University of Cape Town

Masters Level Dissertation

Elements of Design for Indoor Visualisation

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A dissertation submitted in fulfilment of the requirements for the degree of Masters in Engineering

in the

Department of Geomatics

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"You were born with potential.
You were born with goodness and trust.
You were born with ideals and dreams.
You were born with greatness.
You were born with wings.
You are not meant for crawling, so don't.
You have wings. Learn to use them and fly."

Rumi

University of Cape Town

Abstract

Faculty of Engineering
Department of Geomatics

Masters in Engineering

Elements of Design for Indoor Visualisation

by Zaid Gangraker

Indoor visualisation has received little attention. Research related to indoor environments have primarily focussed on the data structuring, localisation and navigation components (Zlatanova et al., 2013).

Visualisation is an integral component in addressing the diverse array of indoor environments. In simple words, "What is the most efficient way to visualise the surrounding indoor environment so that the user can concisely understand their surroundings as well as facilitating the process of navigation?'

This dissertation proposes a holistic approach that consists of two components. The significance of this approach is that it provides a robust and adaptable method in providing a standard to which indoor visualisation can be referenced against.

The first component is a theoretical framework focussing on indoor visualisation and it comprises of principles from several disciplines such as geovisualisation, human-perception theory, spatial cognition, dynamic and 3D environments as well as accommodating emotional processes resulting from human-computer interaction.
The second component is based on the theoretical framework and adopts a practical approach towards indoor visualisation. It consists of a set of design properties that can be used for the design of effective indoor visualisations. The framework is referred to as the "Elements of Design" framework. Both these components aim to provide a set of principles and guidelines that can be used as best practices for the design of indoor visualisations.

In order to practically demonstrate the holistic indoor visualisation approach, multiple indoor visualisation renderings were developed. The visualisation renderings were represented in a three-dimensional virtual environment from a first-person perspective. Each rendering used the design framework differently. Also, each rendering was graded

using a parallel chart that compares how the different visual elements were used per the rendering.

The main findings were that the techniques/ renderings that used the visual elements effectively (enhanced human-perception) resulted in better acquisition and construction of knowledge about the surrounding indoor environment.

Acknowledgements

Firstly, to my parents. These few words cannot sufficiently acknowledge or even pay tribute to them for the role they have played in all facets of my life. I am a result of their ways and teachings. They did not only grant me the opportunity to gain an education but they have educated me about life. They have emphasised the importance of good character rather than monetary or social status. They have embedded qualities such as respect, understanding, giving, modesty, equality and honesty.
To my parents, I am and will forever be eternally grateful for... in simple words... "everything".

Secondly, to my brother Adam. His heart of gold, purity, good nature and zest for life is the glue that keeps our family so strong. Adam, through all your adversities and challenges in life, you have always come out smiling. As your elder brother, I want to say that I am proud of you and your goodness of character has taught me many lessons about life. Thank you for always taking an interest in my studies and for always being so eager to help.

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Abbreviations

2D	Two-dimensional
3D	Three-dimensional
AR	**A**ugmented **R**eality
GPS	**G**lobal **P**ositioning **S**ystem
GUI	**G**raphical **U**ser **I**nterface
HCI	**H**uman-**C**omputer **I**ntercation
IT	**I**nformation **T**echnology
MAR	**M**obile **A**ugmented **R**eality
POI	**P**oints **O**f **I**nterest
RGB	**R**ed **G**reen **B**lue
UCT	**U**niversity of **C**ape **T**own
UI	**U**ser **I**nterface
VE	**V**irtual **E**nvironment
VR	**V**irtual **R**eality

Dedicated to my Parents, Brother, Grandparents and Family

Chapter 1

Introduction

1.1 General

Indoor modelling and mapping has been an actively researched field for the past thirty years. Research into this field has come in the form of Data structuring, As-Built Surveys, Navigation models and Visualisation techniques. The advancements in this field are founded upon developments within fields such as computer vision and image analysis, photogrammetry, robotics, computer graphics, laser scanning and many others (Zlatanova et al., 2013).

