCI: vesco® (Berger and Hari, 2012) and PREFAN (Marsden and Littler, 2000). The benefit of the quantitative approach of RGT is to convey binary oppositions to identify features and design a visualisation that resembles the way information is processed by human beings. In contrast, thematic analysis and discourse analysis are quite common for a qualitative approach. Scholars have also been interested in identifying the meaning of constructs. For example, Birdi (2011) uses a thematic analysis to analyse grid data based on statements elicited from respondents. In addition, the qualitative approach can explore data behaviour that may not be discovered in quantitative analysis. A purely statistical analysis can reduce the wealth of meaning of data. This is supported by Easterby-Smith *et al.* (1996, p. 24), who state that “*any analysis must be referenced against a qualitative appreciation of the data’s meaning”*. They suggest that quantitative analysis of the grid be used as complementary to qualitative analysis.

Table 4.2 Data analysis techniques for RGT

Title	**Data Analysis Techniques**	**Application Software**
Berger and Hari (2012)	Suitable for single grid ▪ Principal Component Analysis (PCA) ▪ Cluster Analysis ▪ Individual Structural Analysis	sci:vesco® version 3.0
Birdi (2011)	Suitable for multiple grid ▪ Thematic Analysis ▪ Theme-Construct-Polar Constructs	Not stated in the paper
Tan, Tung and Xu (2009)	Suitable for multiple grid ▪ Three-layer classification scheme ▪ Class, conceptualisation and meta-category	EW Software
Tan and Hunter (2002)	▪ Linguistic analysis Analyse common constructs ▪ Q-type factor analysis and Multidimensional scaling (MDS) ▪ Multivariate technique	Not stated in the paper
Marsden and Littler (2000)	Principal Component Analysis ▪ Analyse group of questionnaires aligned with the elements	PREFAN
Hassenzahl and Wessler (2000)	Pathfinder Network Analysis	Knowledge Network Organizing Tool (KNOT)
Easterby-Smith, Thorpe and Holman (1996)	Quantitative ▪ Cluster Analysis and Tree representations ▪ Spatial analysis/principal component analysis Qualitative ▪ Discourse and Social Psychology ▪ Discovery of grounded theory	Not stated in the paper
Dillon and McKnight (1990)	Cluster Analysis	FOCUS Programme

Since this study involved both quantitative and qualitative techniques, both data analysis techniques were taken into consideration. A quantitative analysis was used to define a classification of features related to visualisation navigation, whereas qualitative techniques were used to identify factors when evaluating visualisation navigation in the minds of the users.

The data analysis technique adopted in this study is shown in Figure 4.1. This figure explains how these techniques were merged to show its relevancy to this study. The technique starts with a quantitative, a qualitative and a mixed method matrix approach. The first technique, which demonstrates a quantitative approach, was performed by a Principal Component Analysis (PCA). PCA was used to identify and classify features of visualisation methods. The identification and classification process began with construct correlations between the bipolar constructs (triading). Construct correlation produced a list of constructs related to a particular group known as components. These components were important for developing a visualisation classification of features based on users' perceptions. The grid result obtained from the PCA analysis was also extended to identify and validate the relationship between elicited constructs and elements (referring to the seven campus maps). This technique was able to provide the underlying dimensions of data.

The second technique, which focuses on the qualitative approach, was the aggregation of thematic analysis and three layer classification. This technique was used to identify factors elicited from statements given by respondents. These factors describe how respondents perceived the usefulness of visualisation.

In the final stage, results derived from quantitative and qualitative techniques have produced a mixed method matrix, highlighting themes of features for each component. A matrix to compare highest loading constructs for each component (PCA results) with factors elicited from respondents' statements (aggregation of thematic analysis and three layer classification scheme) was conducted. The matrix has provided comprehensive classification features of visualisation methods based on users' perceptions.

The next section of this study will describe how each of these three approaches (quantitative, qualitative and mixed method matrix) were used to obtain results.

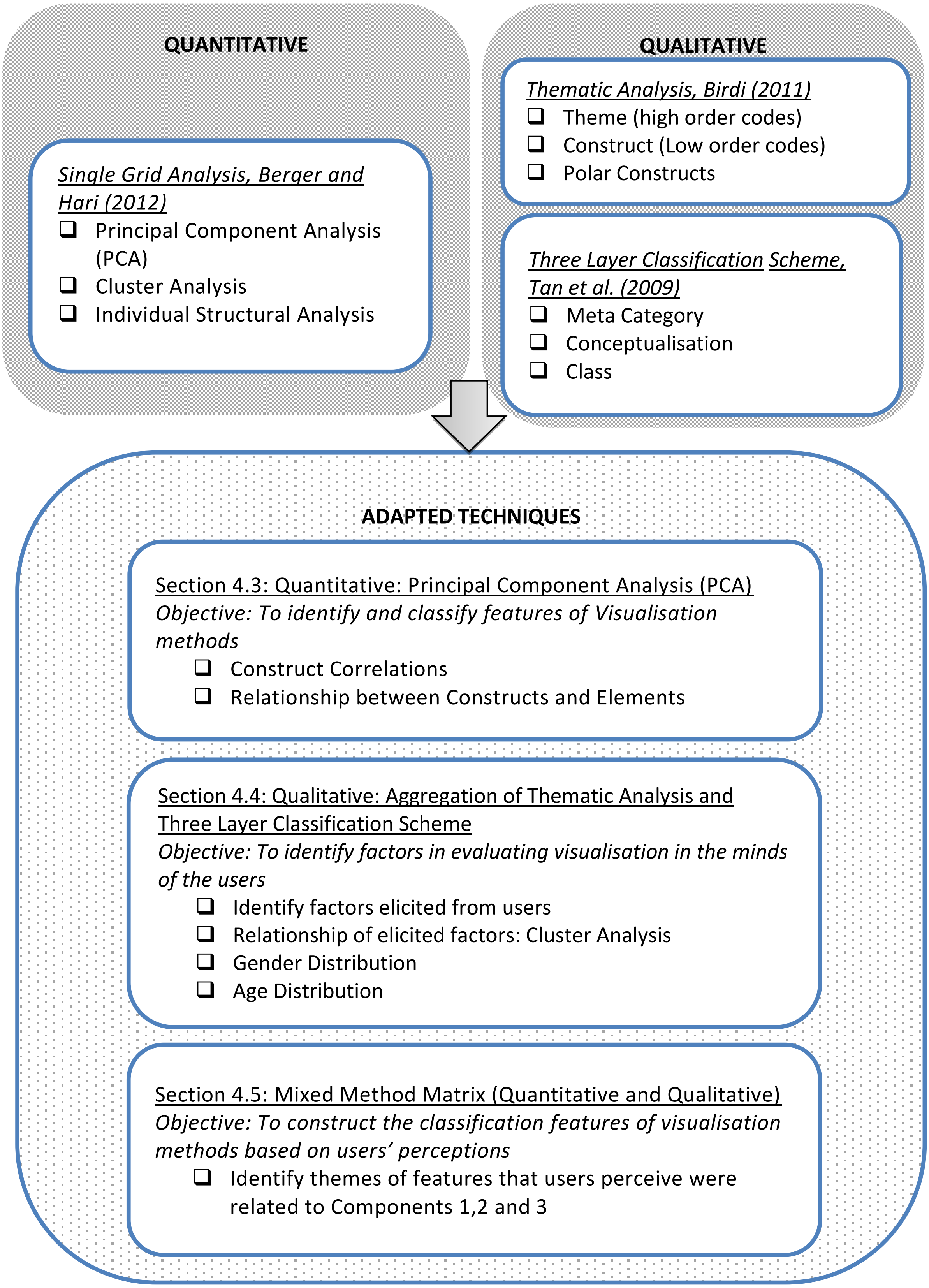


Figure 4.1 The adapted techniques for data analysis

4.3 Quantitative: Principal Component Analysis (PCA)

Berger and Hari (2012) demonstrated the use of RGT in order to understand personal construct systems using a quantitative approach. They discussed a single grid analysis: PCA, Cluster Analysis and Individual Structural Analysis in their paper. However, only PCA was employed in this study because its ability to identify and classify features of visualisation methods. By using PCA, "the observed variables is reduced to a number of principal components which account for most of the variance of the observed variables" (Diana, 2005, p. 1). The analysis was divided into two parts,

a) to identify the highly correlated features (referred to as constructs)
b) to plot the seven campus maps (referred to as elements) to features (referred to as constructs)

There are several types of software available to facilitate Principal Component Analysis specifically for RGT, such as Grid Analysis Package (GAP) (Slater, 1997), PREFAN (Marsden and Littler, 2000), INGRID (Fournier, 1996), Omni Grid (Sewell *et al.*, 1992), WinGrid, IdioGrid, PC-Grid (Metzler and Magargal, 1994), BASIC Repgrid Program, Circumgrid (Chambers and Grice, 1986), RepGridIV, and Web Grid. However, this study was facilitated by Idiogrid version 2.4 (Heine, 2009), based on its availability and reliability to perform the analysis. A summary of quantitative analysis is demonstrated in Figure 4.2.

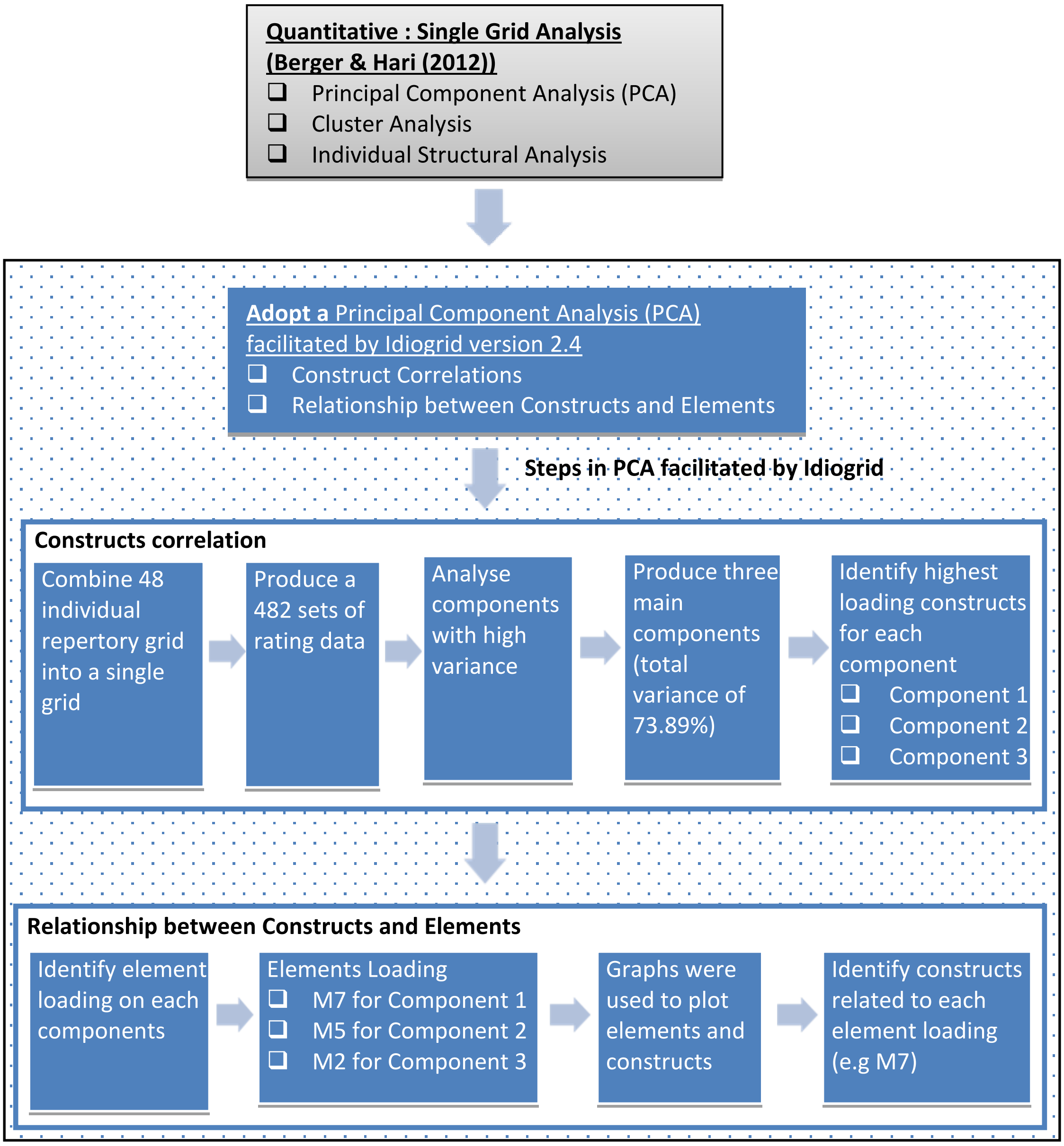


Figure 4.2 Quantitative analysis by PCA

4.3.1 Construct Correlations

A correlation among constructs was conducted to obtain a meaningful interpretation of large samples. Hence, this study has combined data from a multiple grid of 48 respondents to produce a single grid. Scholars (Cassell and Walsh, 2004) argue that grouping or finding themes of several personal constructs cannot be regarded as 'personal construct'. However, this study attempts to propose a collective of personal constructs which do not affect the value of individual constructs. A study by Birdi (2011) demonstrates the benefits of PCA, which not only increases the value of construct, but also reorganises it into a meaningful interpretation.

PCA combined the information from the individual RGT questionnaires into a single grid, with the number of elements equal to those in common in all the grids, and the number of constructs equal to the sum of those in each grid (Marsden and Littler, 2000). This study has combined 48 multiple grids consisting of seven elements and ten constructs, except for one grid that had 12 constructs. The additional two constructs did not affect the purpose of identifying highly correlated features defined by users. According to Marsden and Littler (2000), this is known as idiographic and nomothetic technique. The idiographic approach allowed participants to produce their own personal constructs, while the nomothetic allowed correlations between the constructs.

The sample data taken from Idiogrid version 2.4 shows the way the construct was rated. All elicited constructs (also known as emergent and implicit) are listed in one column. There are 482 sets of rating data derived from a minimum of ten bipolar constructs of 48 respondents. These constructs, gathered from two poles, represent the similarities (emergent) and differences (implicit). Table 4.3 shows 24 constructs from three respondents as a sample of rating data. This figure shows that the same rating scale for different elements represented a meaning. For example, a red mark highlighted how *M1, M2 and M3* were perceived as *attractive* compared with other elements.

Table 4.3 Sample of Rating Data

Constructs		Elements						
***Similar**	***Different**	**M1 2D**	**M2 3D**	**M3 Open data**	**M4 Google Map**	**M5 Sketch**	**M6 GPS Navigation**	**M7 Augmented Reality**
Noisy	Easier to find location	2	1	2	4	5	2	2
General Image	Helpful quick guidance	4	5	4	4	3	1	1
Functional	Navigation	5	1	5	5	3	2	2
Provide relative size of location	Not filled with useful information	5	5	5	4	1	3	3
Easier to find position	Not giving guidance	1	2	1	1	3	5	5
Easier to use	Very confusing	4	4	4	2	1	5	5
Traditional Map	Tracking/Navigation	5	5	5	5	3	1	1
Clear information	Hard to find a place	4	5	4	4	1	1	1
Just showing the locations	Useful to find nearby location	1	5	1	1	3	3	3
Public Notice	Self-oriented	5	5	5	5	3	1	1
Complete Map	Not a complete map	4	5	4	3	2	2	3
Clear	Too high	4	5	5	1	4	5	5
Useful for navigation	No building number	5	5	1	1	1	1	5
Clear depiction	Too much labelling	2	5	1	1	3	2	5
Well labelled	Not clear location	5	5	5	5	2	3	5
Completed and clear	Not clear direction	5	5	4	4	3	2	5
Attractive	Dull	5	5	5	3	1	4	3
Incomplete	Clear instructions	1	1	5	5	4	2	1
Good depictions	Show what is needed	5	5	4	1	1	3	5
Dull	Clear	1	1	1	5	5	2	1
Similar	Different	4	2	4	4	4	2	1
Google map	3D image	5	1	5	5	5	2	1
A bit messy	Easy to find road	4	1	5	5	3	4	1
Not very clear	Give direction	1	2	2	5	2	2	1

**Note: Rating score was arranged as: High Score for Similar= Very (5), Moderately (4) or Neither/Both (3)*
Low Score for Different = Neither/Both (3), Moderately (2) or Very (1)

Results obtained from Principal Component Analysis identified six components and their high variance constructs. Easterby-Smith *et al.* (1996) suggest analysing components with high variance, because this variance indicates the levels of importance. Table 4.4 shows that three components account for a total variance of about 73.89%. Component 1 accounts for 37.51% of the variance, Component 2 accounts for 19.00% and Component 3 accounts for 17.39%. However, Components 4, 5 and 6 were ignored because they account for significantly less variance.

Based on these results, the first three components were used for further analysis. It was suggested that rotated eigenvectors (factors) should be used to achieve a more simple structure (Bryant and Yarnold, 1995). A varimax rotation was selected to perform this task because these components were believed to be uncorrelated (Brown, 2009). Table 4.4 shows the Eigenvalues for Varimax Rotated Components.

Table 4.4 Eigenvalues for Varimax Rotated Components

Component	**Variance (%)**	**Cumulative Variance (%)**
1	37.51	37.51
2	19.00	56.50
3	17.39	73.89
4	9.88	83.77
5	8.91	92.67
6	7.33	100.00

Results in Appendix D.2, D.3 and D.4 show a number of constructs correlate with Components 1, 2 and 3. The analysis of constructs' relationships was measured by the highest loading constructs related to each component (Marsden and Littler, 2000). The highest loading constructs were defined only by variance greater or equal to 0.7 for each component (Heine, 2009).

In summary, these results show an association between constructs that were grouped into three components. Table 4.5 provides a summary of these relationships.

Table 4.5 Highest loading constructs for each component

Component 1	**Component 2**	**Component 3**
❑ Navigation guide	❑ Boundaries are not clear	❑ Numbers
❑ Maps with navigation	❑ (Just numbered) complicated	❑ Provide building number
❑ Giving precise directions	❑ Not clear	❑ Showing numbered buildings
❑ Provide direction	❑ Blank	❑ Able to give direction
❑ Idea about distance	❑ Rational, boring	❑ Useful (building numbers)
❑ Answer the questions	❑ More lifelike	❑ Comfortable, easy
❑ Has a GPS navigation	❑ Drawing	❑ Giving details
❑ Both navigation methods	❑ No services shown	❑ Marks
❑ Show my locations	❑ Single sign	❑ Numbering
❑ Whole picture/interactive	❑ Give surround buildings	❑ Have text in picture
❑ Giving directions	❑ Simple location and building	❑ Having information of building names and number
❑ Relative to the viewer's position	❑ Noisy	❑ No clear info about the distance
❑ Appealing and no reference		❑ Have a road name
❑ Easier to find position		❑ Lead to right place
❑ Simple		❑ Showing pedestrian way
❑ Use directions		❑ Easy to interpret
❑ Sensible, clear		❑ Just the campus
❑ User-friendly		❑ Showing buildings and streets
❑ Not clear		❑ For detailing
❑ Related to the viewer's position		❑ Useful for navigation
❑ Real picture		❑ Clear
❑ Mobile apps		❑ Colourful, clear
❑ Clear		❑ Simpler
❑ Giving direction		❑ Show the way to destinations
❑ Easy to find location		❑ Organised
❑ Lack of information		❑ Bird's eye view
❑ Can't be interested		❑ Show new additions
❑ Not helpful (no signs)		❑ Number, symbol
❑ Real environment		❑ General look
❑ Not useful		❑ Have name of buildings
❑ Natural images		❑ Showing buildings
❑ Real-life photography		
❑ Focus on actual university		
❑ Guide to specific building		
❑ Real photos		
❑ Show location		
❑ Real-life imagery		
❑ Google maps		

Note: A few similar keywords were only mentioned once in the list (e.g *Navigation guide* and *Not clear*).

By adopting Principal Component Analysis (PCA), further analysis of the relationship between constructs and elements can be identified, as explained in the next section.

4.3.2 Relationship between Constructs and Elements

The ability to identify a relationship between constructs and elements is one of the important features of RGT. In this study, constructs represent features based on users' perceptions, whereas elements represent seven campus maps. Users provided a rating for their elicited constructs to determine whether these constructs existed for each campus maps. To demonstrate this relationship, PCA has "*the ability to plot elements in relation to constructs*" (Easterby-Smith *et al.*, 1996, p. 23).

The first step of the analysis was to identify elements loading for each component. Only the highest loading elements (refer to Table 4.6) were chosen, because of the limited number of campus maps involved in this study (Marsden and Littler, 2000). Four other campus maps (M1, M3, M4 and M6) were ignored because they show less relation to any component.

Table 4.6 Elements loading on each component

Components	Elements Loading	Value
Component 1	M7	9.28
Component 2	M5	8.50
Component 3	M2	5.46

Graphs were used to determine relationship between the related constructs and elements, related to particular components. Once all elements and constructs had been plotted in a graph, the distance between three elements (M7, M5 and M2) and constructs was analysed. The distance shows "*how important the construct is to that element*" (Easterby-Smith *et al.*, 1996, p. 23). Prior to that, '*Suppress Construct Labels*' were set to 0.70 to prevent any constructs with a value of less than 0.70 being plotted in the graph. All constructs related to these three elements for each component are shown in Appendix D.6 - D.8. The location for each element was measured consistently using the same scale (illustrated by a *blue triangle* in Appendix D.6 - D.8). The b*lue triangle* is 6.56cm high and 2.3cm wide. It has a blue downward diagonal pattern fill. This can be illustrated briefly by explaining the constructs related to one of the elements. An example from Figure 4.3 (constructs recognised as important for M7) was used, based on the location of the construct plotted on a graph. It can be concluded that M7 was highly defined by those constructs.

- ✓ Idea about distance
- ✓ Navigation Guide
- ✓ Whole picture/ Interactive
- ✓ Relative to the viewer's position
- ✓ Show my locations

- ✓ Provide direction
- ✓ Giving precise directions
- ✓ Maps with navigation

Figure 4.3 Illustration of constructs recognised as important for M7

For confirmation, the list of constructs related to M7 was compared with the original grid. All constructs which were relatively close to M7 (Figure 4.2) are presented in the original grid in Table 4.7. Based on the original grid, M7 was rated *'very'* on each construct.

Table 4.7 Original grid

Constructs		**Elements**						
***Similar**	***Different**	**M1**	**M2**	**M3**	**M4**	**M5**	**M6**	**M7**
Idea about distance	Does not give directions	1	1	1	1	1	4	5
Navigation guide	Map	1	1	1	1	1	5	5
Whole picture/interactive	Real time picture/interactive	1	2	1	1	1	5	5
Relative to the viewer's position	Overall for the campus	1	2	1	1	1	4	5
Show my locations	The whole campus	1	2	1	1	1	5	5
Provide direction	Just a map	1	1	1	1	1	5	5
Giving precise directions	Overall view	1	1	1	1	1	5	5
Maps with navigation	*Maps without navigation*	1	1	1	1	1	5	5

**Note: Based on the Idiogrid requirement, rating score was arranged as:*

High Score for Similar= Very (5), Moderately (4) or Neither/Both (3)

Low Score for Different = Neither/Both (3), Moderately (2) or Very (1)

These results suggest that there was a relationship between: 1) constructs and constructs and 2) constructs and elements. The first relationship was among features of visualisation navigation for the three components. The second relationship was between features of visualisation navigation for the three components with the campus map. According to Hinkle (2009), the use of RGTs not only elicits a positive feature, but also generates negative impressions of visualisation. Thus, to further understand the meaning of these criteria, justification from respondents was required. During an interview session, respondents were asked to explain most of their answers. Their answers or statements were used to explain the factors that they believed were useful for a visualisation. Hence, a qualitative approach to analyse respondents' answers was conducted in the next section.