Commercial enterprises and individuals are beginning to utilise indoor mapping and modelling in their business processes and applications. There are three main reasons why this field is evolving. Firstly, the last two decades have seen greater implementation and interaction with spatial information. Secondly, technological advancements in mobile computing and internet communication industries have facilitated access to spatial information. Thirdly, indoor modelling has advanced both semantically and geometrically, allowing for the development of user-oriented, context-aware applications (Zlatanova et al., 2013).

This dissertation focusses on indoor visualisation and how it can facilitate the navigation process. Day to day activities within indoor environments result in the interaction with copious amounts of surrounding spatial information. The large amounts of information infer the need for a structured set of design principles for indoor visualisation that allows for different levels of information to be presented to the user based on certain parameters such as the user's task and the environmental setting.

Indoor visualisation is an essential component in the navigation process. Existing issues that face indoor visualisation from a navigation perspective are regarding web and mobile devices. Three-dimensional indoor models have traditionally been visualised on desktop systems. However, due to the popularity and growing usage of mobile devices, new visualisations have to be developed to adapt to the relatively small screen real-estate. Also, indoor environments often consist of multiple floors resulting in overlapping of spatial information (Zlatanova et al., 2013).

Emerging problems that may arise in future are real-time change visualisations. Visualising change in 2D is relatively simple and straightforward in comparison to three-dimensions. The challenge is to visualise change in 3D in real-time, especially if mobile devices are being used. In addition to this, the amount of available spatial information will increase resulting in the need for visualisation systems that can filter and present only relevant information to the user. Another challenge is to manage and convey a simplistic design display of information without reducing its complexity (Zlatanova et al., 2013).

1.2 Background

1.2.1 Visualisation

Visualisation is defined as the "development of a visual image in the human mind" (Dulclerci et al., 2004). Visualisation extends further than a simple graphical representation tool. It can be utilised as a cognitive tool and become a powerful strategy in the construction of knowledge using human sensors and cognitive capacities. Stuart Card (1999) elaborates on the above definition and states that "visualisation is the use of visual representations of abstract data, supported by computers and, in order to extend the cognition, in an interactive mode" (Card et al., 1999).

Typical visualisation tools support three main activities:

1. *Exploratory Analysis:* The user intends to discover new knowledge based on input data through an analytical process. The obtained visualisation is explored to discover any tendencies or relations that could form a basis of an hypothesis.
2. *Confirmatory Analysis:* The user has an existing hypothesis and through visual exploration of the visualisation, the hypothesis is accepted or rejected based on any founded evidences.
3. *Presentation:* It is utilised for the graphical display and representation of the relationship, structure and behaviour existing between the data involved (Dulclerci et al., 2004)

All three of the above analyses are used in indoor visualisation and navigation.

1.2.1.1 Geovisualisation

Visualisation has played a pivotal role throughout history in conveying a diverse array of information. There are multiple forms of visualisation techniques across a wide range of fields. There are three different forms of visualisation namely: information visualisation, scientific visualisation and geovisualisation (van Elzakker, 2004).

Geovisualisation is termed as the "visual geospatial displays that explore data and through this exploration it forms hypotheses, develops problem solutions and constructs knowledge" (Kraak, 2003). Elaborating on the statement above and in relation to indoor environments, the spatial surroundings of indoor environments was to be explored resulting in being able to answer questions relevant to indoor surroundings. This ultimately allowed for knowledge acquisition of the surroundings (Kraak, 2003).

Geovisualisation stretches beyond the alternative visual representations of spatial data. It also concerns the interface representing the data and the cognitive aspects of grasping and understanding the data. Alternative and unusual visual representations stimulate visual thinking that reveals patterns that are not visible using conventional mapping methods. Thus, using geovisualisation and alternative map views to represent indoor environments will allow for different levels of information to be revealed to the user (van Elzakker, 2004).