4.4 Qualitative: Aggregation of Thematic Analysis and Three Layer Classification Scheme

4.4.1 Identify factors elicited from respondents

This analysis was specifically to identify factors in evaluating visualisation methods in the minds of the respondents. By aggregating a thematic analysis (Birdi, 2011) and three layer classifications scheme (Tan *et al.*, 2009), hierarchical factors of the data were produced. The aggregation of techniques from these two studies was essential to give a high value of elicited factors. Thematic analysis emphasised the content, which provided the coding procedure to identify the themes, whereas the three layer classification scheme emphasized the hierarchy procedure of classifications. Both are well-defined coding techniques that provided extremely useful assistance to this study. The aggregation has produced three hierarchy of qualitative analysis that is factors (high order codes), theme (low level codes) and group of words. The aggregation process is demonstrated in Figure 4.4.

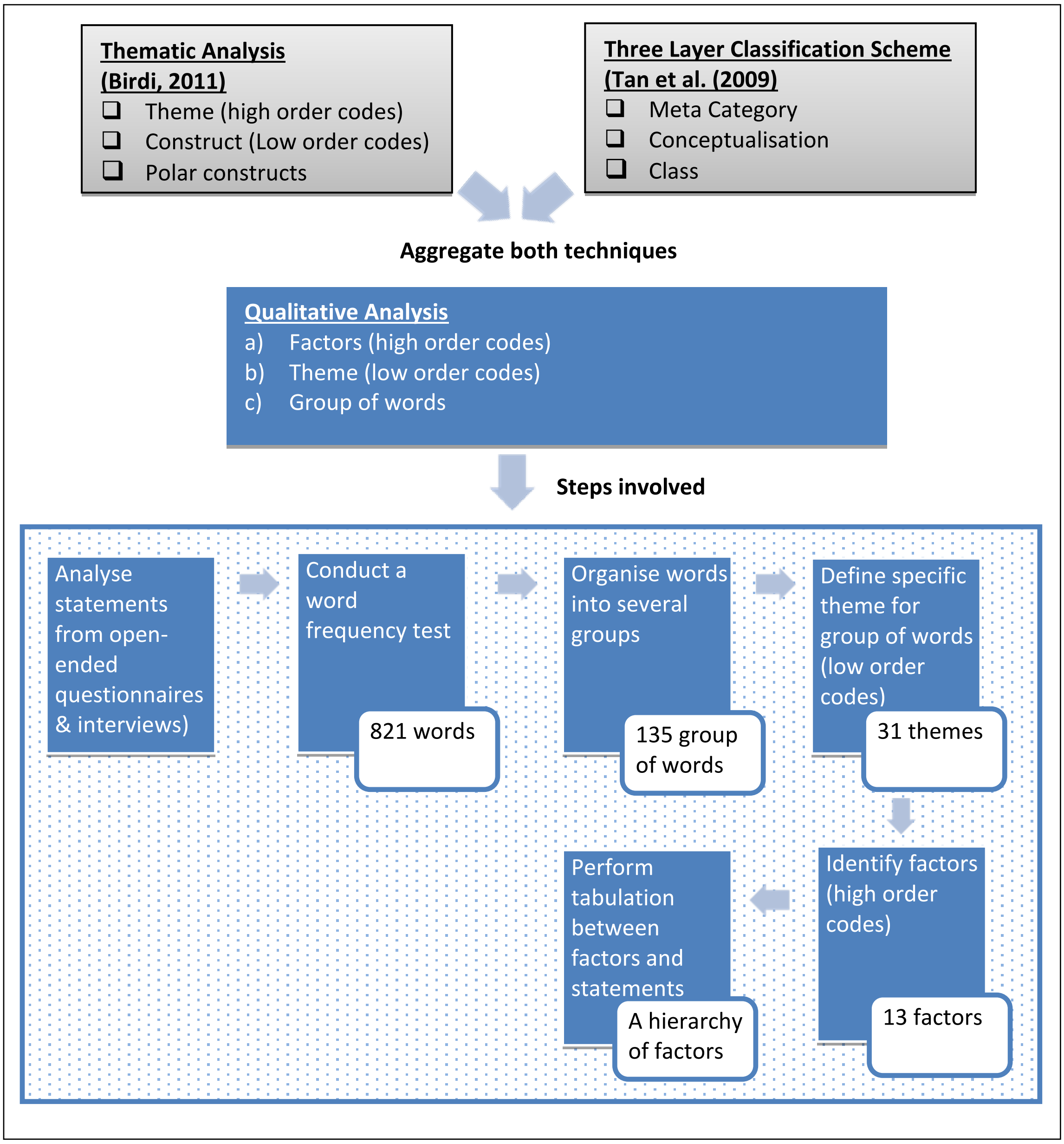


Figure 4.4 The aggregation of thematic analysis and three layer classification scheme

The process began by analysing the statements from open-ended questionnaires and interviews. These statements, elicited from 48 respondents, were recorded in QSR NVIVO version 10. A minimum of ten statements were elicited from each respondent. Data has been grouped by respondent in a separate source file. Samples of statements from two respondents are shown in Appendix E.1. This step as explained by Braun and Clarke (2006) called familiarising with the data. Data in a form of statements were recorded and rereading to get the initial ideas. Transcribing data through QSR NVIVO to generate the initial code is easier compared to manual coding.

Once the statements were recorded, the next step is to develop a coding scheme. Coding scheme can be either manual or by using a tool. Tool supported by NVIVO called a word frequency test was performed because it is more reliable. A word frequency test has listed 821 words, including synonyms. Several common words were excluded in this frequency test using a *stop words list* (for example 'is', 'a', 'are', 'and', 'map, 'Isolutions', 'M1', '32', 'triad', 'similar', 'different'). Each listed words were assessed by referring to the original source. The word frequency gave a sense of the data which assisted in grouping the words. By clicking on each word, all the instances can be viewed to assess its suitability for a meaningful interpretation. If the word does not make any sense to a group of words then it has been ignored. Not all the results are meaningful as indications of concepts, for example was 'just', used in several different senses of meaning and thus not lending itself to any particular groups of words, so judgement will still be needed to select coding categories, but some useful information can be seen very quickly. Compared to manual coding, the use of word frequency output has improved the reliability of analysis. Appendix E.2 shows the sample of words derived from word frequency queries.

The next step of this qualitative analysis was to check if these words are belong to any group. This process were done manually by researcher, however an NVIVO software was used to cross check the words grouping by creating a specific nodes for each groups. Grouping words were based on words of a similar meaning and cross reference with statements elicited from respondents to ensure that it is meaningful. In total, 135 groups of words were obtained from this analysis. A sample of several groups of words is summarized in Appendix E.3. The table shows the number of sources, reference codes and coverage for each group of words. For demonstration purposes, only two sources (*Source 1* and *Source 2*) referring to only ten groups of words was presented. These *sources* do not reflect the same sources, but are intended to show the number of coded sources. These *sources* are followed by references *coded* to indicate the volume of data coded. Additional information, such as coverage of the source coded at the node is also included. These groups of words belong to one theme that will be explained at the end of the analysis.

Once a 135 groups of words is derived, an ongoing analysis for defining a specific theme was conducted. With a support from NVIVO, two levels of thematic analysis were conducted, known as low order and high order codes. The first level of thematic analysis was the low order codes correspond to narrow, focused themes, while the second level known as high order codes are for broader themes. These groups of words were arranged based on similarity of meaning to produce low order codes. For instance, a group of words such as '*clarity',* *'perspectives', 'simplicity', 'general look', ' old', 'organised', 'traditional', 'apparent', 'abstract'* and *'precision'* was related to '*visual appearance'*. Therefore, the word 'visual appearance' was produced to provide a meaningful theme. This process continues until the group of words were completely defined. In total, 31 themes were derived for example 'visual appearance', 'information elements', 'roles' , 'physical structure', 'colour usage' and 'legends'. A hierarchy of the complete themes including their groups of words are summarized in Appendix E.4.

The second level of thematic analysis is to identify a broader theme. This process is known as high order codes that included the researcher's own judgement. Another hierarchy of node were created to group 31 themes and a list of factors was established. The results suggest that visualisation has 13 distinct factors that show the way respondents perceived visualisation usefulness. These factors and the respective themes are demonstrated in Appendix E.5.

The final stage of qualitative analysis is to establish a complete hierarchy of factors. To demonstrate relatively more important factors, tabulation between factors and statements was performed, showing the volume of statements made by respondents. The frequency of statements derived from this tabulation provided a hierarchy of factors. Table 4.8 gives a brief description of each factor, including its frequency. The results in this analysis provide more opportunity for further discussion that can relate to the research question and literature.

Table 4.8 Frequency of factors

Factors	**No of statements**	**Description**
Graphic Design	514	Describes the importance of design principles concerning colour usage, graphic elements, angle and focal point to communicate ideas.
Visual Utility	335	Relates to visual appearance and visual identity that would be more appealing and understandable to users.
Presentation of Information	264	Indicates an implication of having an information structure and elements that are relevant to present information.
Functionality	214	Mainly concentrates on the practicality of visualisation based on roles, usability and benefits.
Text Design	144	Covers the typography usage by examining its readability.
Challenges	105	Highlights particular limitations while applying visualisation.
Human Cognition	62	Indicates human processing ability in creating, codifying and applying knowledge.
Resemblance with Reality	60	Interprets visualisation by identifying objects that mirror reality.
Technology Intervention	52	Relates to the use of hardware and software in visual representation.
Human Behaviour	46	Emphasis on human experience specifically related to emotion and attitude towards visualisation.
Navigation Aid	27	Refers to markers used to give directions or guidance during a navigation process.
Visual Communication	27	Concerns the visual ability to communicate ideas and provide interaction with the target audience.
Benchmark	2	Focus on a standard and measurement that represents a role and function of visualisation.

The results show a hierarchy of usefulness factors elicited from users' perceptions. This factor has been ranked in order of frequency of statements. The most elicited factors were Graphic Design whereas the least elicited factors were Benchmark. These 13 factors were used to define features for the visualisation navigation methods, and could provide insights for designers to develop a visualisation appropriate for users' requirements. A complete list of hierarchical factors, including themes and groups of words is shown in Appendix E.6.

4.4.2 Relationship of elicited factors: Cluster Analysis

These 13 factors in Table 4.8 may closely relate to one another, hence a Cluster Analysis was performed to identify their relationship. The cluster analysis was calculated based on *word similarity* by using *Pearson Correlation Coefficient* (Tan *et al.*, 2009). Results in Appendix E.7 show that these factors indicate a strong positive relationship and a low negative relationship. These relationships are summarized as:

A strong positive relationship:

A strong positive relationship was evident between two factors perceived as useful for visualisation, which were *Visual Utility* and *Graphic Design (r=0.73)*. Statements related to these two factors were discussed to show their usefulness in visualisation. Participants mentioned that they tend to look at a combination of these two factors. Respondents gave the following statements:

> *"It's not black and white, it's more grey, but I prefer colour. Grey doesn't distinguish one thing from another very well and you cannot understand where things and the border are"* (Respondent 1).
>
> *"Often it is helpful, but if it is too zoomed out, I might not really recognise the shape. It defeats the purpose of having those objects if they are not recognisable"* (Respondent 3).
>
> *"Broad and clear because they also have the overview of the campus and not just one building"* (Respondent 6).
>
> *"From my point of view, I choose 3D design, it's more attractive and easier to compare between map and real. In comparison to 3D design, flat images do not provide enough. Because some buildings are quite similar in the same square, 3D is better to realise the difference between them"* (Respondent 16).
>
> *"Because they are more real life and I feel sometimes they give actual representation and it is easier to get around because you know exactly what you are looking for, not just a certain square labelled by certain numbers"* (Respondent 36).

Statements from the five respondents considered that visualisation is useful if it contains elements of Graphic Design. These interpretations were based on the words related to specific groups in defining a factor. They mentioned the importance of having *colour, shapes, broad, 3D design* and *more real life* in visualisation. Having described these elements, it was apparent that respondents recognised the particular characteristics of visualisation and related it to Visual Utility. For example, they mentioned the importance of having a *distinctive, recognisable, clear, attractive* and *actual representation* in visualisation. The first interpretation was that these characteristics would give a meaningful visualisation, for example the need for a colour to distinguish between the elements in any type of visualisation is important, and would require less time to differentiate between the elements in the visualisation. Having more colour with less contrast would bring less benefit to respondents. Respondents would require an additional cognitive task to process indistinguishable colours. The second interpretation of these relationships was that respondents were not able to recognise the shapes if only small-scale images were given to them. By zooming out, however, the true proportion of images could lead to confusion and they might interpret objects wrongly. These findings suggest that the relationships between factors need to be considered by those who want to create a visualisation that users will find useful.

<u>A low negative relationship:</u>

A low negative relationship shows a negative value between two factors that are perceived as useful for visualisation navigation, which are: (1) *Technology Intervention* and *Benchmark* (r=-0.01); (2) *Resemblance with Reality* and *Benchmark* (r=-0.01). Based on users' statements, these factors are not mutually exclusive, which means that combining them could minimise the positive effects of visualisation. If the users' perceptions towards *Technology Intervention* factor were increased, their perceptions towards *Benchmark* were slightly decreased. The second relationship was similar, in that if users' perceptions towards *Resemblance with Reality were* increased, their perceptions towards *Benchmark* factors were slightly decreased.

This section highlights several relationships between factors, based on comments from the user's point of view. Thus, it gives insights and opportunities for designers to understand a combination of factors that should be considered when designing any visualisation. The impact of these combinations will be elaborated on in the Discussion chapter.

As was pointed out in the introduction of this chapter, gender and age may provide significant differences towards the usefulness of visualisation. The following section compares these differences.

4.4.3 Gender Distribution

A further analysis of the usefulness factors known as 'qualitative cross tabulation' was conducted to reveal any characteristics of factors perceived as useful for visualisation navigation. A quantitative cross tabulation tool such as a matrix query can be used to explore a theme across different types of respondent. Hence, comparing 21 males and 27 females with elicited factors produced such results as shown in Table 4.9.

Table 4.9 Matrix query of factors across gender

Factors	**Gender (%)**	
	Male	Female
Graphic Design	44	56
Visual Utility	42	56
Presentation of Information	44	54
Functionality	42	50
Text Design	38	44
Challenges	38	46
Human Cognition	23	33
Resemblance with Reality	31	31
Technology Intervention	21	25
Human Behaviour	21	31
Navigation Aid	15	10
Visual Communication	6	15
Benchmark	2	2

Results in Table 4.9 show a matrix of factors for male and female. As can be seen, it covers 13 usefulness factors of visualisation, and shows that the percentage of statements decreased steadily. Due to the number of females being higher than male, any percentage of factors led by females did not imply a conclusion. However, the three factors having a higher or equal percentage for males compared with females were: '*Resemblance with Reality*', '*Navigation Aid*' and *'Benchmark'*. The first factor, '*Resemblance with Reality*' had an equal percentage (31%) of males and females. The second factor, '*Navigation Aid*' provided more statements (15%) from males than females (10%). The third factor, *'Benchmark'* had an equal percentage (2%) of males and females. These small differences provided insightful findings of gender preference in defining useful factors.

4.4.4 Age Distribution

Another qualitative cross-tabulation of elicited factors was in the area of age. There were five age groups, the highest group being between 21-25 years old, and the lowest number of respondents in the age bracket 36 years and above. Table 4.10 shows these distributions and results suggest that age differences do not have an impact on perceptions of visualisation usefulness.

Table 4.10 Distribution of factor by age

Factors	**Age (%)**				
	20 and below	21-25	26-30	31-35	36 and above
Graphic Design	15	48	21	13	4
Visual Utility	15	46	21	13	4
Presentation of Information	13	48	21	13	4
Functionality	15	46	19	8	4
Text Design	15	31	19	13	4
Challenges	13	40	17	10	4
Human Cognition	10	27	13	6	0
Resemblance with Reality	10	29	15	4	4
Technology Intervention	8	19	15	4	0
Human Behaviour	8	21	13	6	4
Navigation Aid	6	8	4	4	2
Visual Communication	4	15	2	0	0
Benchmark	0	2	2	0	0

The results in this section show 13 usefulness factors of visualisation, produced from an aggregation of thematic analysis and three layer classification schemes. These factors were: 1) Graphic Design; 2) Visual Utility; 3) Presentation of Information; 4) Functionality; 5) Text Design; 6) Challenges; 7) Human Cognition; 8) Resemblance with Reality; 9) Technology Intervention; 10) Human Behaviour; 11) Navigation Aid; 12) Visual Communication; and 13) Benchmark. These usefulness factors were ranked according to the factors most elicited from users. The complete list of hierarchical factors obtained from qualitative analysis of visualisation navigation is presented in Appendix E.6. These usefulness factors provide an insight for further understanding of visualisation usefulness, although little evidence was found to relate to gender and age.

By conducting a Clusters Analysis, a relationship between these 13 factors was derived. These were a strong positive relationship, and a negative relationship. A strong positive relationship was between *Visual Utility* and *Graphic Design* (r=0.73). In contrast, a negative relationship was between:

(1) *Technology Intervention* and *Benchmark* (*r*=-0.01)

(2) *Resemblance with Reality* and *Benchmark* (*r*=-0.01)

In the Discussion chapter, these factors are compared with previous research to indicate any factors that have not been adequately highlighted previously. Findings about factors that have not been adequately highlighted offer additional guidelines for designers in developing visualisation. In contrast, findings related to factors that have been discussed in previous research also became empirical evidence.

4.5 Mixed method matrix (quantitative and qualitative)

This section aims to construct the classification of features of visualisation methods based on users' perceptions. The analysis has used the highest loading constructs (refer to Table 4.5) identified for each of the components in conjunction with 31 themes (refer to Appendix E.5). Marsden and Littler (2000) suggest grouping the constructs into themes so that a comprehensive profile of visualisation navigation methods from user perspectives can be identified. Figure 4.4 illustrates this process, and the total themes for Component 1, Component 2 and Component 3 are demonstrated in Appendix F.

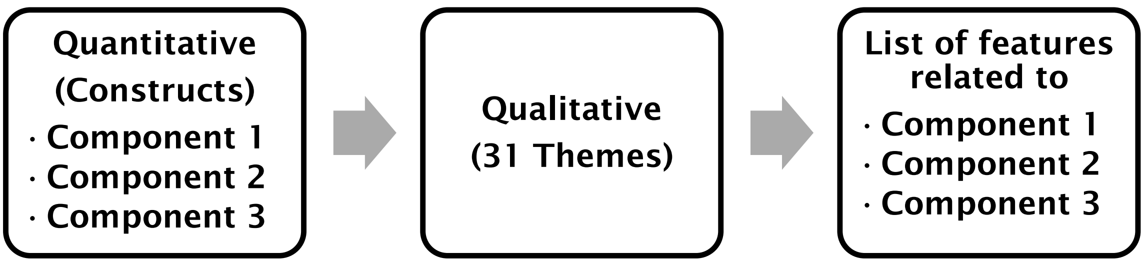


Figure 4.5 Matrix process

Comparing these two results, it can be seen that respondents organised visualisation into related features. A matrix became feasible because a list of words that matched particular themes was produced (Appendix E.6). A number was used to label these themes because there were usually more than two themes under single *Factors*. Based on the matrix shown in

Appendix F.1, the most frequently mentioned constructs in the first classification were characterised by a set of criteria, which were:

> ***Roles***, ***Information Elements***, *Visual Appearance, Visual Appeal, Directions, Type of Map, Graphics Elements, Software Related, Limitation, Legends* and *Interaction.*

For example constructs relating to ***Roles*** included:

> "1=Navigation guide, 2=Maps with navigation, 7=Has a GPS navigation, 8=Both navigation methods, 25=Easy to find location and 34=Guide to specific building".

Another example was constructs relating to ***Information Element*** which were:

> "3=Giving precise directions, 4=Provide direction, 5=Idea about distance, 9=Show my locations, 11=Giving directions, 16=Use directions and 24=Giving direction".

The result has identified that, by using a mixed method matrix, the classification of visualisation features became more comprehensive, as shown in Appendix F.4 (Results of Mixed Method Matrix for the three components). In order to produce a meaningful guideline for designers, a summary of the matrix in the form of guidelines was produced. This was used for developing a useful visualisation, as shown in Table 4.11. This table consists of a sample of the campus map and a list of features of the three components.

Table 4.11 Summary of results

	Component 1 (Augmented Reality)	**Component 2 (Sketch)**	**Component 3 (3D)**
Campus Map	M7	M5	M2
Features	❑ Acts as a navigation guide to help users find location ❑ Becomes a source of information (directions and locations) ❑ Contains adequate legends ❑ An interactive type of map ❑ Clear and sensible visual appearance ❑ The angle of visual was related to the viewer's position ❑ A visual was appealing to users (simple and user friendly) ❑ Acts as a navigational guide ❑ A map was illustrated by an actual type of photography ❑ Mobile apps related ❑ Contains inadequate information ❑ Graphic design focuses on an actual campus environment	❑ Consists of unclear boundaries of visual appearance ❑ Information is limited by complicated numbers ❑ A non-coloured image ❑ A lifelike visual appeal ❑ A drawing-based graphic ❑ Provides a single legend ❑ Includes additional information (buildings, surroundings) ❑ Contains irrelevant information	❑ Information is limited by numbers ❑ Contains detailed information (numbers, directions, name of buildings) ❑ Perceived ease of use ❑ Legends contain texts and symbols ❑ As a tool to guide users to destinations ❑ A navigational type of map ❑ Easy for users to interpret the given information ❑ Recognisable based on a simple visual appearance ❑ A combination of colour was used to represent the graphic ❑ The graphic used a bird's eye view angle

This section concludes that the use of mixed method matrix has demonstrated a development of a comprehensive profile of visualisation methods. The comprehensive profile was derived from a process of combining quantitative and qualitative results. It started by organising the highest loading constructs in rows. Once the constructs were listed, 31 themes from the qualitative results were organised in columns. Due to the long list of themes, only 13 factors were listed to demonstrate this process (refer to Appendices F1 - F3). During this process, themes of features for Component 1 (Augmented Reality), Component 2 (Sketch) and Component 3 (3D) were produced. Finally, both themes and features were summarized to guide designers in fully understanding users' perceptions. This guideline could help designers develop visualisation navigation in the future.

4.6 Summary of results

Overall, this chapter has indicated that the use of RGT can assist in eliciting valuable data to provide further understanding of the visualisation navigation methods. To demonstrate the use of RGTs, the analysis has been divided into three sections, including quantitative, qualitative and mixed method matrix.

The first section focused on quantitative analysis using a Principal Component Analysis (PCA). This analysis shows three components, accounting for a total variance of about 73.89%: Component 1 (Augmented Reality), Component 2 (Sketch) and Component 3 (3D). These three classifications contain features of visualisation methods based on users' perceptions. These classifications contribute to creating a comprehensive profile of visualisation navigation.

The second section was a qualitative analysis, which aggregated a thematic analysis and three layer classification scheme. 13 factors were elicited from users' perceptions: 1) Graphic Design; 2) Visual Utility; 3) Presentation of Information; 4) Functionality; 5) Text Design; 6) Challenges; 7) Human Cognition; 8) Resemblance with Reality; 9) Technology Intervention; 10) Human Behaviour; 11) Navigation Aid; 12) Visual Communication; and 13) Benchmark. Among these factors, two types of relationship were derived from Cluster Analysis. These were a strong positive relationship and a negative relationship. These results contribute to prove the evidence of previous research, and offer a guideline to designers in developing visualisation.

The third section explained the use of mixed method matrix to create a comprehensive profile of visualisation navigation methods. The mixed method matrix used the highest loading constructs (quantitative results) from three classifications in conjunction with 31 themes (qualitative results). This matrix has produced a complete theme of features for the three classifications. The complete theme has strengthened the results, based on user perception for Component 1 (Augmented Reality), Component 2 (Sketch) and Component 3 (3D). A comparison between users' perceptions and features from literature is made in the Discussion chapter to show similarities or differences of features. This comparison could contribute to provide empirical evidence of visualisation navigation methods.

The next chapter will discuss the results, focusing on three research objectives.

Chapter 5: Discussion

5.1 Introduction

This study has provided an alternative methodological approach to evaluate user experience by exploring visualisation navigation. The adoption of RGT governed by personal construct theory (Kelly, 1955) has revealed a different side to visualisation evaluation. This chapter justifies this claim by discussing the implications of RGT and how it can generate valid data for analysing user experience.

5.2 Implications of RGT

Implications of RGT, specifically on the method proposed, were compared with other evaluation approaches to explain the contribution of the study.

5.2.1 Exploring uncommon research paradigm in visualisation research

The study shows the implications of adopting an uncommon paradigm by demonstrating several outcomes, and uncovers a promising area in visualisation research. It was uncommon because, to the researcher's knowledge, it was the first attempt to use a pragmatic paradigm in evaluating visualisation of navigation. The reason is that visualisation research does not usually have a position in both subjective and objective contexts to explore users' perceptions. A subjective context, known as personal construct, revealed the richness of users' personal constructs when evaluating visualisation navigation. Users' personal constructs were aggregated to provide an objective interpretation of visualisation evaluation by presenting it in a guidelines format. The guidelines consist of a list of hierarchical factors, potential implications for practice and richness of the classification of visualisation features. The guidelines offer an alternative to assist designers in understanding users' expectations.

These outcomes support Birdi's (2011) earlier study, which suggested the adoption of both qualitative and quantitative methods in RGT. The use of both methods was appropriate for the study, which focused on in-depth evaluation of users' experience. Shortcomings in previous research, such as that of Vande Moere *et al.* (2012) and Faisal *et al.* (2007), revealed that using a quantitative approach was insufficient for in-depth evaluation of users' experience in visualisation. The use of certain variables in their studies was limited and could not fully represent users' experience. Their studies may only have captured syntactic knowledge (associated with the way humans differentiate between what they perceive), while ignoring semantic knowledge (concerned with meaning). Hence, the adoption of a pragmatic paradigm that includes both was suggested. The adoption has strengthened results of previous studies that RGT is appropriate for quantitative(Banister *et al.*, 1994; Hassenzahl and Wessler, 2000) and qualitative approaches (Marsden and Littler, 2000; Tan *et al.*, 2009).

5.2.2 Improvement on the elicitation method and extensions to the RGT

Shortcomings related to time, skills and tasks in evaluating users' experience in previous research (Hsieh *et al.*, 2008; Lloyd and Dykes, 2011; Slingsby and Dykes, 2012; Wood *et al.*, 2012) have been identified when using workplace based evaluation, experience sampling methods (ESM), thinking aloud, summative assessments, observation, and online experiments with a series of stimulus response tests and online task scenarios. The adoption of RGT has shown an improvement in elicitation method as stated in the study.

First, the adoption of RGT has shown the ability to be conducted in short duration experiments compared to observation and open interviews. The experiment supported previous studies (Hassenzahl and Wessler, 2000; Tan and Hunter, 2002; Alexander *et al.*, 2010) that adopted RGT. In addition, eliciting user experience (triading, laddering, pyramiding and rating process) was improved by having a structured interview via questionnaire to simplify the process. A simple questionnaire allowed users to complete a sentence with a simple adjective. Based on feedback, it demonstrated that the time taken has been reduced, and the three elicitation processes could be conducted within an hour.

Second, competency in communication is essential in research, to avoid misleading information and leading questions (Edwards *et al.*, 2009). Experienced researchers are usually more competent in communication compared to novice researchers. To help novice researchers improve their communication competencies, RGT was designed to assist the researcher in asking structured questions. For example, an RGT extension was constructed to ask questions based on what was written by the users. Hence, the researcher would not discuss something that was not related to the context. The reason for this is that an unstructured interview, without a written form, would be a challenge for a novice researcher. Thus, the RGT extension has contributed to guide researchers with necessary skills in the elicitation process.

Third, the task given was structured and easy to understand. Due to shortcomings related to commitment (Slingsby and Dykes, 2012) and attention from users (Hsieh *et al.*, 2008) in evaluating visualisation, the triading process was simplified, without compromising its value. For example, triading through a questionnaire aimed to elicit only 10 bipolar constructs from users. These 10 constructs were considered sufficient because of the richness in understanding users' perceptions. The process was able to gain users' attention and increase their commitment. Moreover, RGT allowed users to construct their own adjectives, and was convenient for users compared with reaction cards (Merčun, 2014). Support was given by the researcher to assist users if they experienced any difficulties. Hence, any shortcomings related to the task could be avoided by adopting RGT.

5.2.3 Enhancing research credibility

The methodological shortcomings in previous research have identified two important elements relating to research credibility. These shortcomings are simulation setting and researcher's opinion (Barat, 2007; Borkin *et al.*, 2013). To address the shortcomings, the study has integrated the qualitative and quantitative methods demonstrated by RGT.

The choice of simulation setting is essential, because the findings might lead to a conclusion that is not relevant to a study. A review of a study conducted by Borkin *et al.* (2013) showed that an experimental setting was a good example of evaluating user experience. However, the additional game setting might not suitable for the study, because it tested memorability, which is analytical rather than perceptual.

Research findings which solely rely on the researcher's opinion have to be avoided in research. The reason is that most researchers' opinions could lead to biased results. For example, the technique of document analysis is beneficial in providing researchers with more control (Barat, 2007), but the researcher has to aware of its limitations. RGT was used to address the shortcomings by presenting researcher judgement with the data from users to demonstrate the analysis. Users were given the opportunity to express their opinions about the topic, with little interference from the researcher.

Additionally, a software application designed to assist the experiment can give users the ability to control the situation. With the assistance of the software application, interference from the researcher can be reduced.

The obtained outcomes can contribute to any fields of visualisation that need to be evaluated. From a generalisation point of view, the technique is adaptable to any context, although the outcome is domain specific.

5.3 Generating data for analysing user experience

The outcomes composed from a mixed method approach were used as an indicator to uncover user experience. Visualisation of navigation was used as a subject, and findings were valuable to reflect the design as shown in Figure 5.1. The three outcomes were:

a) the elicitation of hierarchical factors to evaluate user experience
b) the exploration of potential implication for practice when designing visualisation navigation (impact of positive and negative relationship)
c) the richness of the classification of visualisation navigation features constructed by user experience

Section 5.3.1 (The list of hierarchical factors to evaluate user experience)		
Objective	**Findings**	**Discussion**
To elicit factors in evaluating visualisation navigation in the minds of the users	13 factors were elicited from user experience. These factors were arranged in hierarchical order measured by their frequency.	▪ Factors that have been discussed in previous research ▪ Factors not discussed in previous research

Section 5.3.2 (The potential implication for practice when designing visualisation navigation)		
Objective	**Findings**	**Discussion**
To explore the relationship between those factors	▪ A strong positive relationship ▪ A negative relationship	▪ Implications of this strong positive relationship to practice ▪ Implications of this negative relationship to practice

Section 5.3.3 (The richness of the classification of visualisation navigation features generated by user experience)		
Objective	**Findings**	**Discussion**
To construct the classification of features related to visualisation navigation based on users' perceptions.	Divided into three components ▪ Component 1 is related to Augmented Reality ▪ Component 2 is related to Sketch ▪ Component 3 is related to 3D	▪ Comparison with actual classification highlighting Similarities and Differences of Features

Figure 5.1 Structure of findings to demonstrate user experience

5.3.1 The list of hierarchical factors to evaluate user experience

The discussion in this section aims to address the first sub-question: ***"How is RGT used to elicit factors that users perceive when using visualization navigation?"*** The findings presented in Chapter 4 suggest 13 factors were perceived as useful in designing visualisation navigation visualisation. These findings were manifested in positive and negative ways to help designers understand user perception. As mentioned in the literature review, usefulness of visualisation is mostly measured based on designer perception. The way visualisation is designed is perceived differently by users; therefore the data collected from the users in this study could help designers to uncover the differences between designers' and users' perceptions of visualisation. To identify these differences, a comparison between the 13 factors and previous research was conducted, as shown in Table 5.1. Results of this comparison show that these factors are divided into two groups:

a) Factors that have been discussed in previous research.

b) Factors that have not been discussed in previous research.

Table 5.1 Comparison between elicited factors and previous research

Factors	**Previous research (refer to Table 2.4, Section 2.4)**
Graphic Design	Agrawala *et al.* (2011) Eppler (2006) Tan *et al.* (2009) Marcus (2014) Zhong and Zhang (2009)
Visual Utility	Doelker (1997) Haase *et al.* (2000) Marcus (2014) Tan *et al.* (2009)
Presentation of Information	Bresciani and Eppler (2009) Haase *et al.* (2000) Tan *et al.* (2009) Wurman (2000)
Functionality	Comi and Eppler (2011) Eppler (2006) Goodwin (2009) Roda *et al.* (2011)
Text Design	Marcus (2014) Tan *et al.* (2009) Dykes *et al.* (2010)
Challenges	Not available
Human Cognition	Burkhard (2005) Eppler (2011) Henderson (1999) Sweller and Chandler (1994) Marcus (2014)
Resemblance with Reality	Borst and Kosslyn (2008)
Technology Intervention	vanWijk (2005) Xiaoyan *et al.* (2012)
Human Behaviour	Not available
Navigation Aid	Tan *et al.* (2009)
Visual Communication	Burkhard (2005) Henderson (1999) Zeiller and Edlinger (2008) Marcus (2014)
Benchmark	Not available

5.3.1.1 Factors that have been discussed in previous research

Graphic Design

Graphic Design is an important design element which highlights the importance of design principles in visualisation. Findings show that users perceived visualisation according to several principles, such as physical structure, colour usage, graphic elements, type of map, angle and focal point to communicate ideas. Several authors (Eppler, 2006; Tan *et al.*, 2009; Agrawala *et* *al.*, 2011; Marcus, 2014) view colour as one important factor in graphic design. According to Eppler (2006), colours are used to give meaning to a certain object. The object is meaningful if it is able to provide a distinctive image to portray its uniqueness (Tan *et al.*, 2009; Agrawala *et al.*, 2011). Moreover, Marcus (2014) explains how colour is used to emphasize important things in visualisation and give a strong contrast. Colours were perceived similarly by respondents in this study:

> "*I think colourful is better because it is looks more attractive, usually we like different colours of maps which can help us distinguish different parts of the maps*" (Respondent 20).

> "*Stressing on the edges of important things*" (Respondent 3).

Participants also found angle and shapes to be important factors in graphic design. Users indicated that it is essential while designing a visualisation tool to provide appropriate angles and shapes, so that it will be easily recognised:

> "*I think the 3D is important because it gives you the sense of shapes of the buildings and is easy to recognise even if you don't follow the pattern there*" (Respondent 3).

> "*I would prefer a bird's eye view before I start the journey to see completely where I have come from to where I have to go*" (Respondent 35).

> "*It has 3D graphic of buildings, so when I pass by a building, from the look of the height and the width, these somehow triangulate to the building so I will know that this is the building*" (Respondent 43).

These elements have been discussed in previous literature (Eppler, 2006; Zhong and Zhang, 2009). The current study empirically validates previous research by asking for users' preferences and insights on the usefulness of each element.

Visual Utility

Visual utility from the users' perspectives was related to visual appearance, visual appeal and visual identity. These three themes represent features of visual utility that could attract users.

In previous literature, Tan *et al.* (2009) claim that visual appearance is an important element in web design. Their study explains that visual appearance will determine whether users will revisit the visualisation. This is because there is some sort of standard, even in a simple design. Findings from the current study acknowledged findings from Tan *et al.* (2009), such as:

> *"Descriptive enough and simple for viewing"* (Respondent 46).

> *"Map 5 is only one colour which does have a good appearance"* (Respondent 16).

Both Doelker (1997) and Haase *et al.* (2000) view visual appeal as an important criteria that could engage users with visualisation. The engaging criteria, as explained by Haase *et al.* (2000) is related to appealing graphics. Users tend to focus more when they experience graphics that do not cause difficulties for them. Similar responses were given by respondents such as:

> *"Realistic image means that they are using real-time scenario, which is easier because you can see exactly the image of the building"*(Respondent 29).

> *"Map 7 is more appealing as you can make out the shape of the building"* (Respondent 22).

Marcus (2014) holds a similar view to Tan *et al.* (2009), which is that *identity* is an important criterion in usability factors. Designs should have a noticeable professional standard or uniqueness. An example of the visual identity factor mentioned by one respondent was:

> *"I find a drawing map is easy to understand, but if buildings have special character I will find a satellite map more useful" (*Respondent 15).

<u>Presentation of Information</u>

Tan *et al.* (2009) state that the presentation of information is an important factor in evaluating visualisation. They explain that effective contrasts and a minimum of irrelevant information have an impact on users' perceptions. Similarly, themes derived from respondents indicated their opinions about information elements, structure, quality and irrelevant information.

The presentation of information included essential elements within the context, such as services, areas, routes and indicators. According to Haase *et al.* (2000), information presentation should help users to understand the meaning of visualisation. The findings in this study support the argument of Haase *et al.* (2000), for example:

> *"Map 7 is the best because it is well-designed, easy to understand, contains only info needed and some of the legends are easy to understand"*(Respondent 43).

Respondents provided several reasons why this information was easy to understand, one reason being that the information was presented in a well-structured format, based on the way it had been categorised and distinguished.

> *"They have really different colours for roads and buildings so it makes them more distinguishable"* (Respondent 10).

High quality content was derived based on the user's ability to distinguish information easily. The information was perceived as reliable and provided concise explanation (Bresciani and

Eppler, 2009). This stimulated the users' reading ability and increased their understanding. This respondent emphasized the need to have reliable visualisation:

> *"I would think that M7 is much more reliable"* (Respondent 39).

However, if visualisation presents too much irrelevant information, it can cause an information anxiety. As explained by Wurman (2000), several factors can contribute towards information anxiety, such as information overload or misunderstanding of information. Information overload exists when there are too many unnecessary elements. Unnecessary elements can cause a lot of misunderstanding, even though they may be considered important by designers. Limiting irrelevant information can simplify the way users perceive visualisation.

> *"Map 4 includes unimportant elements (for a map) like houses around"* (Respondent 8).

<u>Functionality</u>

Research literature supports the idea that a useful visualisation is one that provides functionality (Eppler, 2006; Roda *et al.*, 2011). Key characteristics of functionality include roles and benefits for users. As supported by Goodwin (2009), visual representations need to play several roles. Users' interpretations of useful visualisation were: the ability to provide a platform for users to identify objects, to make a comparison of objects, and to use an object as guidance to complete a given task. In this study, users were given a visualisation navigation (a campus map of Southampton University), and results show that they tended to choose visualisation features that could help them to identify buildings, to compare with their previous experience and to guide them to arrive at their destination easily.

At the same time, users perceived certain roles during their interaction with visualisation. They believed that visualisation gives benefits, such as ease of use, and practicalities. For example:

> *"Map 7 is used as a guide to a specific building (from M2, we can estimate the distance from our current position)"* (Respondent 46).

On the other hand, format is also related to functionality (Comi and Eppler, 2011). Different formats such as 2D and 3D represent different functions and different ways of viewing images. As stated by respondents:

> *"Map 4 and Map 1 are telling people what functions those buildings have"* (Respondent 14).

> *"2D has a benefit because it shows what is behind the buildings, but 3D can't show that part, for example what is behind the buildings, and it is hidden by the tree pictures"* (Respondent 15).

Text Design

Appropriate text design is important, as it helps to strengthen users' ability to read the information. Studies conducted by Tan *et al.* (2009) claim that text usage is important because it has to be practical and able to attract users to read the contents. Findings show that users focus on legends and typography related to text design. Legends should exist in visualisation because they represent symbols and relevant clues for users (Dykes *et al.*, 2010). These legends are a simplified version of the information, for example a service can be transformed into a symbolic shape. Users use these symbolic shapes to help them understand visualisation in the easiest way. One respondent explained,

> *"You can only do the rough estimate. For example when you figure out where you are in a map by checking the legends you can see, based on the scale how far approximately, but it is not as precise as Number 7"* (Respondent 40).

Issues in typography, as raised by Marcus (2014), are related to readability. Readability is the situation where users are able to read and understand a written text without having any difficulties. Users face difficulties when there is too much information which may not necessary.

> *"Hard to read because it's too much information"* (Respondent 47).

Human Cognition

Human cognition is an area of great interest and concern in visualisation studies. A key characteristic of this factor is the use of cognitive skills (Henderson, 1999), as stated similarly by one respondent:

> *"That's a good thing, so 6 and 7 show me exactly where I am, I think yes the other map shows the whole campus, so I need to use my cognitive skills to find where I am"* (Respondent 35).

Eppler (2011) conducted a study on cognitive skills and found that visualisation supported the process of capturing, depicting and integrating knowledge. Similarly, Marcus (2014) suggests that visualisation should support cognitive (mental activities), perceptual (ability to interpret) and psychological (behaviour) abilities. Findings derived from this study show that users were concerned to use visualisation that could support knowledge processes, such as knowledge creation, codification and application. For example, visualisation can support the process of capturing knowledge by providing memorable and recognisable content (Sweller and Chandler, 1994). Respondents agreed that visualisation should be able to support these two roles:

> *"I think 3D is important because it gives you the sense of shapes of the buildings which are easy to recognise even if you don't follow the pattern, and the map gives you recognisable things besides"*
> (Respondent 3)

> *"I think for me it's helpful because I can remember the image and I can match my memory to real scene"* (Respondent 21).

Knowledge that has been captured needs to be codified to prevent misinterpretation (Burkhard, 2005). The codification process was measured based on the ability to interpret the given information. For example, one respondent stated:

> *"Map 5 is too small and hard to be interpreted due to lack of knowledge of the buildings' functions"* (Respondent 30).

The final stage of the knowledge process is the ability to apply knowledge. Respondents proposed that visualisation should provide information that could lead them to reflect, judge and recall things. One respondent demonstrated the way knowledge had been applied:

> *"It reflects the reality, and a lot of things are a combination between the label, the names and the reality, and are closer to reality"* (Respondent 45).

Resemblance with Reality

Another important finding was the similarity of visualisation to reality. Users felt that visualisation can be easily recognised if it bears a resemblance to reality.

> *"M2 is close to the reality"* (Respondent 46).

The findings show that, while using visualisation, users tend to find similarities in structures. For example, research conducted by Borst and Kosslyn (2008) demonstrates how users identify similarities by using memory scanning. Their experiment used memory scanning to indicate the level of engagement with visualisation. It showed that it was increased if similar elements were shared, such as slopes and lines. They concluded that mental images and perceived stimuli can be assessed and depicted in the same way, as visual representation.

Technology Intervention

Visualisation can attract users by embedding advanced technology. Advanced technology can increase visualisation usefulness and the way respondents perceive visualisation. Two themes were mentioned by respondents, which were hardware and software related.

Hardware focuses on technology that uses a computer application in designing visualisation. Computer application in visualisation can be measured by looking at its utility (vanWijk, 2005). Respondents preferred to have technology which they perceived could solve their problems easily:

> *"Yes, I think technology is very helpful especially like GPS in a car, or when you use GPS on your phone it's much better to find a place easier"* (Respondent 8).

Software focuses on the use of different types of algorithm to create apps. These apps are designed based on several contexts, for example, problem context, purpose context and knowledge worker context (Xiaoyan *et al.*, 2012). Findings show that respondents were primarily concerned with problem context, especially when trying to find a location.

> *"It's a kind of algorithm when you type a question, 'I want to go there', so it is show you this way is the shortest path probably, or maybe the optimum path*" (Respondent 8).

Navigation Aid

Visualisation is described as an important design element by Tan *et al.* (2009) because it acts as a *Navigation Aid* for users. They explain that navigation can become a guideline for users by giving a clear depiction of the required information. A clear depiction in this study was related to giving information to users about their current location and position. Users did not want to take a lot of time to understand this information or have difficulties with navigation. The visualisation needed to have the ability to give directions so that users could navigate easily. Participants in the study agreed that this navigational ability would lead them to perceive that visualisation is useful for them:

> *"Like you know where you like to go and you know the position of where you are now, and then you use navigation to tell you the route how can you get there efficiently"* (Respondent 14).

Visual Communication

Many studies describe the importance of visual communication in visualisation (Henderson, 1999; Burkhard, 2005; Marcus, 2014). Two themes related to visual communication were elicited by respondents. These were interaction and target audience.

Interaction has been identified as one of the evaluation criteria to measure proper visualisation techniques (Zeiller and Edlinger, 2008). It is related to the ability to provide communication between users and visualisation. For example, visualisation from one respondent's point of view had the ability to provide both real time and dynamic view:

> *"Map 7 is navigation with real time and dynamic view"* (Respondent 24).

To improve the benefits of visual communication, a target audience is considered important. Burkhard (2005) advocates knowing the context of the recipients is essential to identify appropriate visualisation. Designers should be aware that the audience has different needs, and the ways they think and solve problems are different. Respondents highlighted the importance of differentiating visualisation according to audience:

> *"Map 3 is for people who are more mature to be able to locate"* (Respondent 29).

In conclusion, this section has demonstrated the ten factors elicited in the study to evaluate the usefulness of seven common visualisations for navigation. These factors are: *Graphic Design, Visual Utility, Presentation of Information, Functionality, Text Design, Human Cognition, Resemblance with Reality, Technology Intervention, Navigation Aid and Visual Communication.* All ten factors were summarized as cognitive factors, based on characteristics that were believed to influence users' performance in solving tasks. Users believed that they could solve the stipulated tasks if the visualisations contained these factors. The factors were derived from users' first impressions of a given visualisation. This finding has presented evidence that these ten factors are consistent with previous research. Previous research has discussed these fundamental principles in designing a visualisation, and was essential in the early stage of development. The evidence provided was a starting point for designers to consider factors that increase user performance. Several combinations of principles or guidelines can be used to develop a coherent visualisation. These findings support previous discussions that are summarized in four empirical lenses: (1) Human Cognition, (2) Technology Intervention, (3) Data and Information, and (4) Evaluation Behaviour of Visualisation (refer to Literature Review, Section 2.3).

5.3.1.2 Factors that were not discussed in previous research

The results of this study indicate that three factors that were perceived by users in practice had not been mentioned in previous research. These factors are:

Challenges, Human Behaviour and Benchmark

<u>Challenges</u>

The first factor is *Challenges,* which highlights the limitation in applying visualisation. Findings show that users tend to perceive visualisation by looking at how difficult, confusing, complicated, incomplete and time-consuming a visualisation can be. For example, respondents stated that:

> "*Map 5 and 6 are dull and incomplete*" (Respondent 5).
>
> "*I mean, to be honest, I might find the ways but the time will be longer*" (Respondent 8).
>
> "*Too crowded with symbols/indications that you can get confused, or maybe the image is too small*" (Respondent 22).
>
> *"Shadows thrown by big buildings make a perception of more border, so it is difficult to judge perspectives"* (Respondent 31).
>
> "*A draft of a drawing could be complicated to follow the route/guide*" (Respondent 39).

These five statements express how the respondents perceived using visualisation navigation (such as a campus map of Southampton University). Their statements provide a guideline to potential designers that may help them to avoid creating a visualisation that causes unnecessary challenges. Despite the lack of literature covering the area of identifying challenges for use in applying visualisation, this factor is believed to be an important consideration in designing visualisation tools. Respondents provided 105 comments concerning their challenges in applying visualisation.