1.2.2 Indoor Navigation

Indoor navigation is an important process in three-dimensional, augmented environments. In order for efficient indoor navigation to take place, users resort to three distinct forms of spatial knowledge (Burigat and Chittaro, 2007):

1. Landmark knowledge
2. Route knowledge
3. Survey knowledge

When a user is confronted with an unfamiliar indoor environment, the initial step is to identify landmarks which depict distinctive environmental features that serve as reference points during navigation. Landmarks act as visual indicators that identify different regions in space. Route knowledge is normally gained through a 1st person perspective and it allows for different landmarks to be connected in a sequence which results in paths between locations. The user is able to travel along known paths based on this, but it does not accommodate unfamiliar routes. Lastly, Survey knowledge is gained from a 3rd person perspective (e.g. through maps) or by extensive travelling in an environment and describes relationships among locations which allows for the assessment of certain object locations in an environment. The user generally gains all three forms of spatial knowledge and the formulation of mental images referred to as "cognitive maps" takes place (Burigat and Chittaro, 2007).

There are various factors that contribute towards the difficulties of indoor navigation in three-dimensional environments. Obvious sources of navigation problems are portrayed via unfamiliarity with a particular environment. Also, the lack of intuitiveness based on navigation utilising a keyboard, joystick and mouse movement contributes towards navigation problems. Additional factors such as lack of support for speed control, lack of landmarks and limited field of view all contribute towards the problems that indoor navigation within augmented environments are confronted with (Burigat and Chittaro, 2007).

In order to address the problems stated above, navigation support in the form of indoor navigation aids need to be developed. The first step in developing a visual navigation aid is applying the scenario to the real-world and allow for a solution to be found. The most applicable navigation aid based on the above is an overview map. The overview map allows for self-orientation in relation to the surrounding indoor real environment. It also allows real-time indication of user orientation and position. Overview maps provide the acquisition of survey knowledge which would only be gained via extensive navigation of the surrounding indoor environment (Chittaro et al., 2003).

Another form of support focusses on the guidance or constrain of motion within a augmented indoor environment. Guided navigation can be divided into two forms namely active and passive. In active approaches, the user is actively required to follow some sort of guiding object (e.g. humanoid). The passive approach involves the automatic guidance and thus restricts navigation in specific areas in an environment (Chittaro et al., 2003).

1.2.3 Augmented Reality

Fred Brooks defines AR as intelligence amplification (IA): the use of a computer as a tool to make a task easier for a human to perform (Brooks Jr, 1996). Augmented reality enhances the user's perception of and interaction with the real world. The superimposed virtual objects display information that the user cannot detect with their own senses. The information conveyed by the virtual objects aims to facilitate the user in performing real-world tasks (Azuma, 1997).

Indoor navigation applications readily pair augmented reality with geographic information system (GIS) data by overlaying visual cues onto real world indoor environments in order to facilitate the navigation process (Abboud, 2014).

There are challenges that confront Augmented Reality and they are stated below. All three challenges are relevant to indoor environments.

Augmented Reality is dependent on correct and consistent registration between synthetic elements (usually three-dimensional graphical elements) and the real environment. In order to achieve this seamlessly, the user's position within the environment needs to be continuously determined. Thus, tracking and registration is a fundamental challenge of AR. The fast, robust and precise tracking of the observer, as well as real and virtual objects in the environment is critical for convincing AR applications. This is obviously more complex in indoor environments due to the limitations of GPS positioning in indoor environments (Bimber and Raskar, 2005).

Besides for tracking, display technologies is another challenge that confronts the AR field. Head-mounted displays are still the dominant display medium. However, they still suffer from optical (e.g. limited focus and field of view), technical (e.g. limited resolution, unstable image registration) and human factor (e.g. size and weight) limitations. These factors have resulted in the development of mobile AR applications. Large, heavy head-mounted displays are not ideal for indoor navigation (Bimber and Raskar, 2005).