According to the literature, *Challenges* in visualisation have been discussed in Information visualisation (Liu *et al.*, 2014), Transportation (Pack, 2010) and Health (Faisal *et al.*, 2013). Challenges are perceived as an important factor in developing useful visualisation tools. However, these *Challenges* are perceived mostly by designers, and less from a user's perception. Designers perceive several technical challenges, such as usability and practicality of visualisation across domains (Liu *et al.*, 2014). It has been suggested that displaying a large amount of data can be a challenge to designers (Pack, 2010; Liu *et al.*, 2014). Faisal *et al.* (2013) demonstrated that complex data can cause users to misinterpret the displayed information. Thus the existence of this factor has been acknowledged in previous studies, but not evaluated empirically from the user perspective.

Based on this finding, the effect of *Challenges* is one of the contributions of this study. This factor shows evidence that users also formed a subjective opinion when applying visualisation. Subjective opinion, such as feelings or emotions, had a huge impact on users. They perceived that a visualisation that consists of a factor which gave them emotional challenges was not useful in solving a task. This factor differs from *Visual Utility,* which is more related to physical or tangible reasoning when evaluating visualisation. Therefore, designers need to take into account that the *Challenges* factor could weaken the user's capability of maximising the use of visualisation. This study has provided a list of *Challenges* that should be avoided by designers, such as designing a *Confusing* or *Complicated* visualisation (for further details, refer to Appendix E.6).

Human Behaviour

The second factor is *Human Behaviour*, which emphasises human experience specifically related to emotion and attitude towards visualisation.

> "*Map 2 is attractive and more engaging*" (Respondent 5).
>
> "*It depends on the user information. For example for new students, it is the first time they come to the university, so Map 1 and Map 3 with a whole picture of the university is more useful and provides more information*" (Respondent 16).
>
> "*I feel I want to control technology. I don't like technology telling me what to do*" (Respondent 17).

These three statements show the respondents' experience relating to emotion and attitude. Despite the lack of literature covering the area of identifying human behaviour when applying visualisation, this factor is believed to be an important consideration in designing visualisation. Respondents provided 46 comments concerning human behaviour in applying visualisation.

Searching beyond the visualisation domain, this study was able to identify that this factor has been examined in industrial, psychology and communication domains. The idea of focusing on human behaviour in evaluating visualisation is supported by Giacomin and Bertola (2012) and

Huang *et al.* (2012). Giacomin and Bertola (2012) conducted a study that explored the effect of image format on human emotional response. Results derived from their study have provided a guideline for designers in choosing the type of image and colours to represent energy systems. Similarly, Huang *et al.* (2012) emphasize the need to examine consumers' emotional requirements in product design. They produced a classification of emotional needs that could facilitate designers to make better decisions. As mentioned by Huang *et al.* (2012), there a number of studies about emotions that are related to psychology (Aaron, 2000; Grimm *et al.*, 2007). These studies have used psychological perspectives, such as motivation and feelings to explain human involvement activities. Thus, evidence from previous research has supported the need to consider *Human Behaviour* factors in visualisation. *Human Behaviour* factors may help designers to create visualisation which supports emotional needs and attitudes. Users will be more engaged with visualisation that embraces these criteria.

<u>Benchmark</u>

The third factor is *Benchmark.*

> "*Distances are not measured and don't show where I am at*" (Respondent 33).
>
> "*Standardized the colour according to the roles/functions*" (Respondent 28).

Respondents provided the two comments above concerning the importance of identifying benchmarks in applying visualisation. The first statement indicates that the respondent required information about measuring a distance when applying visualisation. Information about distance was useful for users because they required more than the information they could see with their own eyes. In this sense, distance was able to provide a cognitive task for users to predict and apply their navigational knowledge. The second statement demonstrates a suggestion from a user that visualisation could use a colour coordination in determining the role or function of elements. A colour could simplify the task for users to comprehend the visualisation. This would help users to complete the task without any difficulties.

Although only two statements were elicited from users regarding *Benchmark*, it has raised concerns regarding the importance of having such standards in designing a useful visualisation. This argument may seem weak because of little evidence to support it, but this finding is consistent with previous research. Previous research demonstrates that a *Benchmark* factor has been used in Business (North *et al.*, 2011) and Architecture Design (Fonseca and Duran, 2011). However, these studies demonstrate the use of *Benchmark* as a tool in collecting data, and have only been perceived by researchers, but not users. For example, this factor was used in a controlled environment to measure performance time, an accuracy of response and distance. Users were required to perform a task whilst being observed and measured until they completed it. Several measurement variables were important to validate a list of hypotheses supporting their study. Results such as correlation between distances and image quality have influenced designers in designing a quality image that has an impact on users (Fonseca and Duran, 2011). The evidence from previous research has demonstrated the need to have a *Benchmark* factor in validating visualisation. It is a good indicator that the factor perceived by users can be used as a guideline for designers.

In conclusion, these findings fill a gap in the literature, that these three factors, *Challenges*, *Human Behaviour* and *Benchmark* have not been identified in previous research. A main reason for the lack of research covering these three factors is because there are differences of perception between designers and users. Most designers focus only on explicit factors, such as Graphic Design, whereas users perceive visualisation based on explicit and implicit reasoning. Implicit reasoning, such as feelings or attitude, is more subjective. Subjectivity or affective factors are often excluded by designers as one of the important standards in designing visualisation. Further research should be undertaken to investigate the impact of embedding these three factors in designing a useful visualisation.

5.3.2 The potential implication for practice when designing visualisation navigation

The second sub-research question in this study is, "***How do the elicited factors relate to each other?"*** The results of this study indicate that there is a strong positive relationship and a negative relationship between elicited factors. A discussion of these strong positive and negative relationships includes implication for practice.

5.3.2.1 Implication of a strong positive relationship for practice

<u>(1) *Visual Utility and Graphic Design (r=0.73)*</u>

This study has found that there is a strong relationship (r=0.73) between *Visual Utility* and *Graphic Design*. *Visual Utility* was related to *Visual Appearance, Visual Appeal* and *Visual Identity,* whereas *Graphic Design* was related to *Physical Structure, Colour Usage, Graphic Elements, Type of Map, Angle* and *Focal Point*. The present finding seems to be consistent with other research (Tan *et al.*, 2009; Marcus, 2014), which found a relationship between *Visual Utility and Graphic Design*. Both Marcus (2014) and Tan *et al.* (2009) suggest that these two factors need to be considered for successful visualisation. Marcus (2014) mentioned that graphic design principles and usability factors is essential for successful Graphical User Interface (GUI). One of the usability factors is product identity. The reason is that graphic design principles usually benefit by taking into account strong visual identity. A similar finding was made by Tan *et al.* (2009), who identified a relationship between graphic usage and website identity. Statements such as "*Graphics were used to portray website image"* (Tan *et al.*, 2009, pg 166) show a strong relationship between these two factors.

This strong relationship between *Visual Utility* and *Graphic Design* may be explained by visual communication theory. Three principles in visual communication theory (information design, information architecture and information art) explain the human tendency to perceive visualisation. For example, once users saw graphics elements such as shapes, they tended to relate to the visual appearance if it was simple and pleasing to the eye. It forms a possible explanation, but it is important to bear in mind the possible bias in these responses. In general, therefore, it seems that these relationships can give designers a good indication of which elements are generally important in designing a visualisation.

An implication of this is the possibility that an explanatory model can be developed to guide designers in producing an engaging visualisation. Designers can embed one or two themes of each factor when designing a useful visualisation. Themes for graphic design (such as physical structure, colour usage, graphic elements, type of map, angle and focal point) could be combined with visual utility (visual appearance, visual appeal and visual identity).

Results from this study also indicate that there is an opportunity for further research in the future. For example, more research on this relationship needs to be undertaken to investigate impact on users, such as increased understanding, and reduce the processing time. Thus, a study of users' ability to evaluate visual utility in a more effective way would benefit visualisation research.

5.3.2.2 Implication of a negative relationship for practice

Very little is found in the literature on the findings about this negative relationship. In this study, results found three factors with a low negative relationship. These negative relationships are briefly explained as follows:

(1) *Benchmark* and *Technology Intervention (r=-0.01)*

Results show that if users' perception towards Benchmark has been increasing, their perception towards *Technology Intervention* has been slightly decreasing. This finding does not support previous research (vanWijk, 2005; Xiaoyan *et al.*, 2012). According to vanWijk (2005) and Xiaoyan *et al.* (2012), *Benchmark* is associated with *Technology Intervention*. *Benchmark* is related to *Measurement*, whereas *Technology Intervention* is related to *Hardware* and *Software*. vanWijk (2005) emphasizes the need to have a concrete measurement of visualisation from a technological point of view. Similarly, Xiaoyan *et al.* (2012) provide an example of the use of measurement as part of an essential component in knowledge management systems. Measurement is part of the problem context dimension concerning the potential solutions. These scholars demonstrate that the two factors were an important factor in conducting their studies. The reason is that these studies were in a different context, which was more related to automated knowledge management systems. Both studies were perceived from a technology point of view, which did not involve user perception. They used the two factors to give an objective view, to produce a quantitative result.

This differs from the current study, which focuses on user perception, giving a subjective view and producing both quantitative and qualitative results. The reason for this discrepancy could be related to emerging trends in information technology. The rapid changes of trend in information technology demand that users should become more competent. Users may be faced with difficulties in adapting to this demand, because they do not have similar adaptability. Hence, the findings in this study claim that users do not tend to relate to *Technology Intervention* with *Benchmark* factors. The study suggests that designers should pay more attention to the existence of the two factors. Combining these two factors when designing a visualisation may create difficulties for users. The positive effects of visualisation can be maximised if the two factors are not combined.

(2) Resemblance with Reality and Benchmark *(r=-0.01)*

The evidence shows a low negative relationship between the two factors, *Resemblance with Reality* and *Benchmark*. This negative relationship indicates that if visualisation resembles reality, it may be more difficult to measure. These results differ from those of Borst and Kosslyn (2008), who claim that it is possible to measure reality and perception. *Reality* in their comprehensive study refers to *Visual Mental Imagery*. They conclude that *visual mental imagery* and *visual perception* can be measured and depicted in the same way. To measure these two conditions, Borst and Kosslyn (2008) examined patterns of dots by scanning users' memories. Users were given a paper and asked to draw the location of dots based on an image they had seen earlier. This task revealed that users were able to produce similar structures in both conditions. It is interesting that their study was able to demonstrate the process of scanning thoroughly, even though it could not be used to support the argument that *Resemblance with Reality* and *Benchmark* have a negative relationship. The reason is because the visual representations used in our studies were not similar. Visuals with a pattern of dots (Borst and Kosslyn, 2008) were considered a single object. However, the campus map used in this study is a combination of multiple objects and a related environment. The relationship between objects and environment, known as affordance concept (Bresciani and Eppler, 2010), is often interpreted as subjective and difficult to measure. Users' interpretations might vary and differ from one another.

According to this negative relationship, the current study can infer that subjectivity has an impact on visualisation usefulness based on user perception.

This finding may help designers to be aware of subjectivity, and avoid trying to emphasise both factors at the same time. For example, to relate a visual to reality might not be a good idea for designers if they want to have a concrete measurement of visualisation. Thus, this guideline is useful for designers setting their target prior to any visualisation development.

5.3.3 The richness of the classification of visualisation navigation features constructed by user experience

This section is used to discuss a classification of features of visualisation navigation based on users' perceptions. Hence, a third sub-research question was designed, being "**How are features of visualisation navigation subjectively construed by users?**"

In the current study, a comparison was made by conducting a mixed method matrix. This matrix produced a classification of features of visualisation navigation methods from user perspectives (Refer to Table 4.11). The method used shows a different way of producing a comprehensive profile of classifying visualisation navigation features. The empirical evidence strengthens the classification claimed in previous studies. The empirical evidence shows three main classifications. These classifications consist of several features derived from the highest loading constructs (quantitative analysis) and themes (qualitative analysis). They were:

(1) Component 1 which represents an Augmented Reality

The most comprehensive features derived in this study are described under Component 1, which represents an Augmented Reality. A list of features for Augmented Reality was demonstrated as:

a) Act as a navigation guide to help users find location
b) Become a source of information (directions and locations)
c) Contain adequate legends
d) An interactive type of map
e) Clear and sensible visual appearance
f) The angle of visual was related to the viewers' position
g) A visual was appealing to users (simple and user friendly)
h) Act as a navigational guide
i) A map was illustrated by an actual type of photography
j) Mobile apps related
k) Contain inadequate information
l) Graphic design focuses on an actual campus environment.

Users showed a tendency to classify features on the basis of high level usability of graphic design. High level usability of graphic design referred not only to physical structure, but also to graphics elements consisting of navigation and interaction. These features further supported the idea of the knowledge map that was discussed in Section 2.2.1.3 (Knowledge Map). First, a physical structure of this classification was similar to the cartographic format in the knowledge map (Eppler, 2008). Cartographic format in this classification was described by users as graphic design within the actual campus environment. Second, high level usability shows that users acknowledged the importance of a navigational feature in visualisation which reflects the knowledge map. According to a definition by Davenport and Prusak (1998, p. 72), "*a knowledge map whether it is an actual map, knowledge yellow pages or a cleverly constructed database points to knowledge but does not contain it. It is a guide not a repository*". Hence, the emphasis of a map should not only be to contain information, but also to navigate users to find a location. The navigation feature emphasised the need to have an interactive visualisation which was essential for users to complete their task. In conclusion, this finding may help designers to adopt high level usability factors in graphic design.

(2) Component 2 which represents a Sketch

Findings show that Component 2, which represents a Sketch, contains several features based on user perception. These features are summarized as follows:

a) Consist of unclear boundaries of visual appearance
b) Information is limited by complicated numbers
c) A non-coloured image
d) A lifelike visual appeal
e) A drawing-based graphic
f) Provide a single legend
g) Include additional information (buildings, surroundings)
h) Contain irrelevant information.

Features elicited from users' perceptions were in line with previous literature. These features were grouped based on a minimum adoption of graphic design. The use of minimum adoption of graphic design usually acts as a tool in conveying initial ideas in the form of graphics. Initial ideas do not usually require a complex form of graphics, and the sketch has successfully demonstrated its role in this process. The role of communication represented by sketch is discussed by Eppler and Pfister (2011) and Lane and Seery (2011). These scholars emphasise the need to use a sketch to share ideas visually. Thus, this result is consistent with previous research, and does not show many differences with features elicited by users' perceptions.

(3) <u>Component 3 which represents a 3D</u>

Evidence shows that Component 3 which represents 3D has been classified by users based on several features. These features are:

a) Information is limited by numbers
b) Contain detailed information (numbers, directions, name of buildings)
c) Perceived ease of use
d) Legends contain texts and symbols
e) As a tool to guide users to destinations
f) A navigational type of map
g) Easy for users to interpret the given information
h) Recognisable based on a simple visual appearance
i) A combination of colour was used to represent the graphic
j) The graphic used a bird's eye view angle.

This result is consistent with previous literature that 3D features are mainly emphasised in graphic design. Graphic design, such as colours, legends and detailed information, are important features in this classification. 3D is like an intensive sketch focused on physical structure and data formats. As discussed in Section 2.2.1.2 (Conceptual Diagram), a physical feature consists of shapes (pyramids, matrices or boxes), lines, dots, items, or arrows (Eppler, 2006; Zhong and Zhang, 2009). These features have their own definition and are widely understood by most users. Hence, this finding confirms that users' perceptions were similar to previous literature.

In conclusion, a further discussion on the comprehensive profiles in classifying a visualisation navigation features can be illustrated briefly by conducting a comparison between users' perceptions and features from the literature as shown in Figure 5.2. User perception referred to Component 1 (Augmented Reality), and actual classification referred to a Location-based Augmented Reality of Highfield Campus. This comparison was used to identify if there were any similarities or differences of features in both conditions.

Figure 5.2 A comparison of users' perceptions and features from the literature of a location-based augmented reality of Highfield Campus

AUGMENTED REALITY FEATURES FROM USERS' PERCEPTIONS

(1) Act as a navigation guide to help users find location
(2) Become a source of information (directions and locations)
(3) Contain adequate legends
(4) An interactive type of map
(5) Clear and sensible visual appearance
(6) The angle of visual was related to the viewers' position
(7) A visual was appealing to users (simple and user friendly)
(8) Act as a navigational guide
(9) A map was illustrated by an actual type of photography
(10) Mobile apps related
(11) Contain inadequate information
(12) Graphic design focuses on an actual campus environment

Users' Perceptions

FEATURES OF VISUALISATION NAVIGATION METHODS FROM THE LITERATURE

Conceptual Diagram	**Knowledge Maps**	**Heuristic Sketch**
(1) Recognisable through pre-defined shapes (pyramids, matrices or boxes), lines, dots, items, arrows (2) Consists of analytical data-labelled boxes with embedded text known as entities and relationships (3) A concise overview through structured information	(1) Guidance, not repository that point to knowledge (2) Act as navigation aid (3) Structured in table format	(1) Depictive elements (boundaries and arrows) (2) Symbolic elements (names, populations and distances)

Features from Literature

A LOCATION-BASED AUGMENTED REALITY (M7)

These results, consistent with Marsden and Littler (2000), found different features when adopting RGTs to identify the structure and content of consumer behaviour systems. Features elicited in the current study using the same techniques provided different perceptions towards visualisation. The usual methods, such as questionnaires, may limit respondents' perceptions and reduce the wealth of data. For instance, there were features that only existed in one condition, such as *Interactive, Clear, Appealing, Simple, User-friendly* and *Real Picture*. These features are not mentioned in previous research, but were considered important to guide designers in identifying elements that should be included when designing visualisation. For example, designers should include *Interactive* features as part of Augmented Reality application. Further studies could be done to investigate the guidelines of each visualisation navigation method.

Another reason was a different focus when interpreting visualisation. The visualisation was designed as an *Integration of Elements*, whereas users interpreted it as a *Segmentation of Elements*. *Integration of Elements* means a combination of several elements that designers consider have the potential to help users. User perception was different, because their focus was only on elements that were perceived as useful. It is important to note that these possibilities might be different if visualisation is applied in different contexts, such as social or business.

However, this finding is in agreement with Birdi (2011), features from users' perceptions being similar to features found in previous research. For example, there were a few similarities of features such as *Navigation* and *Guidance* that existed in both conditions. From these similarities, it can be assumed that visualisation successfully achieved meeting the objective.

The discussion discovered several differences and similarities between features of users' perceptions and visualisation navigation methods. Both revealed unexpected findings. The findings show that features that were similar can be used to prove the visualisation concepts of previous research. Empirical evidence based on users' preferences in using visualisation methods has proved the visualisation concepts. Moreover, features that were different can be used as an additional guideline for designers. New features derived in this study can be used to suggest a better classification of current visualisation methods in a hybrid form. Previous research (Eppler, 2008; Zhou *et al.*, 2011) show that scholars have argued about visualisation classification because it contains a lot of ambiguity, and it is difficult to find a distinction. Therefore, this hybrid classification may appear as a solution to reduce this argument.

5.4 Summary of discussions

This chapter has presented a discussion of research findings in relation to the theories and literature reviewed in Chapter 2.

Section 5.2 demonstrates the implications of using RGT in the field of visualisation research. From the results obtained, it is evident that RGT can play a role in eliciting users' experience on visualisation. Three implications have been discussed: (1) exploring an uncommon research paradigm; (2) improvement on the elicitation method and extensions to the RGT; and (3) enhancing research credibility. The contributions were derived by comparing RGT with other evaluation approaches. Generally the adoption of RGT has improved this method of study.

Section 5.3 focuses on the outcomes derived from a mixed method approach when evaluating user experience. These outcomes were used as indicators to reflect most of design. First was the elicitation of hierarchical factors associated with user experience. The 13 elicited factors were divided into two groups, which were cognitive and affective factors. The cognitive factors were: *Graphic Design, Visual Utility, Presentation of Information, Functionality, Text Design, Human Cognition, Resemblance with Reality, Technology Intervention, Navigation Aid and Visual Communication.* These cognitive factors were consistent with four theoretical lenses of previous studies, which were: (1) Human Cognition, (2) Technology Intervention, (3) Data and Information, and (4) Visualisation Behaviour. These fundamental factors could be used as a guideline for designers when developing a coherent visualisation. The affective factors were*: Challenges*, *Human Behaviour* and *Benchmark*. These factors have not been identified in previous research. This discussion points out gaps between designers' and users' perceptions towards visualisation. Explicit factors become a focus for designers, whereas explicit and implicit factors become a focus for users. Regardless of the subjectivity of implicit factors, this study suggests that embedding these factors could have an impact on future research into visualisation.

Second was the exploration of practical implications when designing visualisation navigation (the impact of positive and negative relationship). The implications were explained, based on two groups: (1) factors that have a strong positive relationship; (2) factors that have a negative relationship. Factors that have a strong positive relationship are *Visual Utility* and *Graphic Design*. This study suggests that this strong positive relationship could contribute in becoming an explanatory model for designers. The model could guide designers to embed any themes from these two factors in producing an engaging visualisation. The discussion indicates that there is a potential for research in the future, focusing on the relationship of factors. Factors that have a negative relationship are (1) *Benchmark* and *Technology Intervention*, and (2) *Resemblance with Reality* and *Benchmark*. These relationships are not supported in previous studies because of the issues of subjectivity. The discussion concludes that designers should be aware that combining factors that have a negative relationship might not be a good idea. The reason is that this combination could not maximise the positive effect of visualisation, and also becomes a challenge to users. This study has provided a guideline to help designers to plan before developing a visualisation.

Third was the richness of the classification of visualisation navigation features constructed from users' experience. Three classifications were derived: (1) Component 1 which represents an Augmented Reality (high level usability of graphic design); (2) Component 2 which represents a Sketch (minimum adoption of graphic design); (3) Component 3 which represents 3D (mainly emphasised on graphic design). Several features from highest loading constructs (quantitative analysis) and themes (qualitative analysis) were derived to produce these classifications. The discussion goes on to identify similarities and differences of features between users' perceptions and visualisation navigation methods. This comparison uses Component 1, which represents an Augmented Reality as an example, and may be summarized as: (1) Features that were similar have proved visualisation concepts based on empirical evidence; (2) Features that were different could become an additional guideline for designers. A hybrid classification was produced to reduce the ambiguity of visualisation classifications.

Chapter 6: Conclusion

6.1 Introduction

The aim of this chapter is to present the conclusion of the research, which explores the contributions of RGT as a method for eliciting the user's experience in visualisation navigation. The chapter begins with a review of the research aims and objectives. The major findings of the study are then discussed in light of the research aim and questions, followed by the research limitations. The contribution of the research is also examined. The chapter concludes with suggestions for future research.

6.2 Restatement of aims, objectives and findings

Returning to the question posed at the beginning of this study, the aim of the study was as follows:

To provide an alternative methodological approach to evaluate user experience by exploring visualisation navigation.

Evaluating user experience is essential in visualisation studies to provide an understanding of visualisation. In order to evaluate user experience, a pragmatic approach using RGT, which is uncommon, was adopted to explore a different side of visualisation. To the researcher's knowledge, it has been the first attempt to use a pragmatic paradigm in evaluating visualisation. It is quite common to conduct research guided by either Positivism or Interpretivism. Two major discussions in the study were the implications of RGT and generating data for analysing user experience.

6.2.1 Implications of RGT

The first research objective was to base the study on a pragmatic approach, using RGT in evaluating user experience. This objective led the researcher to formulate a research question as follows:

- What is the impact of a pragmatic approach with the adoption of RGT in evaluating user experience for visualisation of navigation?

RGTs governed by personal construct theory (Kelly, 1955) can have an impact on visualisation research. A review of some visualisation research has demonstrated the variety of ways in which the approach can be used. The literature review has also indicated that well-known techniques such as observation, document analysis and questionnaires were valuable, but too common. It has revealed that such a gap is most valuable when a mixed method approach is made possible and justified. The data analysis approach is explained to show the process.

The strength of RGT in eliciting user experience in a structured approach indicates three areas in which it can make a valuable contribution within visualisation research:

- Exploring uncommon research paradigms in visualisation research
- Improvement of the elicitation method and extensions to the RGT
- Enhancing research credibility.

6.2.2 Generating data for analysing user experience

The second research objective focused on exploring the use of a high and low task approach of RGT in visualisation research. To achieve this objective, this study needs to address the following research question:

- How can the use of RGT be demonstrated to elicit users' experience using a high and low task approach in visualisation research?

User experience was analysed by a structured and explicit method in RGT. Data elicited were used to demonstrate the impact of the chosen approach. For instance, in exploring which factors are valued, their degree of importance and how they can be used, examples of its application within a certain context are introduced. This was the focus of several studies reviewed in the thesis which adopted RGT (Edwards *et al.*, 2009; Heine, 2009; Hinkle, 2009; Tan *et al.*, 2009; Alexander *et al.*, 2010; Berger and Hari, 2012). In order to address this methodological gap, RGT has generated data for analysing user experience by focusing on three objectives. These three objectives were discussed by explaining associated findings as follows:

(1) The list of hierarchical factors to evaluate user experience
(2) The potential implication for practice when designing visualisation navigation
(3) The richness of the classification of visualisation navigation features generated by user experience

6.2.2.1 The list of hierarchical factors to evaluate user experience

These findings derived with the objective to elicit factors in evaluating visualisation navigation in the minds of the users. The findings of the current study indicate that 13 factors were identified when applying visualisation navigation. These can be summarized as cognitive and affective factors that explained users' experience. The cognitive factors were: *Graphic Design*, *Visual Utility*, *Presentation of Information*, *Functionality*, *Text Design*, *Human Cognition*, *Resemblance with Reality*, *Technology Intervention*, *Navigation Aid* and *Visual Communication*. These ten factors have been widely discussed by scholars in several theoretical lenses, as discussed in the Literature Review (Section 2.2.2). Theoretical lenses, such as Human Cognition, Technology Intervention, Data and Information and Evaluation Visualisation Behaviour explain how these factors are perceived as important to users. They are thought to be fundamental in designing a visualisation, and are essential in the early stage of development. Designers tend to use several combinations of principles or guidelines when developing a coherent visualisation.

The affective factors were: *Challenges*, *Human Behaviour* and *Benchmark .* These three factors have not been elicited previously using different methods. The main reason for the lack of research covering these three factors is because they seem to be more related to subjective opinions, such as feelings. They are less explicit, and make it difficult for designers to follow any set of standards. Similarly, scholars tend to focus less on factors that are difficult to measure. By contrast, the way users perceive visualisation is based on explicit and implicit reasoning. A gap, shown in the differences in user perception towards visualisation was derived, based on this comparison of factors with previous literature. Hence, this study provides an insightful way of looking at visualisation. In addition, these three factors add to a growing body of literature on users' experience of visualisation.

The findings can also be used by designers to evaluate visualisation methods in a specific scenario or task. It is relevant because the results can be used as a starting point for designers to identify appropriate visualisation factors that could benefit users. Users' first impressions were used to determine the important elements and reflect their preferences concerning visualisation navigation, such as presentation of information and resemblance with reality.

6.2.2.2 The potential implication for practice when designing visualisation navigation

A potential implication for practice could be when the elicited factors are used as input to develop visualisation navigation. Hence, exploring the importance of the relationship between those factors became one of the objectives of the research. The results demonstrate that the potential implications are based on two groups: (1) factors that have a strong positive relationship; (2) factors that have a negative relationship.

Factors that have a strong positive relationship are *Visual Utility and Graphic Design. Visual Utility* is related to *Visual Appearance*, *Visual Appeal* and *Visual Identity*, whereas *Graphic Design* is related to *Physical Structure*, *Colour Usage*, *Graphic Elements*, *Type of Map*, *Angle* and *Focal Point*. A combination of any of these elements could guide designers in identifying factors that are generally important when designing a visualisation. They could use one or two themes from each factor, such as colour usage and visual appeal, as the main focus in their design. Hence, this study provides a guideline in the form of an explanatory model to produce an engaging visualisation. In addition, this study indicates that there is an opportunity for further research in the future, focusing on the relationship of factors.

There are three factors that indicate a negative relationship, based on users' perceptions. These are: (1) *Benchmark* and *Technology Intervention*, (2) *Resemblance with Reality* and *Benchmark*. This negative relationship is not supported by previous research, because it is related to subjectivity. The evidence in this study explains a core understanding of user challenges. A guideline based on this evidence could help designers to become aware of the difficulties faced by users in using visualisation. This guideline recommends that designers ought to pay attention to these negative relationships. To maximise the positive effects of visualisation, designers should avoid combining these three factors.

6.2.2.3 The richness of the classification of visualisation navigation features generated by user experience

Another impact of RGT adoption was the ability to provide the richness of personal construct that is often missing in a quantitative approach (Marsden and Littler, 2000). Scholars (Hassenzahl and Wessler, 2000; Hinkle, 2009; Tan *et al.*, 2009) have used RGT to elicit the form of visualisation subjectivity. They suggested that studies related to visualisation research could consider the use of RGT to elicit users' experience. Therefore, another objective was focusing on constructing the classification of features related to visualisation navigation based on users' perceptions. To achieve this objective, a process of classification is described in this study. By having a mixed method approach, a matrix between qualitative and quantitative elements has produced a classification of features based on users' perceptions. Three major classifications were derived:

(1) Component 1 which represents an Augmented Reality: shows a tendency to classify features based on high level usability of graphic design.

(2) Component 2 which represents a Sketch: demonstrates that features are grouped based on a minimum adoption of graphic design.

(3) Component 3 which represents a 3D: is mainly emphasised by graphic design.

Each component consists of several features derived from highest loading constructs (quantitative analysis) and themes (qualitative analysis). The method used shows a different way of producing a comprehensive profile of classifying visualisation navigation features. A comparison was made between features, based on users' perceptions and visualisation navigation methods. This comparison was used to identify any similarities or differences of features that could be re-worked to improve the visualisation process. An Augmented Reality was used to demonstrate the process, and shows results beyond designers' expectations. The finding indicates that features of visualisation navigation could become an additional guideline for designers when developing a useful visualisation in the future.

Fundamentally, this study is a piece of work to test visualisation methods and compare them. The constructs that were elicited from each participant provide considerable empirical evidence to support different aspects of visualisation methods. By determining the students' preferences in the use of particular visualisation methods for a specific task, new constructs could be elicited. This could be crucial for identifying new constructs, because it suggests a better classification of current visualisation methods. The new classification may appear as a hybrid method between three classifications, which will reduce the ambiguity of classification distinction.

6.3 Limitations

The findings in this study are subject to at least four limitations. First, the perception of designers was not included in the research. The study was carried out only from the perception of users, without empirically comparing these with designers' perceptions. The comparison might generate another body of literature and emphasize the similarities and differences when interpreting the same visualisation methods. Thus, the framework derived in this study is only applicable to a general idea of user perception.

Second, the current study was not specifically designed to evaluate factors relating to measuring the effectiveness of visualisation. The researcher was aware of the scarcity of literature to provide guidelines in choosing a method to measure the effectiveness of visualisation. The focus of this study is hence limited to eliciting factors perceived by users to evaluate visualisation navigation.

Third, the use of a convenience sample may become an issue in generalising the collected data. Difficulty in gathering a representative sample was due to reasons such as availability of users to participate in this experiment. Several users indicated that the time taken in the experimental procedure was considered too long. However, those who participated gave their full attention and provided highly valuable data towards the study.

Fourth, visualisation navigation was comprised of several representation methods based on existing literature. The selection was based on the most common visualisation methods of campus maps. Only seven visualisation samples were used in the experimental procedure. To conclude, these five limitations could lead the way for future research opportunities.

6.4 Contributions

There are several contributions that can be claimed from this study, on a methodological, theoretical, contextual and practical level.

On a methodological level, this study follows a pragmatic paradigm which is uncommon for visualisation research exploring user perception of visualisation. By adopting this paradigm, the study manages to resolve a conflict between the constructivist approach and aggregation of personal constructs. A constructivist approach leans towards subjectivity, whereas aggregation of personal constructs leans towards objectivity. An aggregation of personal constructs provides a generalization of findings.

Adopting a mixed-method approach in the form of RGT is also part of the contribution. The use of RGT shows a different way of evaluating visualisation. This technique integrates both qualitative and quantitative analyses to elicit factors and to classify visualisation navigation features based on users' perceptions. In addition, the technique allows researchers to use the same sample of respondents to avoid inconsistency in their answers while conducting the experiment.

Furthermore, this technique explores the opportunities of using software application to extend the use of RGT, and demonstrates its practicability within an experimental environment. For example, three images randomly selected by software and a questionnaire were given to users at the same time, reflecting an improvement of procedure in collecting data.

On a theoretical level, the study attempts to fill a gap in the theoretical basis to explain visualisation navigation based on user experience. Several theories, such as information, visual cognition, colour and visual communication theory have been widely used in visualisation research. However, little is known about any theory that focuses on evaluating user experience of visualisation navigation. Hence, the study explains theories under two focal points, visual elements and human insights. The combination of theories used to explain this study has provided theoretical guidelines that could be used in future research.

Secondly, empirical debates about visualisation have produced a comprehensive list of visualisation studies. The list of studies reveals four lenses in past research: human cognition, technology intervention, data and information, and evaluation behaviour. These four lenses show the evolution and transition of visualisation navigation. This may be useful as a framework for future reference.

Thirdly, this study evaluates users' experience that includes cognitive and affective factors. These factors are demonstrated based on the constructs elicited from the users. Users' interpretation contributes a different perception from past research. The results demonstrate that 13 usefulness factors and a hybrid classification were derived in this study.

On a contextual level, this study provides a framework for the exploration of visualisation literature. Firstly, the framework adds to a growing body of literature on users' experience of visualisation. Users' experience was applied to determine the important elements that affect first impressions of visualisation. Their first impressions were based on specific domains within the HE sphere.

Visualisation in an HE perspective is essential because it is widely implemented by users in their daily routine. The unique characteristics of this domain setting bring a new meaning to users' perspectives, and it is worth discovering how visualisation impacts on an HE environment. There are a lot of applications in HE relating to visualisation. By providing empirical evidence of visualisation in HE, further development can be conducted with a different focus in visualisation research.

On a practical level, the current research aims to bridge the gap between designers, users and academicians by empirically investigating the visualisation phenomenon. To the best of my knowledge, there have been no studies so far that evaluate visualisation navigation with a pragmatic approach. This pragmatic approach has contributed to practice by defining the core understanding and explaining user challenges. A core understanding of visualisation evaluation from the user's perception could contribute to providing a guideline for designers. This study contributes to the selection of visualisation features that help designers to create an appropriate visualisation for various groups of users. For example, users who have no prior knowledge about a location might need more detailed information compared to those who are more familiar with it. The core understanding also includes a classification of visualisation navigation features based on users' perceptions. This empirical evidence provides a list of features that are suitable for several methods. Features that are flexible are essential to guide designers in choosing appropriate methods. For example, Augmented Reality is suitable for navigational purposes. Both core understandings may help to face the challenges of designing an effective visualisation in the future.

6.5 Future Research

It is suggested that further research be undertaken in the following areas: (1) to broaden the context; (2) to extend the evaluation criteria; and (3) for experimental enhancement.

First, the context of evaluating visualisation could be broadened by focusing on social or business contexts. The sample of various types of location map could provide valuable insights into navigation issues in general. It would be worthwhile for researchers to gain insights into a larger sample. Such studies could contribute to develop a framework of visualisation across several contexts.

Second, extending the evaluation criteria by obtaining designers' perceptions, rather than merely focusing on users' perceptions is recommended. Several similarities or differences might be generated from a comparison between designers' and users' perceptions. Thus, future studies could provide a comprehensive guideline to evaluate visualisation.

Third, experimental enhancement should be carried out to determine the effectiveness of visualisation methods. Instead of providing a list of visualisation methods, users could also be involved in identifying an appropriate list. For example, researchers could provide a list of visualisation methods, while users would be required to give a rating based on commonly used visualisations. This process would give a more specific insight into visualisation methods based on user preference. Another challenge is to improve steps in collecting data. The improved steps could ensure that time could be reduced and resources maximized in evaluating visualisation.

Appendices

Appendix A Respondent Toolkit (Consent Form and Questionnaire)

CONSENT FORM (01)

Study title: Repertory Grid Technique: a Pragmatic Approach of Evaluating User Experience in Visualisation Navigation

Researcher name: Azira Binti Ab Aziz

Ethics reference: 7776

Please initial the box (es) if you agree with the statement(s):

I have read and understood the information sheet (23-09-13/v01) and have had the opportunity to ask questions about the study. ☐

I agree to take part in this research project and agree for my data to be used for the purpose of this study ☐

I understand my participation is voluntary and I may withdraw at any time without my legal rights being affected ☐

I am happy for the interview to be tape-recorded. ☐

I am happy to be contacted regarding other unspecified research projects. I therefore consent to the University retaining my personal details on a database, kept separately from the research data detailed above. The 'validity' of my consent is conditional upon the University complying with the Data Protection Act and I understand that I can request my details be removed from this database at any time. ☐

I understand that information collected about me during my participation in this study will be stored on a password protected computer and that this information will only be used for the purpose of this study. All files containing any personal data will be made anonymous.

Name of participant ……………………………………………………………

Signature of participant…………………………………………………………..

Date………………………………………………………………………………

QUESTIONNAIRE

UNIVERSITY OF Southampton

Date:

Dear Participant,

My name is Azira Ab Aziz and I am a graduate student at the University of Southampton.
For my PhD thesis, I am examining a link between theory and practical applications of evaluating user experience in visualisation navigation. Because you are newcomers to Southampton University who have recently had your induction to the campus, I am inviting you to participate in my research by completing the attached survey.
Thank you for taking the time to participate in very important research. The following questionnaire will take approximately 45 minute to complete. The data collected will provide useful information regarding your preferences in applying different visualisation navigation methods in specific scenarios. Your answers will be completely anonymous. All survey results will be published in my doctoral thesis.

Sincerely

Azira Ab Aziz
A.Ab-Aziz@soton.ac.uk
School of Management
Faculty of Business and Law
Southampton University

REPERTORY GRID TECHNIQUES

Instruction: Please answer all the questions

1 Please enter your email address

2 Please enter your programme of study

☐ Psychology ☐ Computer Science ☐ Management

3 Please select your age group

☐ 20 or below ☐ 21-25 ☐ 26-30 ☐ 31-35 ☐ 36 & above

4 Please select your gender

☐ Male ☐ Female

1st Triad

A1 In what way is one of these maps different from the other two?
(specify according to its usefulness to you in finding locations of the Isolutions Department)

Map__is_______________ and Maps __& ___are_________________.
(map number) (different) (map number) (similar)

A2 For Researcher Use Only (Please describe the reason for your decision)

2nd Triad

B1 In what way is one of these maps different from the other two?
(specify according to its usefulness to you in finding locations of the Isolutions Department)

Map__is_______________ and Maps __& ___are_________________.
(map number) (different) (map number) (similar)

B2 For Researcher Use Only (Please describe the reason for your decision)

3rd Triad	
C1	In what way is one of these maps different from the other two? (specify according to its usefulness to you in finding locations of the Isolutions Department)

Map__is_______________ and Maps ___& ___are_________________.
(map number) (different) (map number) (similar)

C2	For Researcher Use Only (Please describe the reason for your decision)

4th Triad	
D1	In what way is one of these maps different from the other two? (specify according to its usefulness to you in finding locations of the Isolutions Department)

Map__is_______________ and Maps ___& ___are_________________.
(map number) (different) (map number) (similar)

D2	For Researcher Use Only (Please describe the reason for your decision)

5th Triad	
E1	In what way is one of these maps different from the other two? (specify according to its usefulness to you in finding locations of the Isolutions Department)

Map__is_______________ and Maps ___& ___are_________________.
(map number) (different) (map number) (similar)

E2	For Researcher Use Only (Please describe the reason for your decision)

6th Triad	
F1	In what way is one of these maps different from the other two? (specify according to its usefulness to you in finding locations of the Isolutions Department)

Map__is_______________ and Maps __& ___are________________.
(map number) (different) (map number) (similar)

F2	For Researcher Use Only (Please describe the reason for your decision)

7th Triad	
G1	In what way is one of these maps different from the other two? (specify according to its usefulness to you in finding locations of the Isolutions Department)

Map__is_______________ and Maps __& ___are________________.
(map number) (different) (map number) (similar)

G2	For Researcher Use Only (Please describe the reason for your decision)

8th Triad	
H1	In what way is one of these maps different from the other two? (specify according to its usefulness to you in finding locations of the Isolutions Department)

Map__is_______________ and Maps __& ___are________________.
(map number) (different) (map number) (similar)

H2	For Researcher Use Only (Please describe the reason for your decision)

9th Triad

I1	In what way is one of these maps different from the other two? (specify according to its usefulness to you in finding locations of the Isolutions Department)

Map__is_______________ and Maps ___& ___are________________.
(map number) (different) (map number) (similar)

I2	For Researcher Use Only (Please describe the reason for your decision)

10th Triad

J1	In what way is one of these maps different from the other two? (specify according to its usefulness to you in finding locations of the Isolutions Department)

Map__is_______________ and Maps ___& ___are________________.
(map number) (different) (map number) (similar)

J2	For Researcher Use Only (Please describe the reason for your decision)

Thank you for your cooperation

REPERTORY GRID TECHNIQUES [RATING FORM]

Instruction: *Please rate the campus maps according to your listed opinions. Use the rating scale given below*

Scale

Very	Moderately	Neither/Both	Moderately	Very
1	2	3	4	5

	Construct (Different)	**CAMPUS MAP** M1	M2	M3	M4	M5	M6	M7	**Construct (Similar)**	
A1(i)										A1(ii)
B1(i)										B1(ii)
C1(i)										C1(ii)
D1(i)										D1(ii)
E1(i)										E1(ii)
F1(i)										F1(ii)
G1(i)										G1(ii)
H1(i)										H1(ii)
I1(i)										I1(ii)
J1(i)										J1(ii)

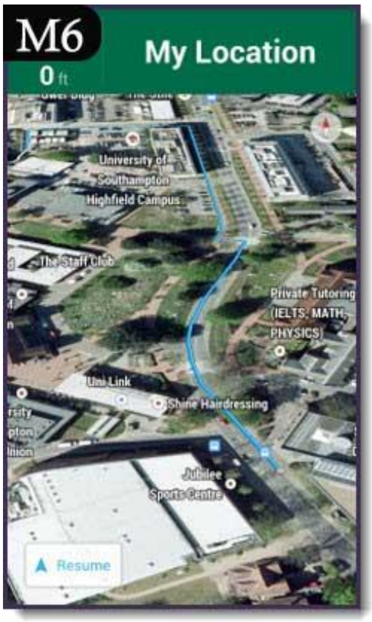
Appendix B Sample of Campus Map

Appendix B


M3
Transport
Catering & Accommodation
Services
Culture & Entertainment
Health & Beauty
Tourism & Religion
Retail
Education
Sports
Events


M4


M5


M6
My Location
0 ft
University of
Southampton
Highfield Campus
The Staff Club
Private Tutoring
(IELTS, MATH,
PHYSICS)
Uni-Link
Shine Hairdressing
Jubilee
Sports Centre
Resume


M7
13:06
AR pedestrian navigation
Next turn in
50 metres
Total distance
left to walk
368 metres

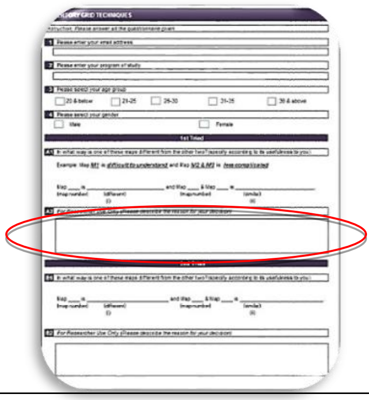
Appendix C Experimental Flow Chart

TRIADING

Image Randomizer
Projected on Smart Board Screen

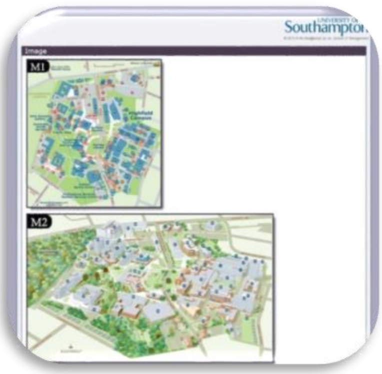
Triading Form
Respondents fill in the constructs

LADDERING AND PYRAMIDING



Semi-structured interview
Elaborate on each of their constructs in the questionnaire

RATING



Rate each of their constructs by referring to the list of images projected on Smart Board screen

Appendix D Quantitative: Principal Component Analysis

D.1 Correlation between Constructs and Components

Varimax rotated principal components of construct correlations

Construct ID	Construct	Component 1	Component 2	Component 3
1	Noisy	-0.24	0.70	-0.48
2	General image	-0.95	-0.25	0.08
3	Functional	-0.45	-0.30	-0.54
4	Provide relative size of location	-0.35	-0.91	0.15
5	Easier to find position	0.90	0.36	0.18
6	Easier to use	0.63	-0.62	0.33
7	Traditional map	-0.93	-0.37	-0.05
8	Clear information	-0.75	-0.63	0.10
9	Just showing the locations	0.19	0.34	0.59
10	Public notice	-0.93	-0.37	-0.05
11	Complete map	-0.53	-0.62	0.37
12	Clear	0.40	0.05	0.40
13	Useful for navigation	0.01	-0.31	0.81
14	Clear depiction	0.24	0.23	0.66
15	Well labelled	-0.19	-0.87	0.06
16	Completed and clear	-0.35	-0.46	0.39
17	Attractive	-0.12	-0.85	0.27
18	Incomplete	-0.36	0.16	-0.91
19	Good depictions	0.18	-0.56	0.59
20	Dull	-0.26	0.60	-0.45
21	Similar	-0.73	0.10	-0.42
22	Google map	-0.59	0.12	-0.51
23	A bit messy	-0.24	-0.23	-0.66
24	Confusing	-0.27	-0.10	-0.90
25	Not very clear	-0.32	-0.10	-0.58
26	Like plans of the building, google map	-0.08	0.32	-0.88
27	Informative	0.07	-0.03	-0.84
28	Picture	-0.99	0.02	-0.08
29	Almost the same	-0.99	0.02	-0.08
30	Showing the whole pictures	-0.98	0.01	-0.07

31	No shadows	-0.69	0.15	0.28
32	Aerial view	-0.82	0.13	-0.24
33	Drawn map	-0.72	0.17	0.28
34	Entire map	-0.91	0.10	-0.11
35	Not a photograph	-0.72	0.17	0.28
36	No 3d instructions	-0.98	0.02	-0.09
37	Basic map	-0.99	0.02	-0.08
38	No services shows	0.32	0.73	0.26
39	Buildings not numbered	0.47	0.33	-0.82
40	Roads are not numbered	0.31	-0.17	-0.37
41	Easy to interpret	0.48	-0.31	0.82
42	Giving direction	0.57	-0.01	0.35
43	Giving direction	0.77	-0.15	0.52
44	Depicted in simpler notations	0.68	-0.01	0.37
45	Provide the current location	0.65	-0.43	0.53
46	Easier and pleasing to look	0.61	-0.47	0.46
47	Having information of building names and number	0.28	-0.33	0.84
48	Easy to find location	0.76	-0.30	0.31
49	Symbolized with logo	0.37	-0.08	0.21
50	Represented with logo	-0.74	-0.06	0.66
51	Images	-0.55	0.33	-0.26
52	Overall view	-0.93	-0.04	-0.21
53	Clear	0.26	-0.04	0.81
54	3D	0.35	-0.37	0.12
55	General look	0.12	0.61	0.74
56	Lead to right place	0.20	-0.42	0.83
57	Do not show any locations	-0.98	0.02	-0.09
58	Just the campus	0.48	-0.31	0.82
59	Show the way to destinations	0.04	-0.30	0.76
60	Make the sense	0.68	-0.37	0.47
61	(Just numbered) complicated	-0.08	0.90	0.15
62	Confusing	-0.71	0.59	-0.19
63	Diagrammatic	-0.96	0.24	-0.09
64	Broad and confusing	-0.79	0.52	-0.07
65	Blank	-0.48	0.86	0.07
66	Pictorial	-0.86	0.38	0.18
67	Specific (does not mislead)	0.44	-0.86	0.05
68	Do not have building name and number	0.59	0.62	0.46
69	Pictorial and confusing	-0.79	0.50	0.18