The third challenge facing AR is real-time rendering. AR mainly focusses on superimposing the real environment with virtual graphical elements. Thus, fast and realistic rendering methods play an important role in a seamless AR application. The ultimate goal would be to integrate graphical elements into the real environment in such a way that the observer can no longer distinguish between the real and virtual. For this to happen, virtual objects would have to follow a consistent shadow-casting, occlusion and inter-reflection behaviour. These factors are difficult to account for in indoor environments due to their intricacies i.e. poor lighting, multi-levels, dynamic, occluding objects etc (Bimber and Raskar, 2005).

The relevance of AR to indoor visualisation is that it provides an intuitive interface solution to access complex real world information comprising of dynamic features and instant responses (Liarokapis et al., 2005)

1.3 Problem Statement

Indoor visualisation has received little attention. Research related to indoor environments have primarily focussed on the data structuring, localisation and navigation components (Zlatanova et al., 2013).

Visualisation is an integral component in addressing the diversity and complex nature of indoor environments. In simple words, “What is the most efficient way to visualise the surrounding indoor environment so that the user can concisely understand their surroundings as well as facilitating the process of navigation?”

Indoor visualisation based solely on the human vision system does not solve the problems facing indoor environments such as occlusion, restricted field-of-view, limited lighting and lack of texture (Du et al., 2011). However, extending on this process by adapting the visualisation to go beyond the “real” in order to enhance the latent, hidden spatial information that the human eye cannot see will address these problems. The latent information is usually absorbed at a sub-concious level. Enhancing the visualisation aspects will allow for the user to be presented with different levels of spatial information together with gaining a better perception, comprehension and understanding of their surroundings.

1.4 Objectives

This dissertation aims to develop a holistic approach towards indoor visualisation based on a theoretical and practical component. These components aim to provide a set of guidelines and principles that can be used as best practices for the effective design of indoor visualisations. These principles and guidelines are necessary in order to provide the user with the ability to select the levels of information he/she is interested in based on the user's task in the indoor environment.

The theoretical component merges concepts from several disciplines such as cartography, geovisualisation, augmented reality, indoor navigation, human-perception theory, spatial cognition and human-computer interaction. The practical component demonstrates the best practices using a set of indoor visualisation renderings that aim to enhance the visualisation experience for the user.

1.5 Research Questions

The research questions below aim to address the objectives of the research. The research questions are as follows:

1. What aspects of visualisation can be used in order to enhance the visualisation and navigation process in indoor environments?
2. How can the human-perception theory be utilised in order to facilitate indoor visualisation?
3. What is the importance of accounting for different human-environmental interactions and user-tasks in the indoor environment?
4. How can the user interface influence the user's mood and emotion based on the visualisation experience using the interface?

1.6 Methodology

This dissertation addresses indoor visualisation through an holistic approach. The approach consists of two components- a theoretical and practical component.

In order for the theoretical component to be developed, background research relevant to the problem was extensively done. The theory was based on existing concepts such as geovisualisation, human-perception theory, spatial cognition, human-computer interaction and augmented reality. All these concepts had contributing elements towards addressing indoor visualisation. These concepts were then used to define a theoretical framework that formed the basis of the practical component.

The theoretical framework was then extended to provide a practical aspect. The practical component, as stated previously, derived from the theoretical concepts mentioned previously. The theory was used to develop a design framework that can be used as design criteria for indoor visualisations. The framework consisted of different visual variables that were derived during the compilation of theory.

In order to apply and demonstrate the proposed approach, multiple indoor visualisation renderings were developed. The renderings comprised of different forms of visualisation techniques that used the framework as guidance and effective design criteria. The different visualisations were then graded using parallel charts resulting in the ability for different visualisations to be compared.

Figure 1.1 provides a visual summary of the proposed approach towards indoor visualisation consisting of a theoretical and practical component.