70	Not clear	-0.53	0.75	0.19
71	Clear	-0.67	0.45	0.37
72	Macro and extensive	-0.54	0.05	-0.24
73	Large-scale and clear	-0.42	0.22	0.31
74	Large scale and have signal	0.24	0.23	-0.92
75	Map and virtual route	0.62	-0.02	0.09
76	Mapping the locations	-0.36	-0.55	0.38
77	Colourful	0.38	0.33	-0.67
78	Mapping with building signal	0.16	0.17	-0.96
79	Colourful, clear	-0.28	0.24	-0.45
80	Know the exact location	-0.19	0.46	0.10
81	Complicated	-0.65	-0.71	-0.02
82	The same layout	-0.68	-0.72	-0.02
83	The whole campus	-0.57	-0.22	-0.07
84	The same structure	-0.75	-0.23	-0.08
85	The same structure	-0.75	-0.23	-0.08
86	Complanate	-0.55	0.23	-0.23
87	Bird's eye view	-0.54	0.04	0.75
88	Detailed and clearly guided	-0.67	-0.69	0.10
89	Colourful and vivid	0.23	-0.96	0.07
90	Complete view	-0.99	0.02	-0.08
91	90% perspective	-0.50	0.11	-0.50
92	Drawn	-0.56	0.57	0.20
93	Birds' eye view	-0.55	0.25	-0.46
94	Top-view/ bird	-0.10	0.28	-0.23
95	Map from top view	-0.55	0.25	-0.46
96	Details of area	0.08	-0.78	0.20
97	Top view, find way on your own	-0.96	0.18	-0.19
98	Top view, not necessary information	-0.92	0.18	0.03
99	Details of area	-0.35	-0.70	0.43
100	Information towards destination	0.68	-0.44	0.59
101	Natural images	0.72	-0.17	-0.28
102	Map	-0.99	0.02	-0.08
103	Useful info included	-0.51	-0.57	-0.42
104	Map	-0.99	0.02	-0.08
105	3D	0.67	-0.11	0.48
106	Colour	0.23	-0.96	0.07
107	Navigation guide	0.99	-0.02	0.08
108	Whole uni	-0.99	0.02	-0.08
109	Navigation guide	0.99	-0.02	0.08

110	2D	-0.67	0.11	-0.48
111	Top view	-0.69	-0.20	-0.23
112	Broad	-0.86	-0.10	0.21
113	With route	-0.69	-0.10	0.22
114	Detailed	-0.69	-0.10	0.22
115	Colourful	-0.17	-0.87	0.21
116	Clear	-0.74	-0.61	0.15
117	Buildings and streets are named	-0.95	-0.02	0.07
118	Numbered and symbols	-0.79	-0.51	0.11
119	Clearly numbered	-0.60	-0.67	0.17
120	Similar scales	-0.89	-0.33	0.21
121	Numbers	-0.01	0.13	0.98
122	Real picture	0.82	-0.14	-0.20
123	3D	0.61	-0.20	0.32
124	Coloured	0.28	-0.90	0.22
125	Symbols	-0.89	-0.21	-0.21
126	Above view	-0.65	0.15	-0.41
127	Rectangular maps	-0.09	-0.53	-0.28
128	All part of university	-0.99	0.02	-0.08
129	Map	-0.71	-0.35	0.19
130	A well definite area	-0.68	-0.72	-0.02
131	Bird's eye view	-0.25	-0.63	0.63
132	Provides icons	0.05	-0.06	-0.06
133	Not giving directions	0.03	0.01	-0.05
134	Giving details	-0.17	-0.01	0.87
135	Just showing the campus	-0.87	-0.18	0.44
136	Giving directions	0.93	-0.01	0.06
137	Showing numbered buildings	-0.17	-0.01	0.96
138	Showing details	0.09	-0.48	0.62
139	Showing icons instead	0.23	0.10	-0.96
140	Bird's eye views	-0.97	-0.03	0.12
141	Real view and hard to find the place	0.63	0.55	-0.46
142	Sketch with distractions	0.51	0.42	-0.69
143	Overall view	-0.94	-0.32	0.07
144	Passive views	-0.99	0.02	-0.08
145	Used for imagination	-0.94	-0.29	0.18
146	Showing the way to go	0.67	-0.35	0.64
147	Includes different departments	-0.81	-0.44	-0.06
148	Locations of different departments	-0.15	-0.12	-0.94

149	For any means of transportation	-0.67	-0.22	0.53
150	Showing buildings and streets	-0.08	-0.31	0.82
151	Overview	-0.83	-0.04	-0.11
152	Broader look	-0.76	0.18	-0.13
153	Labelled	-0.30	-0.44	0.35
154	Overall view	-0.78	0.27	0.01
155	More realistic	0.66	0.18	-0.19
156	Overviews	-0.57	0.14	-0.26
157	Overviews and harder to decipher	-0.20	0.25	-0.23
158	More lifelike	0.50	0.77	-0.10
159	Outlines to give general ideas	-0.72	0.10	-0.44
160	More informational and broader view	-0.72	-0.30	-0.11
161	Structure	0.13	-0.44	0.49
162	Include instructions	0.31	-0.58	-0.21
163	Building structure	0.23	-0.78	0.50
164	Roads	0.14	0.49	-0.06
165	Easy to visualize	0.29	0.27	0.23
166	Colourful	-0.22	-0.91	0.20
167	Picture	0.58	0.27	0.27
168	Appealing	-0.16	-0.15	0.30
169	Overall/helicopter view	-0.96	-0.20	-0.07
170	Too many symbols	-0.73	-0.43	-0.35
171	Whole campus	-0.99	0.02	-0.08
172	Colour	0.25	-0.64	0.60
173	Keys and symbols	-0.09	-0.41	-0.86
174	Keys and symbols	-0.03	-0.88	-0.12
175	Graphical representation	-0.68	-0.18	0.32
176	Whole campus	-0.99	0.02	-0.08
177	Whole campus	-0.99	0.02	-0.08
178	Roads labelled clearly	-0.54	0.46	0.24
179	Don't represent a view	-0.81	0.02	0.12
180	Show new additions	-0.16	0.16	0.75
181	Colourful	0.25	-0.64	0.60
182	Conventional	-0.92	0.30	0.03
183	Have clear info	-0.34	-0.70	-0.39
184	Both have legends	-0.15	-0.88	-0.18
185	Confusing	-0.34	0.47	-0.52
186	Not real images	-0.48	0.55	-0.12
187	No clear info about the distance	0.35	0.40	0.84

188	No clear information	-0.86	0.15	-0.42
189	3D images	0.65	-0.31	-0.20
190	Confusing	-0.61	0.42	-0.36
191	2D	-0.56	-0.35	0.13
192	Pictures	-0.62	-0.15	0.12
193	Computerized photos	-0.63	0.66	0.05
194	The area is same but the structures are different	-0.88	-0.22	0.09
195	Drawn pictures	-0.32	-0.57	0.30
196	View from sky	-0.45	0.21	-0.22
197	Large area	-0.98	0.02	-0.09
198	Easier to understand	0.21	-0.65	0.46
199	General maps	-0.67	-0.46	-0.06
200	Same area	-0.63	-0.23	0.02
201	Overall layout	-0.88	0.07	0.03
202	3D	0.61	-0.20	0.32
203	General maps of campus	-0.95	0.14	0.16
204	Colours	0.49	-0.73	0.11
205	Real life photography	0.72	-0.17	-0.28
206	More information	0.07	-0.80	-0.28
207	Real-life imagery	0.70	-0.36	-0.23
208	Use directions	0.88	-0.09	0.22
209	Show facilities (colour coding)	-0.41	-0.60	-0.44
210	Computer-generated graphic	-0.65	0.06	0.49
211	Have overview	-0.98	0.02	-0.09
212	No instruction	-0.99	0.02	-0.08
213	Not showing current location	-0.98	0.02	-0.09
214	Not colourful	0.38	0.45	0.60
215	Idea about distance	0.98	-0.02	0.09
216	Overview of whole campus	-0.93	0.01	-0.06
217	Without terrain	-0.62	0.21	0.22
218	Colourful	0.07	-0.96	-0.24
219	Have information	-0.22	0.12	-0.51
220	Have name of buildings	0.30	0.48	0.73
221	Clear	0.78	-0.45	-0.07
222	Focus on actual university	0.72	-0.29	0.29
223	Actual buildings and signs	0.20	-0.83	0.06
224	Helpful	0.66	-0.56	0.18
225	Have signage	0.34	-0.92	-0.12
226	2D maps	-0.99	0.02	-0.08
227	Just visual	-0.99	0.02	-0.08

228	Prepared by programmes	-0.18	0.20	0.37
229	Answer the questions	0.98	0.06	0.05
230	User-friendly	0.86	0.25	0.41
231	Vague	0.15	0.58	-0.46
232	Not clear in visualisations	0.15	0.58	-0.46
233	Wide view	-0.72	-0.49	-0.41
234	Descriptive and simple	-0.24	0.05	0.54
235	Useful (building numbers)	0.10	0.21	0.91
236	Guide to specific building	0.72	0.49	0.41
237	Just an idea of whole searched area	-0.13	-0.02	-0.72
238	Able to give direction	0.12	0.23	0.95
239	Provide building number	0.01	-0.01	0.98
240	Useful to main places	-0.19	0.34	-0.37
241	An area of building	-0.65	-0.40	0.09
242	Google maps	0.60	0.20	-0.35
243	Google maps	0.60	0.20	-0.35
244	With captcha	-0.26	-0.60	-0.75
245	Close views	0.10	-0.91	0.24
246	Clear	-0.15	-0.78	0.32
247	With directions	-0.11	-0.81	-0.19
248	Colours	0.23	-0.96	0.07
249	Not clear	-0.27	0.85	-0.25
250	No clear directions	0.66	0.40	-0.36
251	Modern and colourful	0.04	-0.95	0.06
252	3D	0.48	-0.26	0.13
253	Layout maps	-0.89	-0.33	0.21
254	Of the campus	-0.98	0.02	-0.09
255	Detailed campus layout	-0.94	-0.29	0.18
256	Showing buildings	0.29	0.10	0.73
257	Google maps	0.70	-0.12	-0.57
258	More detailed	0.07	-0.97	0.05
259	Electronic	0.62	-0.60	-0.16
260	Images of campus	0.05	-0.06	-0.06
261	More complete	-0.85	-0.01	-0.37
262	Many buildings	-0.82	-0.13	-0.38
263	Cover wider area	-0.80	-0.01	0.19
264	More informative	-0.43	-0.47	0.60
265	Difficult	0.68	-0.05	-0.48
266	Drawings	-0.55	0.25	0.09
267	Complicated	-0.21	0.24	-0.67

268	Using numbers	-0.42	0.25	0.51
269	Using icons	-0.72	0.17	0.28
270	Showing pedestrian way	0.20	-0.42	0.83
271	Whole sight	-0.43	0.62	0.35
272	Colourful	-0.80	-0.23	-0.55
273	Not clear	0.86	0.46	-0.09
274	A little bit clearer	0.08	-0.93	0.26
275	Also good	0.33	0.19	0.17
276	For detailing	-0.47	-0.33	0.82
277	Quite complex	0.05	-0.10	-0.06
278	Normal	0.45	0.65	-0.36
279	Not professional	0.60	0.67	-0.17
280	Useful	0.12	-0.69	-0.45
281	Coloured	-0.28	-0.92	-0.26
282	Bird's eye view	-0.75	0.08	-0.37
283	Comprehensive	-0.99	0.02	-0.08
284	Satellite images	0.56	-0.18	-0.35
285	Have signs	-0.76	-0.59	-0.17
286	Have text in picture	0.19	0.42	0.85
287	Show my locations	0.96	-0.04	0.20
288	Harder to read	-0.91	-0.11	-0.35
289	Tilted	-0.62	-0.33	-0.02
290	Organised	-0.38	0.52	0.76
291	Vertically representing	-0.96	0.04	-0.20
292	Colourful	0.23	-0.96	0.07
293	Maps with navigation	0.99	-0.02	0.08
294	Maps only	-0.99	0.02	-0.08
295	Labelling with numbers	-0.42	-0.60	0.34
296	Labelling with numbers	-0.42	-0.60	0.34
297	Traditional maps	-0.99	0.02	-0.08
298	Labelling with symbols and numbers	-0.52	-0.76	0.14
299	Showing names of buildings	0.34	0.60	0.57
300	Labelling with symbols	0.07	-0.05	-0.99
301	Two-dimensional	-0.46	0.25	-0.24
302	Overall for the campus	-0.98	0.02	-0.09
303	Relative to the viewer's position	0.93	-0.05	0.22
304	Top-view of the campus	-0.99	0.02	-0.08
305	Overall view with highlights	-0.84	-0.19	-0.23
306	Related to the viewer's position	0.86	-0.05	0.24
307	Overall view of the campus	-0.96	0.04	-0.20

308	From bird's eye view	-0.73	0.05	-0.24
309	Realistic images	0.63	-0.30	0.01
310	Stressing on the edges	-0.35	0.45	-0.13
311	Vocabularies and shapes	-0.21	-0.75	-0.43
312	Overviews and general pictures	0.23	-0.67	0.59
313	Marks	-0.23	-0.34	0.87
314	Find certain location	0.39	-0.80	0.44
315	Showing direction and numbers	0.11	-0.57	-0.64
316	Sense of direction, name and number	-0.75	-0.25	0.60
317	Related to what you want to find	0.04	0.59	-0.69
318	Classified the building	0.54	-0.63	0.43
319	Detailed and easy to find building	0.40	-0.40	-0.78
320	Include road name and direction of buildings	-0.90	-0.33	0.23
321	Looking over campus	-0.74	-0.39	0.40
322	Full maps of campus	-0.86	-0.23	0.26
323	They pin point where things are	-0.23	-0.20	-0.86
324	Give an overview of campus	-0.93	-0.03	0.27
325	Pin point locations other than building number	-0.06	-0.21	-0.91
326	Satellite views	0.39	-0.11	-0.51
327	Give overviews of campus	-0.86	-0.17	0.05
328	Either building number or location	-0.26	-0.18	-0.50
329	Both navigations methods	0.97	0.14	-0.03
330	Map views	-0.21	0.22	0.44
331	Layouts	-0.55	0.16	0.32
332	Marking notation	-0.19	-0.25	-0.15
333	Mobile apps	0.79	-0.32	-0.37
334	Mobile apps	0.04	0.16	0.29
335	Practical	0.43	-0.50	0.03
336	Abstract maps	0.23	-0.88	-0.25
337	Not clear	-0.55	0.44	0.61
338	Much more detailed	0.47	-0.46	-0.67
339	Interesting and easier	0.16	-0.14	-0.51
340	Include surrounding in a larger scale	-0.22	-0.13	0.13
341	Whole campus	-0.98	-0.18	-0.07
342	Structure	0.36	-0.26	0.24
343	Colourful, clear	0.05	-0.41	0.81

344	Number, symbol	-0.38	0.41	0.75
345	Name of facilities	0.08	-0.68	-0.46
346	Google Earth	0.46	0.33	-0.39
347	Have a road name	0.28	-0.33	0.84
348	All building in campus	-0.56	-0.63	-0.04
349	Only a map	-0.30	-0.73	-0.01
350	Tell all locations	-0.21	-0.83	0.00
351	Coloured	-0.12	-0.93	-0.24
352	Graphics made	-0.68	-0.18	0.32
353	Flat/2D	-0.73	0.19	-0.23
354	Numbering	0.23	0.20	0.86
355	Static/more general	-0.99	0.02	-0.08
356	Giving a lot of info	0.44	-0.81	0.24
357	Normal static maps	-0.82	0.16	-0.12
358	Giving precise directions	0.99	-0.02	0.08
359	Helpful	0.47	-0.57	0.49
360	Drawn	-0.50	0.23	0.21
361	Overview of campus	-0.54	0.63	0.24
362	Colourful	-0.63	-0.71	-0.25
363	Display the whole	-0.53	0.02	0.36
364	Detailed building and colours	0.07	-0.05	-0.94
365	Simulate in virtual worlds	-0.82	-0.07	0.48
366	Detailed information	0.41	-0.46	0.14
367	Specific details and interface buildings	0.52	-0.48	-0.56
368	Real environment	0.74	0.16	-0.36
369	Show several buildings	-0.80	0.02	-0.09
370	Whole buildings	-0.72	0.50	-0.29
371	Represent building and not walkaway	-0.70	-0.15	-0.27
372	Scattered	-0.10	-0.21	0.21
373	3D	0.41	-0.64	0.59
374	Reflects the place	0.09	-0.75	0.44
375	Not clear	-0.41	0.87	-0.07
376	Not understandable	-0.87	0.44	0.10
377	General map	-0.82	-0.10	0.32
378	Need more study	-0.82	-0.10	0.32
379	Drawing	-0.51	0.77	-0.34
380	The map not clear	-0.34	0.59	-0.29
381	Broad and clear	-0.51	-0.24	0.26
382	Rational, boring	0.32	0.82	0.29

383	Simple	0.89	-0.17	0.03
384	Broad, clear	-0.22	-0.35	0.45
385	Easy, readable	0.10	-0.85	0.48
386	Brief, overview	-0.03	0.05	0.67
387	Overloaded, colourful	-0.56	-0.08	-0.75
388	Readable, bright	0.39	-0.65	0.45
389	Comfortable, easy	0.12	0.05	0.90
390	Sensible, clear	0.88	0.13	0.31
391	Overall	-0.22	0.24	-0.87
392	Provide direction	0.99	-0.02	0.08
393	Show location	-0.74	-0.08	-0.23
394	General	-0.92	0.02	-0.09
395	Not real photo	-0.72	0.17	0.28
396	General	-0.99	0.02	-0.08
397	Show the structure	-0.55	0.15	0.27
398	Real photos	0.72	-0.17	-0.28
399	Not real photo, general	-0.91	0.10	0.11
400	Three-dimensional	0.67	-0.11	0.48
401	Number and boxes	-0.68	0.43	0.21
402	Certain part of university	0.59	0.21	-0.74
403	Drawings of location	-0.03	0.26	-0.36
404	Showing icons of location	-0.93	0.01	-0.06
405	Showing location from an overview of entire location	-0.55	0.16	-0.79
406	For mature people	-0.35	0.23	-0.08
407	Easier to locate places	0.67	0.36	0.46
408	Overall view	-0.49	-0.20	-0.51
409	Numbering	0.27	0.22	0.49
410	Using symbol and numbers	-0.05	-0.86	0.08
411	Detail	-0.44	-0.82	0.18
412	Detail and colour	-0.09	-0.76	0.21
413	Detail of the picture	-0.05	-0.89	0.45
414	Real images	-0.10	-0.92	0.06
415	View of picture	-0.73	0.05	-0.24
416	No label	-0.69	-0.10	0.22
417	Top view	-0.67	-0.11	-0.08
418	Location and explanation are the same	-0.53	0.09	0.07
419	Have explanation	-0.75	-0.23	-0.08
420	Lively picture	-0.77	0.04	0.23
421	Simple location and building	0.41	0.72	0.37

422	Overview of campus	-0.60	-0.22	0.46
423	Lack of information	0.75	0.67	0.02
424	No activities	0.34	0.58	0.65
425	Too complicated/too simple	0.44	0.66	-0.41
426	Colourful	-0.33	-0.93	-0.12
427	Easy to identify places	-0.43	-0.82	0.16
428	Flat designs	-0.10	0.28	-0.23
429	No determined point to go	0.49	0.61	-0.52
430	Single sign	0.54	0.73	0.21
431	Labelled and detailed	0.65	-0.35	-0.54
432	Appealing and no reference	0.91	0.13	-0.37
433	Has GPS navigation	0.98	-0.02	0.09
434	Whole picture/interactive	0.96	-0.04	0.20
435	No distance	0.36	0.40	0.25
436	Don't have compass	-0.62	0.02	-0.09
437	Buildings have numbers	-0.48	-0.62	-0.28
438	Distances not measured	0.33	-0.06	-0.16
439	Show location	0.72	-0.47	-0.06
440	General to specific	0.16	-0.52	-0.03
441	Lacking information	-0.88	-0.20	-0.23
442	Same area	-0.62	0.02	-0.09
443	Similar locality info	-0.24	0.37	0.21
444	Satellite view	-0.62	0.02	-0.09
445	Too much information	-0.62	-0.42	-0.08
446	Location	-0.63	-0.10	0.13
447	Congestion/confusion	-0.91	0.13	-0.28
448	Signs	-0.63	-0.08	-0.39
449	Format	-0.48	0.31	-0.82
450	Building names	-0.72	0.22	-0.42
451	Campus as a whole	-0.99	0.02	-0.08
452	Give surround buildings	0.46	0.73	0.35
453	Different facilities	-0.19	-0.88	-0.42
454	Satellite map	0.02	-0.05	-0.46
455	The whole campus	-0.99	0.02	-0.08
456	Name of building	0.57	0.58	0.41
457	2D	-0.59	0.12	-0.51
458	Satellite map	0.68	-0.05	-0.48
459	Some facilities	-0.51	-0.57	-0.42
460	Some facilities	-0.84	-0.33	-0.30
461	Maps	-0.56	-0.51	0.33
462	Numbers	0.06	0.21	0.91

463	Not useful	0.73	0.65	0.11
464	Clearer	-0.73	-0.65	-0.11
465	Can't be interested	0.75	0.67	0.02
466	Easy to understand	-0.63	-0.54	-0.29
467	Showing the exact building	-0.98	-0.18	-0.07
468	Not helpful (no signs)	0.75	0.67	0.02
469	No numbers or signs	0.47	0.33	-0.82
470	Numbers	-0.75	-0.67	-0.02
471	Easier to understand	0.57	-0.38	0.69
472	Simpler	0.55	0.08	0.77
473	Adequate information	0.11	-0.36	0.65
474	Unorganized information	-0.37	0.25	-0.71
475	Less sophisticated	-0.40	0.41	-0.48
476	Design is bad	-0.57	0.18	-0.63
477	Missing details	-0.17	0.36	-0.59
478	Boundaries are not clear	0.40	0.91	-0.02
479	Less scattered information	-0.26	0.33	-0.87
480	Less/more info than needed	0.05	0.54	-0.51
481	Represent the whole building	0.45	-0.29	-0.20
482	No navigation	-0.59	0.12	-0.51

D.2 Constructs which highly correlate with Component 1

Contruct ID	Contruct	Component 1
107	Navigation guide	0.99
109	Navigation guide	0.99
293	Maps with navigation	0.99
358	Giving precise directions	0.99
392	Provide direction	0.99
215	Idea about distance	0.98
229	Answer the questions	0.98
433	Has a GPS navigation	0.98
329	Both navigation methods	0.97
287	Show my locations	0.96
434	Whole picture/interactive	0.96
136	Giving directions	0.93
303	Relative to the viewer's position	0.93
432	Appealing and no reference	0.91
5	Easier to find position	0.90
383	Simple	0.89
208	Use directions	0.88
390	Sensible, clear	0.88
230	User-friendly	0.86
273	Not clear	0.86
306	Related to the viewer's position	0.86
122	Real picture	0.82
333	Mobile apps	0.79
221	Clear	0.78
43	Giving direction	0.77
48	Easy to find location	0.76
423	Lack of information	0.75
465	Can't be interested	0.75
468	Not helpful (no signs)	0.75
368	Real environment	0.74
463	Not useful	0.73
101	Natural images	0.72
205	Real-life photography	0.72
222	Focus on actual university	0.72
236	Guide to specific building	0.72
398	Real photos	0.72
439	Show location	0.72
207	Real-life imagery	0.70
257	Google maps	0.70

D.3 Constructs which highly correlate with Component 2

Construct ID	Construct	Component 2
478	Boundaries are not clear	0.91
61	(Just numbered) complicated	0.90
375	Not clear	0.87
65	Blank	0.86
249	Not clear	0.85
382	Rational, boring	0.82
158	More life-like	0.77
379	Drawing	0.77
70	Not clear	0.75
38	No services shown	0.73
430	Single sign	0.73
452	Give surround buildings	0.73
421	Simple location and building	0.72
1	Noisy	0.70

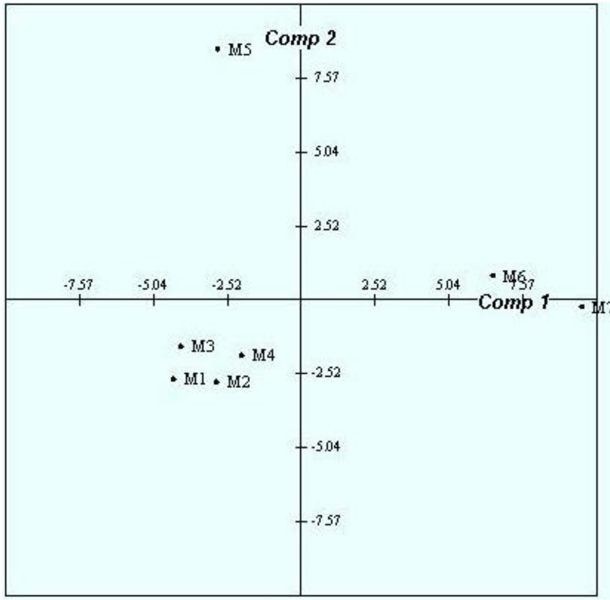
D.4 Constructs which highly correlate with Component 3

Construct ID	Construct	Component 3
121	Numbers	0.98
239	Provide building number	0.98
137	Showing numbered buildings	0.96
238	Able to give direction	0.95
235	Useful (building numbers)	0.91
462	Numbers	0.91
389	Comfortable, easy	0.90
134	Giving details	0.87
313	Marks	0.87
354	Numbering	0.86
286	Have text in picture	0.85
47	Having information of building names and numbers	0.84
187	No clear info about the distance	0.84
347	Have a road name	0.84
56	Lead to right place	0.83
270	Showing pedestrian way	0.83
41	Easy to interpret	0.82
58	Just the campus	0.82
150	Showing buildings and streets	0.82
276	For detailing	0.82
13	Useful for navigation	0.81
53	Clear	0.81
343	Colourful, clear	0.81
472	Simpler	0.77
59	Show the way to destinations	0.76
290	Organised	0.76
87	Bird’s eye view	0.75
180	Show new additions	0.75
344	Number, symbol	0.75
55	General look	0.74
220	Have name of buildings	0.73
256	Showing buildings	0.73

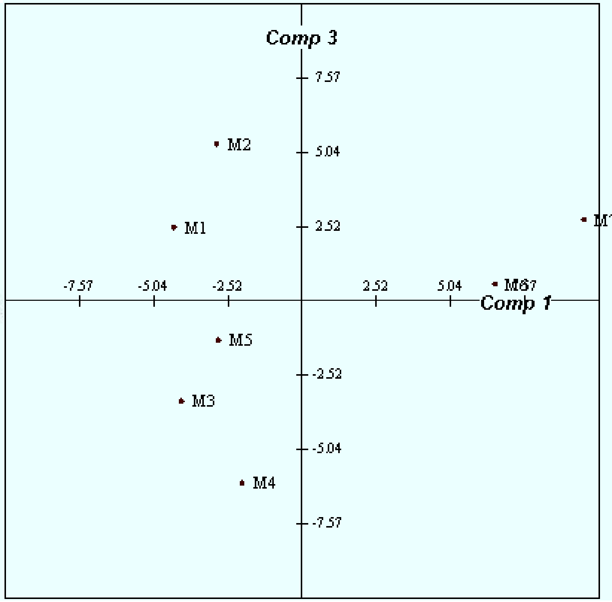
D.5 Principal component analysis of elements

PCA (varimax) for Visualisation Navigation

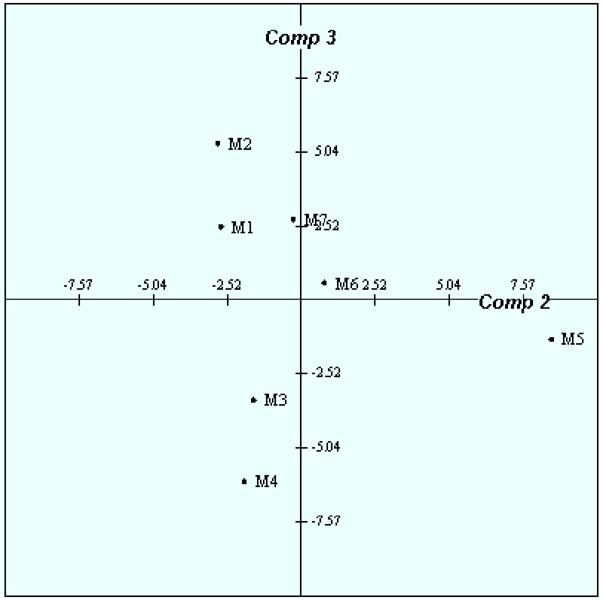
Axis Range: -10.09 to 10.09



<u>*A: Component 1 & Component 2*</u>

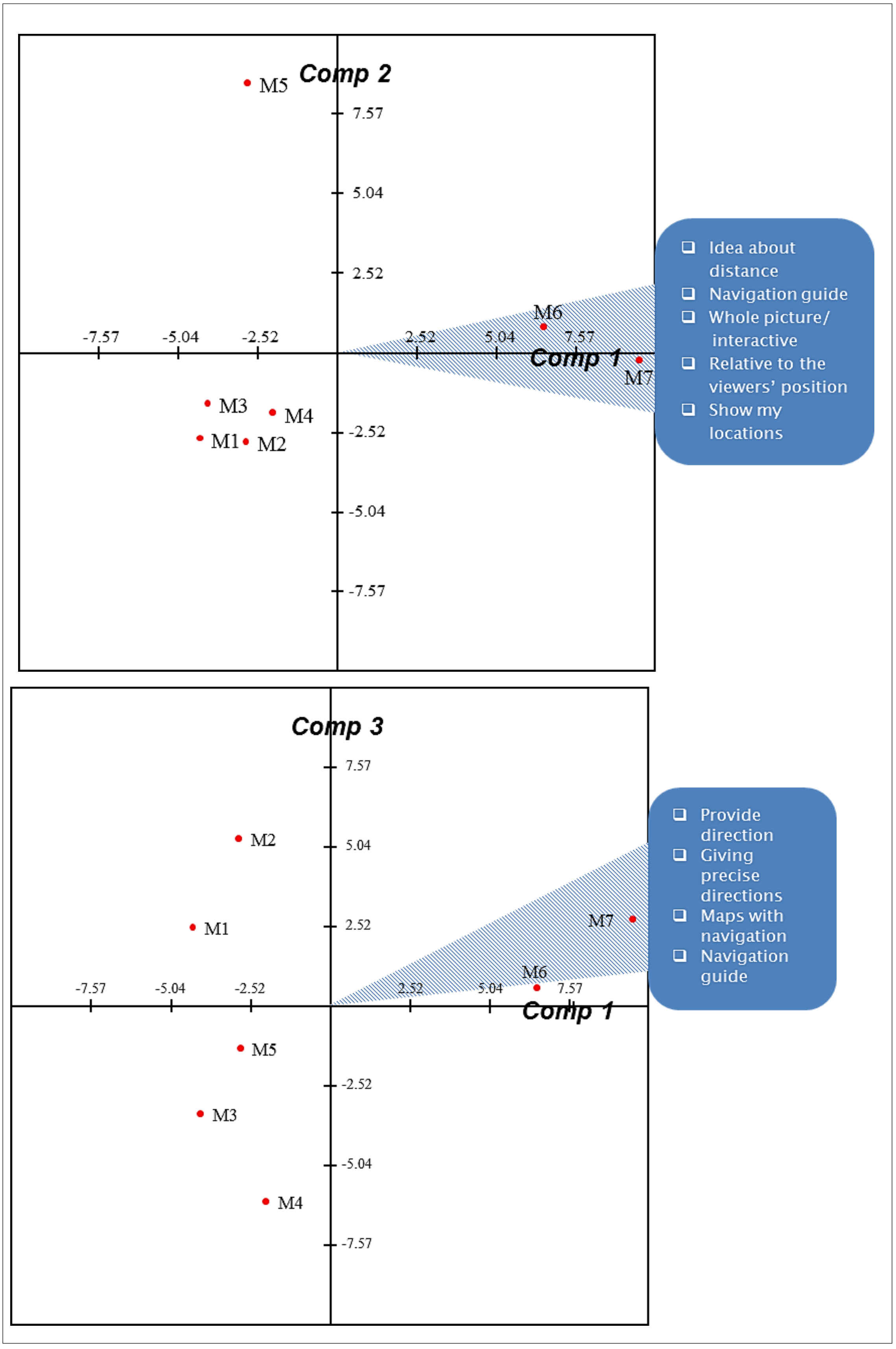


<u>*B: Component 1 & Component 3*</u>

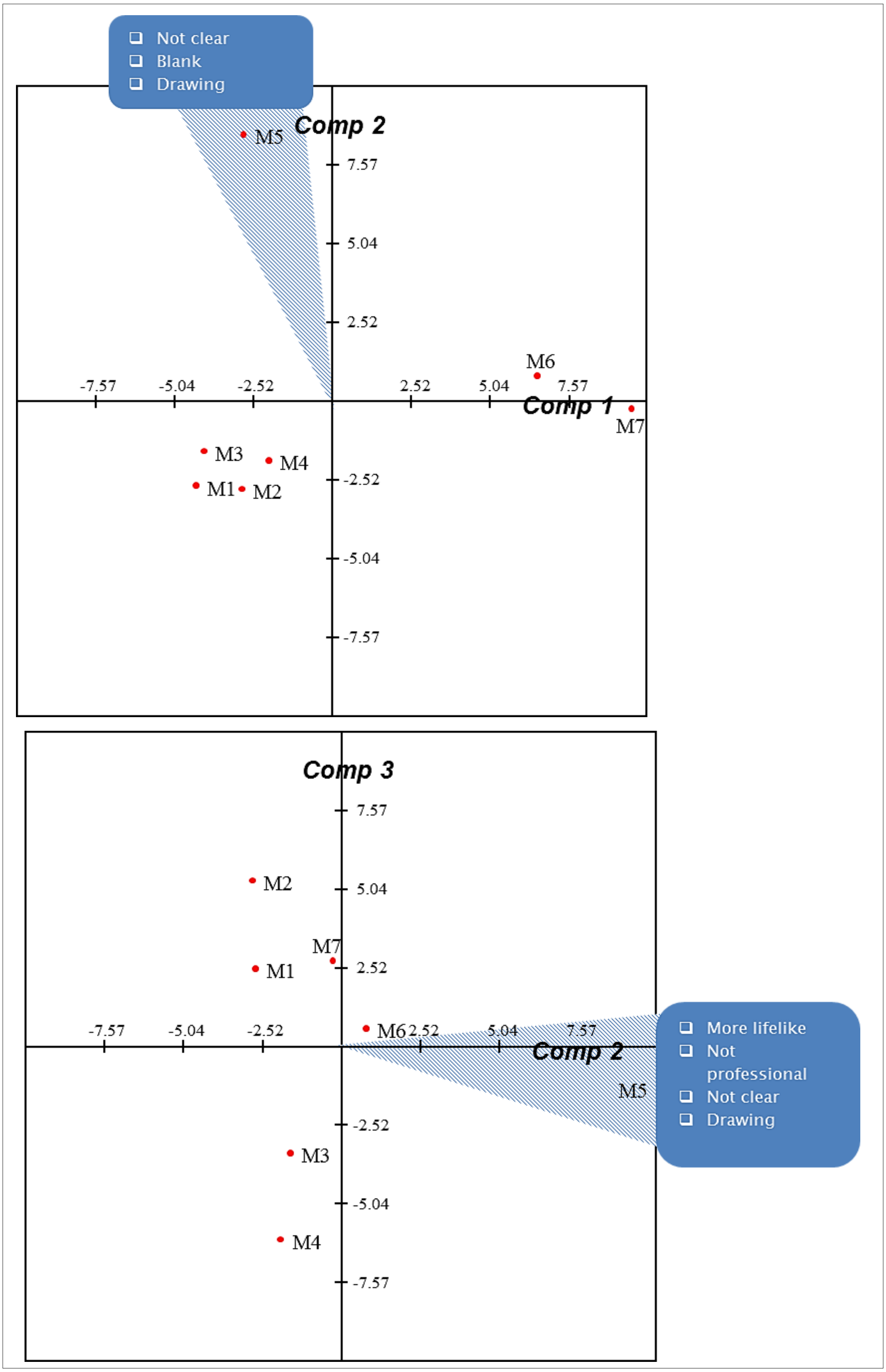


<u>*C: Component 2 & Component*</u>

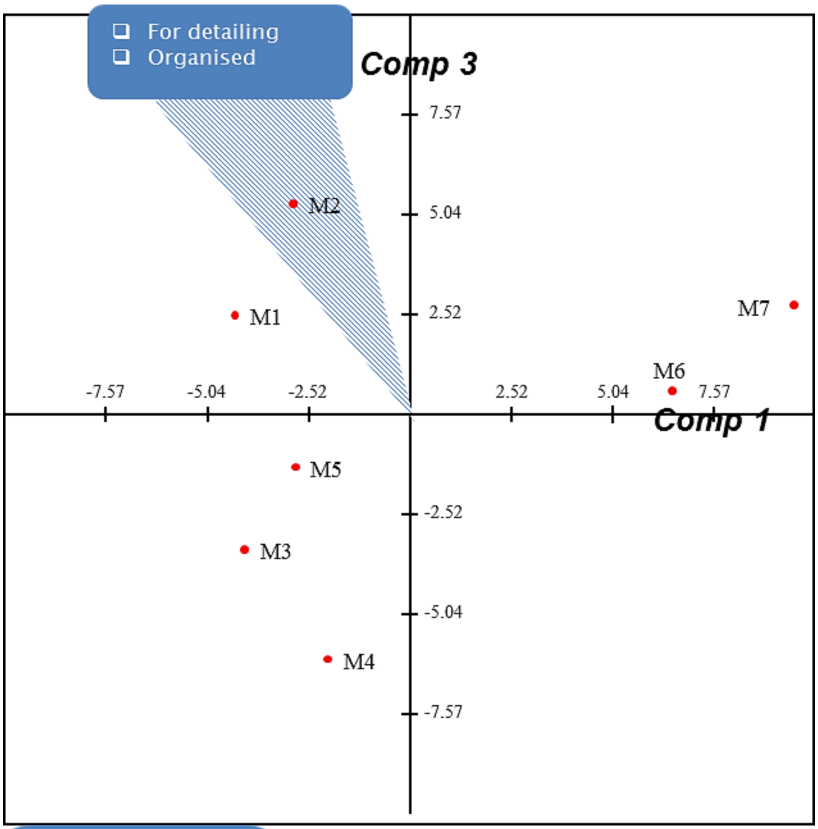
D.6 Graph for Component 1 (M7)

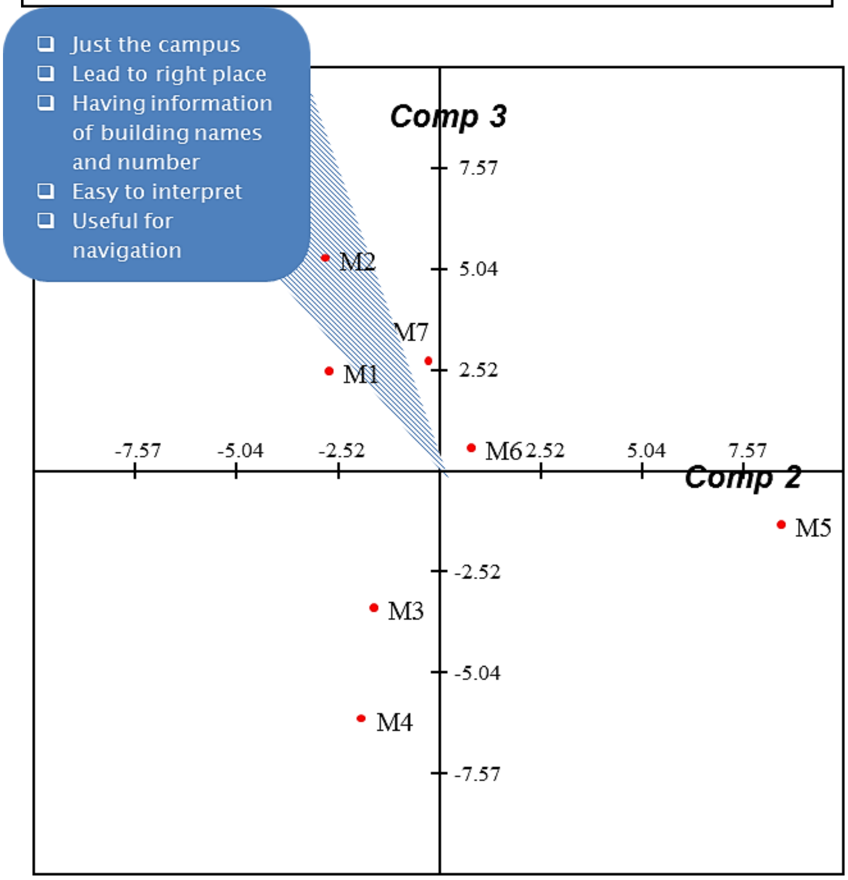


D.7 Graph for Component 2 (M5)



D.8 Graph for Component 3 (M2)





Appendix E Aggregation of Thematic Analysis and Three Layer Classification Scheme

E.1 Statements (open-ended questionnaires and interviews)

Question: In what way is one of these maps different from the other two?
(specify according to its usefulness to you in finding locations of the Isolutions Department)

RESPONDENT A

1ST TRIAD

Open-ended questionnaire

Map *1* is *hard to interpret at the first glance* and Maps *2 and 7* are *easier to interpret because the image is in the form of physical buildings*

Interview

It was a real experience to find a building and it is hard to find the building because it is not clearly represented by the number I want to find.

2ND TRIAD

Open-ended questionnaire

Map *4* is *image of other buildings which are not university premises are included* and Map *2 and 7* are *giving directions and distance (for M7) and shape of buildings are picturized (for M2)*

Interview

M7 tells us how far the building is from where you stand, and M2 gives a bird's eye view so even though the university premises are big at first sight, you possibly can find the building where they are at.

RESPONDENT B

1ST TRIAD

Open-ended questionnaire

Map *5* is *grey* and Maps *1 and 4* are *coloured*

Interview

Definitely preferred coloured, because I think it sometimes can help me to locate something I know, e.g. trees, buses

2ND TRIAD

Open-ended questionnaire

Map *7* is *street view* and Maps *1 and 6* are *bird's eye views*

Interview
This depends on two things, I would prefer the bird's eye view before I start the journey to see completely from where I am to where I have to go, but when on my way I have street view on my phone. It is very practical in case I don't know where to go, in case I don't remember

E.2 Words frequency results

Word Frequency Results

Word	Length	Count	Weighted	Similar Words
see	3	774	2.39	catch, catching, check, checking, consider, control, determined, experience, eyesight, figure, figuring, image, learn, look, looking, looks, meet, meeting, picture, pictures, picturized, realise, realised, regard, see, seeing, understanding, understands, view, viewing, views, visit, visual, visualisation, visualise, visualised, visuals
open	4	747	4.32	clear, clearly, give, gives, giving, loose, open, reception, surface
building	8	720	4.56	building, buildings, construction, figure, figuring, form, make, makes, shape, shapes
find	4	548	2.78	detect, detecting, determined, feel, feeling, find, finding, get, gets, getting, happen, notice, received, see, seei
ended	5	504	3.40	close, complete, completely, ended, ends, last, overal, stop, stops, terminal
place	5	483	1.82	direct, direction, directions, directly, identified, identify, local, locality, localize, locate, located, locating, locat point, pointing, points, position, positionally, positioning, post, put, putting, rank, rating, set, site, situation, situ
like	4	442	2.86	alike, care, compare, compared, comparing, like, likes, potential, probably, similarity, wish
just	4	387	1.97	exact, exactly, good, goods, hard, hardly, just, precise, right, simply
think	5	384	2.06	believe, consider, guess, imagination, imagine, imagining, intelligent, mean, means, reason, recall, remember thinks, thought
show	4	379	1.08	appear, demonstrate, demonstrating, depicted, depiction, depictions, design, designed, designs, display, disp picture, pictures, picturized, point, pointing, points, present, presented, read, show, showing, shows
view	4	378	1.34	aspects, consider, opinion, panorama, perspective, perspectives, position, positionally, positioning, scene, s thought, view, viewing, views
way	3	322	1.37	direct, direction, directions, directly, mean, means, path, paths, room, way, ways
useful	6	311	1.98	apply, enjoy, function, functional, functions, practical, practicalities, practically, purpose, purposes, roles, use
clear	5	304	0.87	clarity, clear, clearly, intelligent, make, makes, pass, passed, passing, readable, realise, realised, solve, sol understanding, understands
direction	9	279	0.68	direct, direction, directions, directly, flat, focus, focused, focusing, guidance, guide, guides, head, immediatel management, now, organised, organising, point, pointing, points, straight, take, takes, taking, train

E.3 Group of words and statements

Group Of words	Statements
Clarity	▪ Source 1, 15 references coded [22.25% Coverage] Reference 1 - 0.70% Coverage *Broad, clear* Reference 2 - 1.22% Coverage *It's more easy to understand where I am.* Reference 3 - 0.46% Coverage *Rational, boring* Reference 4 - 2.47% Coverage *Map 5 only has one colour and compared to M3 is more boring and the graph is not so clear* Reference 5 - 3.31% Coverage *Rational because M3 has colour, it's easier to understand and the*

	<u>*other is not. It's very principled/disciplined*</u> Reference 6 - 0.67% Coverage <u>*Broad, clear*</u> Reference 7 - 2.52% Coverage <u>*Broad and clear because it also has an overview of the campus and not just one building*</u> Reference 8 - 0.61% Coverage Old, dark Reference 9 - 3.63% Coverage <u>*Sometimes too narrow which cannot make you understand where you are.*</u> Reference 10 - 0.44% Coverage <u>*Clear*</u> Reference 11 - 2.09% Coverage <u>*Compared to 3 and 4, I think 7 is more clear (colour, brightness)*</u> Reference 12 - 0.58% Coverage <u>*Boring, dark*</u> Reference 13 - 0.75% Coverage <u>*Readable, bright*</u> Reference 14 - 2.12% Coverage <u>*The buildings' colours are bright compared to M5 which are all dark or grey*</u> Reference 15 - 0.70% Coverage <u>*Sensible, clear*</u> ▪ Source 2, 15 references coded [20.85% Coverage] Reference 1 - 0.38% Coverage <u>*Easier to understand*</u> Reference 2 - 1.91% Coverage <u>*First of all, legends are overlapping so you don't see all of them for example when you look at this you don't see what is underneath, something blue but not clear*</u> Reference 3 - 1.17% Coverage <u>*Secondly, I have to understand every legend. They are not clear*</u> Reference 4 - 2.18% Coverage <u>*It is easier to understand that one, but because this one contains the numbers and buildings you see the names of the roads are clear and some of the legends are easy to understand*</u>