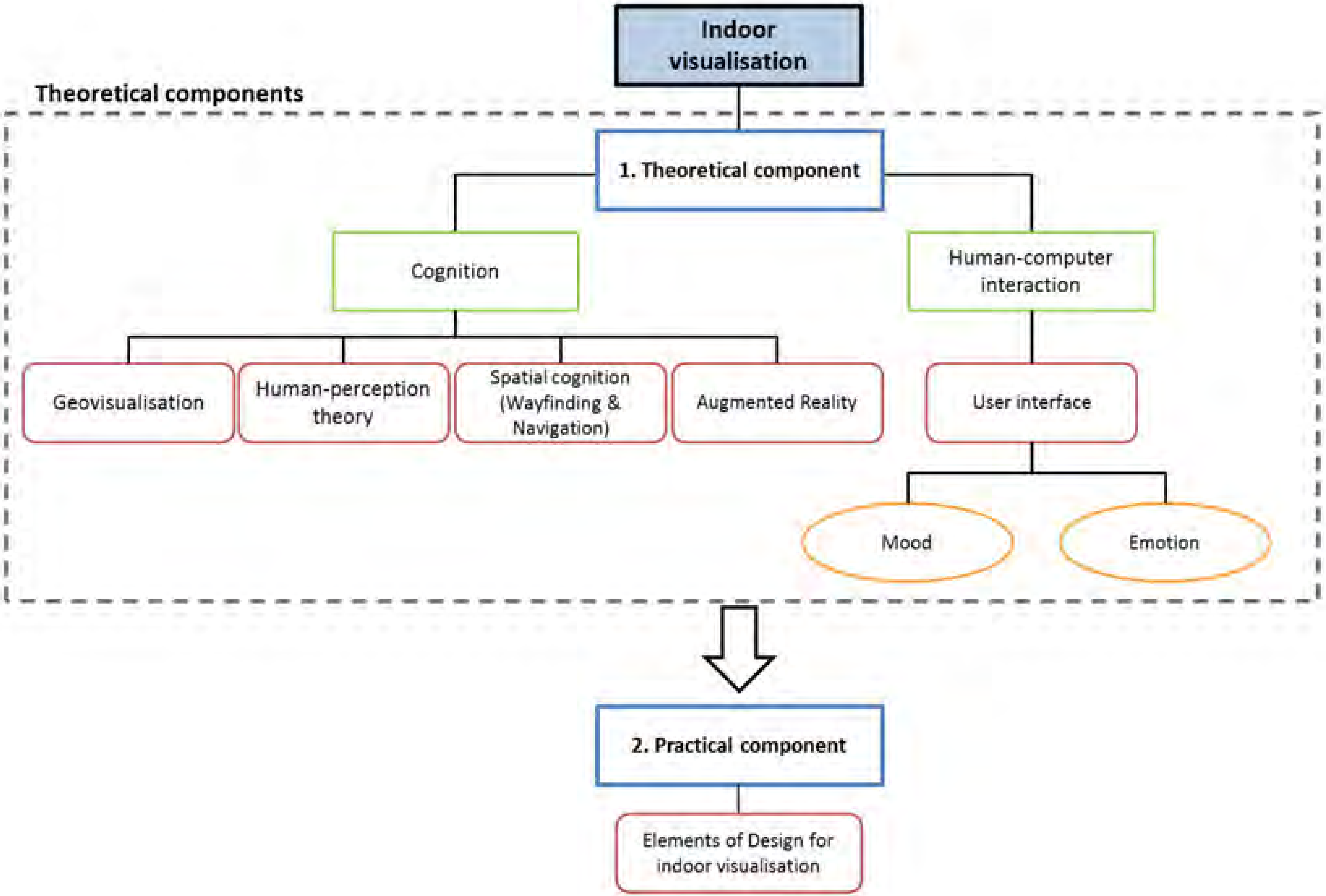

FIGURE 1.1: Holistic approach for indoor visualisation consisting of a theoretical and practical component. The theoretical component comprises of multiple fields addressing human cognition and human-computer interaction. The practical component derives from the theoretical component and can be used as an effective design criteria for indoor visualisations.