	Reference 5 - 1.48% Coverage *6 is similar in a good way. It gives you a snapshot. The Jubilee sports centre is really clear, it reflects reality* Reference 6 - 1.59% Coverage *It tells you your way by foot, but the destination is not clear so there is missing information but in a way this is better than the first .* Reference 7 - 1.74% Coverage *Map 4 this sort of map is like a satellite map. What I see now is everything is mostly grass and green areas. The buildings are not clear from this view* Reference 8 - 3.00% Coverage *1 and 3 ARE much simpler than Map 4 because there is not much noise as I said, the buildings are clear, roads are clear, there is space between buildings they are legends, Well the legends are there also in Map 4 but I mean the view is clear for you to decide* Reference 9 - 0.47% Coverage *It's not clear to me where it is in the map* Reference 10 - 1.01% Coverage *…Is the best because it is well-designed, easy to understand,contains only info needed* Reference 11 - 0.95% Coverage *The best because it well designed, easy to understand, has only the needed info* Reference 12 - 1.18% Coverage *The best because it is well designed, easy to understand, contains only the info need* Reference 13 - 1.58% Coverage *More helpful but even if it has legends, it is not well designed, I mean the boundaries are not clear in the map* Reference 14 - 0.67% Coverage *Snapshot of the real building, the title is clear* Reference 15 - 1.54% Coverage *The info is either more or less than needed , design is bad, buildings are small, details missing, boundaries are not clear*
Perspectives	▪ Source 1, 3 references coded [5.51% Coverage] Reference 1 - 2.35% Coverage *I prefer broad because I can see the overview*

	Reference 2 - 2.52% Coverage *Broad and clear because it also has an overview of the campus and not just one building* Reference 3 - 0.64% Coverage *Brief, overview* ▪ Source 2, 2 references coded [4.72% Coverage] Reference 1 - 1.50% Coverage *Don't have a compass and panoramic picture* Reference 2 - 3.22% Coverage *The panoramic pictures are just like zooming out the map and I keep saying that it's got more helpful*
Simplicity	▪ Source 1, 6 references coded [8.45% Coverage] Reference 1 - 0.30% Coverage *Simple* Reference 2 - 1.64% Coverage *Simple because there is less building and I think it's simpler than others* Reference 3 - 0.47% Coverage *Simple and easy* Reference 4 - 1.16% Coverage *It is simpler but we don't know which building that is* Reference 5 - 3.30% Coverage *Simple because it's simple and easy, we can see directly. I recognise these buildings, and from these buildings, I know which way to go* Reference 6 - 1.57% Coverage *I prefer numbers, numbers are simpler but can be long and not artistic* ▪ Source 2, 2 references coded [3.91% Coverage] Reference 1 - 1.15% Coverage *Simple enough to make out the route/roads/lanes* Reference 2 - 2.76% Coverage *It's simple because especially like M6, you know you can see the road and you don't have too many coloured things to refer to*

Appendix E

General look	▪ Source 1, 2 references coded [9.29% Coverage] Reference 1 - 5.05% Coverage *6 tells me the name of the buildings and that's a good thing because I know what the look like because I've been here for a while on the campus and I know some of the buildings, so it's good to have some indicator of which building is which, yes the picture does provide* Reference 2 - 4.23% Coverage *I think Number 3 is unclear because you don't really recognise it as a campus. It looks more like geometrical shapes together in this picture so it doesn't really look very organised. It looks like a mess so it's really hard to identify* ▪ Source 2, 1 reference coded [4.53% Coverage] Reference 1 - 4.53% Coverage *You can see the buildings and how they look and you can see the trees, cars and more landmarks, and where the flat one lies is just lines to show where the buildings are, but you can't actually see how they stand*
Old	▪ Source 1, 2 references coded [2.24% Coverage] Reference 1 - 1.86% Coverage *Just one colour and it's quite old and maybe it's because of my eyes, but I cannot read it* Reference 2 - 0.38% Coverage *Quite old* ▪ Source 2, 2 references coded [1.67% Coverage] Reference 1 - 0.97% Coverage *Is like a treasure map like an old map, it is not that useful* Reference 2 - 0.69% Coverage *It's an old map, it's not been updated for year,*
Organised	▪ Source 1, 1 reference coded [3.59% Coverage] Reference 1 - 3.59% Coverage *The maps has its own place. It shows you how to go from there so it's kind of an intelligent system, programmed by humans and can give you information* ▪ Source 2, 1 reference coded [2.04% Coverage]

	Reference 1 - 2.04% Coverage *The navigating system presumably used some form of GPS that pinpoints locations so it could give you a walking guide*
Traditional	▪ Source 1, 3 references coded [6.00 Coverage] Reference 1 - 1.47% Coverage *Just a traditional map so people need to find their own position* Reference 2 - 1.21% Coverage *I think for most people traditional maps are very useful* Reference 3 - 3.33% Coverage *I mean I would choose traditional because traditional can give you a brief idea of the surroundings. You can be familiar with the surrounding environment* ▪ *Source 2, 2 references coded [1.93% Coverage]* Reference 1 - 0.70% Coverage *Are traditional maps* Reference 2 - 1.23% Coverage *It only shows the symbols (traditional)*
Apparent	▪ Source 1, 1 reference coded [0.90% Coverage] Reference 1 - 0.90% Coverage *Certain buildings have outstanding characters* ▪ Source 2, 1 reference coded [0.87% Coverage] Reference 1 - 0.87% Coverage *Only one colour does have a good appearance*
Abstract	▪ Source 1, 1 reference coded [0.67% Coverage] Reference 1 - 0.67% Coverage *Abstract maps of the campus* ▪ Source 2, 1 reference coded [0.38% Coverage] Reference 1 - 0.38% Coverage *Abstract, not clear*

Precision	▪ Source 1, 1 reference coded [0.54% Coverage] Reference 1 - 0.54% Coverage *Giving precise directions* ▪ Source 2, 1 reference coded [0.23% Coverage] Reference 1 - 0.23% Coverage *Is precise*

*Please note that English is not the first language for the majority of respondents.

E.4 Theme of words (low level codes)

Theme-Group of Words	Group of Words
Visual Appearance	Clarity
	Perspectives
	Simplicity
	General look
	Old
	Organised
	Traditional
	Apparent
	Abstract
	Precision
Information Elements	Directions
	Facilities
	Distance
	Instruction
	Areas
	Routes
	Indicators
	Border
Roles	Navigation
	Identification
	Comparison
	Guidance
	Functional
	Purpose
	Integrated
	Estimation
	Orientation
	Plan
	Forecast
	Explanation
	Constructive
	Clarification
Physical Structure	Scale

	Shapes
	Layout
	Structure
	Pattern
Colour Usage	Colourful
	Monotone
	Elegant
Legends	Symbol
	Legend
	Label
	Signal
	Clue
Limitation	Confusing
	Difficulties
	Complicated
	Incomplete
	Time-consuming
Graphics Elements	Three-dimensional image
	Factual
	Two-dimensional image
	Depiction
	Artificial
	Cartoonic
	Blueprint
Type of Map	Satellite photo
	Real photo
	Pictorial
	Static
	Computerized photo
	Graphic
Similarities	Related to similar objects
	Reality
Angle	Top view
	Bird’s eye view
	Satellite view
	Tilted view
Visual Appeal	Realistic
	Appealing
	User-friendly
	Image quality
	Attractive
	Intelligent
	Creative
	Originality
Benefits	Informative
	Complete
	Brief
	Achievable
	Practicalities
	Additional

Appendix E

	Convenience
	Accessibility
	Principle
	Advanced
	Updated
Emotional Attachment	Feeling
Hardware Related	Technology
	Computer application
Quality of Content	Adequacy
	Relevant
	Comprehensive
	Accuracy
	Reliable
	Cohesive
Directions	Position
	Pointer
Creating Insights	Imagination
	Coherent
	Cognitive
	Attention
	Ideas
Codify Knowledge	Memorize
	Interpret
Software Related	Apps
	Augmented
	Algorithm
Apply Knowledge	Reflection
	Judgment
	Recall
Irrelevant Information	Crowded
	Boundaries
	Noise
	Accessories
Typography	Readability
	Number
Interaction	Dynamic view
	Interactive
	Passive view
Visual Identity	Uniqueness
	Character
	Antique
	Sophisticated
	Professional
	Criteria
Structure of Information	Categorised
	Distinguishable
	Scattered
Use of Experience	Experience
Target Audience	Group of user
Focal Point	Focus

Measurement	Standardized
Engagement	Engaging

E.5 Factors (high order codes)

Factors	**Theme-Group of words**
Graphic Design	Physical structure
	Colour usage
	Graphic elements
	Type of map
	Angle
	Focal point
Visual Utility	Visual appearance
	Visual appeal
	Visual identity
Presentation of Information	Information elements
	Quality of content
	Irrelevant information
	Structure of information
Functionality	Roles
	Benefits
Text Design	Legends
	Typography
Challenges	Limitation
Human Cognition	Creating insights
	Codify knowledge
	Apply knowledge
Resemblance with Reality	Similarities
Technology Intervention	Hardware related
	Software related
Human Behaviour	Emotional attachment
	Use of experience
	Engagement
Navigation Aid	Directions
Visual Communication	Interaction
	Target audience
Benchmark	Measurement

E.6 Hierarchical factors that respondents perceive as useful while using visualisation navigation methods

Factors	Theme-Group of words	Group of words
Graphic Design	Physical Structure	Scale
		Shapes
		Layout
		Structure
		Pattern
	Colour Usage	Colourful
		Monotone
		Elegant
	Graphic Elements	Three-dimensional image
		Two-dimensional image
		Factual
		Depiction
		Artificial
		Cartoonic
		Blueprint
	Type of Map	Satellite photo
		Real photo
		Pictorial
		Static
		Computerized Photo
		Graphic
	Angle	Top view
		Bird's eye view
		Satellite view
		Tilted view
	Focal Point	Focus
Visual Utility	Visual Appearance	Clarity
		Perspectives
		Simplicity
		General look
		Old
		Organised
		Traditional
		Apparent
		Abstract
		Precision
	Visual Appeal	Realistic
		Appealing
		User-friendly
		Image quality
		Attractive
		Intelligent
		Creative
		Originality

	Visual Identity	Uniqueness
		Character
		Antique
		Sophisticated
		Professional
		Criteria
Presentation of Information	Information Elements	Directions
		Facilities
		Distance
		Instruction
		Areas
		Routes
		Indicators
		Border
	Quality of Content	Adequacy
		Relevant
		Comprehensive
		Accuracy
		Reliable
		Cohesive
	Irrelevant Information	Crowded
		Boundaries
		Noise
		Accessories
	Structure of Information	Categorised
		Distinguishable
		Scattered
Functionality	Roles	Navigation
		Identification
		Comparison
		Guidance
		Functional
		Purpose
		Integrated
		Estimation
		Orientation
		Plan
		Forecast
		Explanation
		Constructive
		Clarification
	Benefits	Informative
		Complete
		Brief
		Achievable
		Practicalities
		Additional
		Convenience
		Accessibility
		Principle

Appendix E

		Advanced
		Updated
Text Design	Legends	Symbol
		Legend
		Label
		Signal
		Clue
	Typography	Readability
		Number
Challenges	Limitation	Confusing
		Difficulties
		Complicated
		Incomplete
		Time-consuming
Human Cognition	Creating Insights	Imagination
		Coherent
		Cognitive
		Attention
		Ideas
	Codify Knowledge	Memorize
		Interpret
	Apply Knowledge	Reflection
		Judgment
		Recall
Resemblance with Reality	Similarities	Related to similar objects
		Reality
Technology Intervention	Hardware Related	Technology
		Computer application
	Software Related	Apps
		Augmented
		Algorithm
Human Behaviour	Emotional Attachment	Feeling
	Use of Experience	Experience
	Engagement	Engaging
Navigation Aid	Directions	Position
		Pointer
Visual Communication	Interaction	Dynamic view
		Interactive
		Passive view
	Target Audience	Group of user
Benchmark	Measurement	Standardized

E.7 Relationship of elicited factors: Cluster Analysis

Factor A	Factor B	Pearson correlation coefficient
Visual Utility	Graphic Design	0.73
Graphic Design	Functionality	0.69
Human Behaviour	Graphic Design	0.67
Human Behaviour	Functionality	0.65
Visual Utility	Functionality	0.64
Human Cognition	Functionality	0.63
Technology Intervention	Human Behaviour	0.60
Resemblance with Reality	Human Behaviour	0.59
Text Design	Graphic Design	0.58
Visual Utility	Human Behaviour	0.57
Technology Intervention	Functionality	0.57
Human Cognition	Graphic Design	0.57
Technology Intervention	Resemblance with Reality	0.57
Visual Utility	Text Design	0.56
Graphic Design	Challenges	0.56
Technology Intervention	Graphic Design	0.55
Text Design	Functionality	0.53
Text Design	Challenges	0.53
Visual Communication	Human Behaviour	0.52
Human Cognition	Human Behaviour	0.52
Functionality	Challenges	0.52
Resemblance with Reality	Graphic Design	0.53
Text Design	Human Behaviour	0.51
Technology Intervention	Human Cognition	0.51
Visual Utility	Human Cognition	0.51
Visual Communication	Functionality	0.51
Visual Communication	Graphic Design	0.49
Visual Utility	Technology Intervention	0.49
Human Cognition	Challenges	0.48
Visual Utility	Challenges	0.48
Human Behaviour	Challenges	0.47
Visual Utility	Visual Communication	0.44
Navigation Aid	Functionality	0.43
Text Design	Human Cognition	0.43
Visual Communication	Human Cognition	0.43
Visual Communication	Technology Intervention	0.42
Visual Utility	Resemblance with Reality	0.42
Resemblance with Reality	Functionality	0.42

Visual Communication	Resemblance with Reality	0.39
Technology Intervention	Challenges	0.38
Presentation of Information	Graphic Design	0.37
Resemblance with Reality	Human Cognition	0.37
Text Design	Technology Intervention	0.37
Visual Communication	Challenges	0.36
Visual Utility	Presentation of Information	0.36
Text Design	Resemblance with Reality	0.34
Resemblance with Reality	Challenges	0.34
Presentation of Information	Functionality	0.31
Visual Communication	Text Design	0.31
Presentation of Information	Human Behaviour	0.30
Presentation of Information	Challenges	0.30
Navigation Aid	Graphic Design	0.30
Visual Utility	Navigation Aid	0.30
Navigation Aid	Human Behaviour	0.30
Text Design	Presentation of Information	0.29
Technology Intervention	Presentation of Information	0.27
Navigation Aid	Human Cognition	0.27
Technology Intervention	Navigation Aid	0.26
Navigation Aid	Challenges	0.26
Presentation of Information	Human Cognition	0.25
Visual Communication	Navigation Aid	0.24
Resemblance with Reality	Presentation of Information	0.22
Text Design	Navigation Aid	0.22
Resemblance with Reality	Navigation Aid	0.22
Visual Communication	Presentation of Information	0.18
Presentation of Information	Navigation Aid	0.16
Graphic Design	Benchmark	0.08
Visual Utility	Benchmark	0.03
Visual Communication	Benchmark	0.03
Human Behaviour	Benchmark	0.02
Functionality	Benchmark	0.02
Presentation of Information	Benchmark	0.02
Navigation Aid	Benchmark	0.01
Text Design	Benchmark	0.01
Human Cognition	Benchmark	0.01
Challenges	Benchmark	0.00
Technology Intervention	Benchmark	-0.01
Resemblance with Reality	Benchmark	-0.01

Appendix F Mixed Method Matrix (Qualitative and Quantitative)

F.1 Matrix of Component 1

	Factors												
Component 1 (Constructs)	**Graphic Design**	**Visual Utility**	**Presentation of Information**	**Functionality**	**Text Design**	**Challenges**	**Human Cognition**	**Resemblance with Reality**	**Technology Intervention**	**Human Behaviour**	**Navigation Aid**	**Visual Communication**	**Benchmark**
Navigation guide				**1**									
Maps with navigation				**2**									
Giving precise directions			**3**										
Provide direction			**4**										
Idea about distance			**5**										
Answer the questions					**6**								
Has a GPS navigation				**7**									
Both navigation methods				**8**									
Show my location			**9**										
Whole picture/interactive												**10**	
Giving directions			**11**										
Relative to the viewer's position		**12**											
Appealing and no reference		**13**											
Easier to find position											**14**		
Simple		**15**											
Use directions			**16**										
Sensible, clear		**17**											
User-friendly		**18**											
Not clear		**19**											

Appendix F

Related to the viewer's position		**20**											
Real picture	**21**												
Mobile apps									**22**				
Clear		**23**											
Giving direction			**24**										
Easy to find location				**25**									
Lack of information						**26**							
Can't be interested						**27**							
Not helpful (no signs)					**28**								
Real environment		**29**											
Not useful						**30**							
Natural images	**31**												
Real-life photography	**32**												
Focus on actual building	**33**												
Guide to specific building				**34**									
Real photos	**35**												
Real-life imagery	**36**												
Google maps	**37**												

<u>Themes</u>

1=Roles
2=Roles
3=Information Elements
4=Information Elements
5=Information Elements
6=Legends
7=Roles
8=Roles
9=Information Elements
10=Interaction
11=Information Elements
12=Visual Appearance
13=Visual Appeal
14=Directions
15=Visual Appeal
16=Information Elements
17=Visual Appearance
18=Visual Appeal
19=Visual Appearance
20=Visual Appearance
21=Type of Map
22=Software Related
23=Visual Appearance
24=Information Elements
25=Roles
26=Limitation
27=Limitation
28=Legends
29=Visual Appeal
30=Limitation
31=Type of Map
32=Type of Map
33=Graphic Elements
34=Roles
35=Type of Map
36=Type of Map
37=Type of Map

F.2 Matrix of Component 2

	Factors												
Component 2 (Constructs)	**Graphic Design**	**Visual Utility**	**Presentation of Information**	**Functionality**	**Text Design**	**Challenges**	**Human Cognition**	**Resemblance with Reality**	**Technology Intervention**	**Human Behaviour**	**Navigation Aid**	**Visual Communication**	**Benchmark**
Boundaries are not clear		**1**											
(Just numbered) complicated						**2**							
Not clear		**3**											
Blank	**4**												
Rational, boring		**5**											
More lifelike		**6**											
Drawing	**7**												
Not clear		**8**											
No services shown			**9**										
Single sign					**10**								
Gives surrounding buildings			**11**										
Simple location and building			**12**										
Noisy			**13**										

<u>Themes</u>

1=Visual Appearance
2=Limitation
3=Visual Appearance
4=Colour Usage
5=Visual Appearance
6=Visual Appeal
7=Graphic Elements
8=Visual Appearance
9=Information Elements
10=Legends
11=Information Elements
12=Information Elements
13=Irrelevant Information

F.3 Matrix of Component 3

	Factors												
Component 3 (Constructs)	**Graphic Design**	**Visual Utility**	**Presentation of Information**	**Functionality**	**Text Design**	**Challenges**	**Human Cognition**	**Resemblance with Reality**	**Technology Intervention**	**Human Behaviour**	**Navigation Aid**	**Visual Communication**	**Benchmark**
Numbers						**1**							
Provide building number			**2**										
Showing numbered buildings			**3**										
Able to give direction			**4**										
Useful (building numbers)			**5**										
Comfortable, easy				**6**									
Giving details			**7**										
Marks					**8**								
Numbering						**9**							
Have text in picture					**10**								
Having information of building names and numbers			**11**										
No clear info about the distance			**12**										
Have a road name			**13**										
Lead to right place				**14**									
Showing pedestrian way				**15**									
Easy to interpret							**16**						
Just the campus			**17**										
Showing buildings and streets			**18**										
For detailing			**19**										
Useful for navigation				**20**									
Clear		**21**											

Colourful, clear	**22**	**23**											
Simpler		**24**											
Show the way to destinations				**25**									
Organised		**26**											
Bird's eye view	**27**												
Show new additions				**28**									
Number, symbol					**29**								
General look		**30**											
Have name of buildings			**31**										
Showing buildings			**32**										

Themes

1=Limitation
2=Information Elements
3=Information Elements
4=Information Elements
5=Information Elements
6=Ease of Use
7=Information Elements
8=Legends
9=Limitation
10=Legends
11=Information Elements
12=Information Elements
13=Information Elements
14=Roles
15=Roles
16=Codify Knowledge
17=Information Elements
18=Information Elements
19=Information Elements
20=Roles
21=Visual Appearance
22=Colour Usage
23=Visual Appearance
24=Visual Appearance
25=Roles
26=Visual Appearance
27=Angle
28=Ease of use
29=Legends
30=Visual Appearance
31=Information Elements
32=InformationElements

F.4 Results of Mixed Method Matrix of the three components

	Component 1 (Augmented Reality)	**Component 2 (Sketch)**	**Component 3 (3D)**
Campus Map	M7	M5	M2
Users' perceptions of visualisation navigation	*Roles* ❑ Navigation guide ❑ Maps with navigation ❑ Has a GPS navigation ❑ Both navigation methods ❑ Easy to find location ❑ Guide to specific building *Information Elements* ❑ Giving precise directions ❑ Provide direction ❑ Idea about distance ❑ Show my locations ❑ Giving directions ❑ Use directions ❑ Giving direction *Legends* ❑ Answer the questions ❑ Not helpful (no signs) *Interaction* ❑ Whole picture/interactive Visual Appearance ❑ Relative to the viewer's position ❑ Sensible, clear ❑ Not clear	*Visual appearance* ❑ Boundaries are not clear ❑ Not clear ❑ Rational, boring *Limitation* ❑ (Just numbered) complicated *Colour usage* ❑ Blank *Visual Appeal* ❑ More lifelike *Graphic Elements* ❑ Drawing *Legends* ❑ Single sign *Information Elements* ❑ No services shown ❑ Gives surrounding buildings ❑ Simple location and building *Irrelevant Information* ❑ Noisy	*Limitation* ❑ Numbers ❑ Numbering *Information Elements* ❑ Provide building number ❑ Showing numbered buildings ❑ Able to give direction ❑ Useful (building numbers) ❑ Giving details ❑ Having information of building names and number ❑ No clear info about the distance ❑ Have a road name ❑ Just the campus ❑ Showing buildings and streets ❑ For detailing ❑ Have name of buildings ❑ Showing buildings *Ease of use* ❑ Comfortable, easy ❑ Show new additions *Legends* ❑ Marks ❑ Have text in picture ❑ Number, symbol

	❑ Related to the viewer's position ❑ Clear *Visual Appeal* ❑ Appealing and no reference ❑ Simple ❑ User-friendly ❑ Real environment *Directions* ❑ Easier to find position *Type of Map* ❑ Real picture ❑ Natural images ❑ Real-life photography ❑ Real photos ❑ Real-life imagery ❑ Google maps *Graphics Elements* ❑ Focus on actual university *Software Related* ❑ Mobile apps *Limitation* ❑ Lack of information ❑ Can't be interested ❑ Not useful		*Roles* ❑ Lead to right place ❑ Showing pedestrian way ❑ Useful for navigation ❑ Show the way to destinations *Codify Knowledge* ❑ Easy to interpret *Visual Appearance* ❑ Clear ❑ Colourful, clear ❑ Simpler ❑ Organised ❑ General look *Colour usage* ❑ Colourful, clear *Angle* ❑ Bird’s eye view

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