1.7 Structure of the Research Project

This research project consists of five chapters namely:

- **Chapter 1: Introduction-** This chapter introduces the general concepts that this research is based upon. In addition to this, the objectives, research questions and methodology are also defined.
- **Chapter 2: Literature Review-** This chapter provides scenarios depicting typical experiences in indoor environments. Each scenario is addressed by identifying current mapping methods as well as alternative solutions. In addition to this, concepts such as human perception, spatial thinking, way-finding and navigation and human-computer interaction are also investigated.
- **Chapter 3: Method-** This chapter contains the methodological details of how the conceptual renderings were generated as well as defining the Elements of Design framework. It also provides an example how the results are presented in the following chapter
- **Chapter 4: Results-** This chapter presents the visualisation rendering results using figures, parallel charts and a description. It also looks at different environmental interactions, a sample user interface design and different screen estates.
- **Chapter 5: Conclusions and Future Work-** This chapter provides a brief summary of the results and the implications of these results. Future research directions are also discussed.
- **Appendix: Storyboard** The appendix contains a scenario and applies different visualisation techniques to different events in the scenario using a storyboard layout

Chapter 2

Literature Review

2.1 Introduction

The navigation and visualisation of indoor environments have drawn the attention of researchers worldwide. The main reason is due to the relevance this field has in terms of the time spent indoors as well as advancements in technology that have provided new possibilities. Developers are driven to design applications that facilitate daily human activities and that focus on supporting users and improve their lifestyle.

The following section addresses indoor visualisation through the use of scenarios that depict typical indoor experiences as well as additional concepts that contribute towards indoor environmental understanding and lastly, novel indoor applications are also presented.

2.2 Structure of Literature Review

The structure of this literature review is divided into four sections as seen below:

The first section presents scenarios in an indoor environment (Sophie's experiences). The current forms of indoor visualisation are then discussed based on the presented scenario as well as alternative solutions that include dynamic, three-dimensional visualisations and geovisualisation.

The second section aims to understand and explain indoor environments. At the outset, it defines the human-environmental relationship through environmental psychology within an indoor environment. In addition to this, the human-perception theory from a visualisation perspective is investigated as it contributes towards the understanding of indoor space. Way-finding within an indoor environment as well as augmented systems guided by cognition are also investigated.

The third section discusses the emotional processes involved when dealing with human-computer interaction. This section investigates how interface design has emotion and mood altering abilities.

The fourth and last section presents related works in the form of novel indoor visualisations. These include orienteering visualisations, an application called "Framy-AR" and an indoor way-finding application called "MAR".

2.3 The Scenario

The scenarios below comprise of typical, daily experiences in indoor environments. Each scenario identifies problems in indoor environments i.e. overlapping of information due to multiple floors, occlusion, voluminous amounts of spatial information etc. In addition to the demonstrated scenarios, relevant indoor visualisations/mapping techniques are also presented. Each scenario is addressed by a current mapping technique as well as alternative solutions.

The purpose of the scenarios is to show the current in indoor visualisation and how the problems have or might be solved.

All three scenarios were posed by Nossum (2013).

2.3.1 Sophie's Scenario 1

Sophie is an ordinary high-school teenager who is sociable, a lover of social media and is mobile dependent. Her favourite place is the Mall of Europe which comprises of hundreds of shops with multiple levels. Before Sophie visits the mall, she communicates with her friends via mobile to find out where they are in the mall (Nossum, 2013c).

The scenario above raises the following questions:

- What will Sophie see on her mobile device? (visual communication)
- What type of map can best help Sophie see her friends across multiple floors? (form of the environment)
- How will what Sophie sees on her mobile device affect her emotionally? (emotional state)
- How is Sophie interacting with the environment? (context)

The following section addresses the questions above using Nossum's (2013) solution as well as alternative solutions. Nossum's solution is the Vertical Colour Map.

2.3.1.1 Vertical Colour Map

The first step to visualising entities across multiple floors was utilizing the visual variable colour to indicate different floors based on a unique colour. The use of colour takes great advantage of the selective and ordering properties associated with colour to communicate

FIGURE 2.1: Four different implementations of the vertical colour map using colour to differentiate between floors and transparency to reduce visual cluttering (Nossum, 2013c)

differentiation between different floors as well as the relationship between them. This concept is called "vertical colour maps" (Nossum, 2013e).

The vertical colour map has best success when the user is familiar with the internal structure of the environment. This type of map provides a good alternative to the conventional floorplan map. Figure 2.1 depicts this concept (Nossum, 2013e).

2.3.1.2 Alternative solutions

The previous indoor visualisation method (Vertical Colour Map) is a simplistic, two-dimensional technique that uses colour and symbology to convey information to the user. In order to address the questions raised by the scenario more thoroughly and enhance the current mapping method, two concepts are investigated. These concepts are Dynamic, 3D visualisations and Geovisualisation.

Dynamic and 3D Visualisations

Static maps are constructed from one-dimensional visual variables e.g. not dynamic, no interaction, paper-based etc. Dynamic maps are constructed within two or three spatial dimensions and the atemporal dimension. Dynamic maps express three cartographic modes that are not possible with static displays: animation- illusion of motion, sonification- representation of data with sound and interaction- ability to modify display (Dibiase et al., 1992).

Indoor visualisations will need to become dynamic and be represented in three-dimensions in order to improve current indoor mapping methods. Dynamic maps consist of three dynamic variables namely duration, order and rate of change. The correct manipulation of these variables will allow for effective indoor visualisations (Dibiase et al., 1992).

Three-dimensional visualisations provide a better understanding of spatial information and spatial relations between entities in indoor environments. The problem that faces three-dimensional visualisations is the inability of a cube, which represents the indoor space, to display all information without hiding some information. The solution to this problem is to add interactivity which allows the user to manipulate the visualisation by controls such as zooming, panning and rotation for example. The important interactive controls are brushing and linking (Dibiase et al., 1992).

There are four effective design criteria when developing three-dimensional, dynamic visualisations. They are: (Dibiase et al., 1992):

1. **Completeness-** all information required for the way-finding task is present
2. **Perceptibility-** all relevant information is represented by the visualisation and appears at a readable scale i.e visual clutter is reduced
3. **Semantic clarity-** use of symbols and map features are simple but imbued with meaning (self-explanatory)
4. **Convenience-** all information is displayed and updated in real-time to enhance way-finding i.e visualisation is congruent with user perspective

All criteria are relevant in order to facilitate effective indoor navigation and stimulate better understanding of the surroundings.

The issues that confront dynamic and 3D visualisations are due to perceptual limitations of humans. One of the major strengths of a dynamic visualisation is the ability for a visualisation to change. However, the assumption is that the user perceives this change

FIGURE 2.2: 3D indoor visualisation of a mall with an interactive interface (Walters, 2011)

but this is not always the case. This phenomenon is referred to as "change blindness" and accounts for changes in stimuli that are not perceived by the user. The degree of change blindness depends on the rate of change and the position of change. The change may be facilitated by smoother transitions and change clues to limit the effect of change blindness (Fish et al., 2011).

Another observed form of blindness is referred to as "inattentional blindness". The result of this effect is the same as change blindness in that the viewer does not perceive the displayed information. However, the information displayed in a dynamic visualisation is said to have a fixed time of display or lifespan. The user can seldom see beyond or past the actual point in time without actually interacting and manipulating the visualisation. Thus, this effect leads to the assumption that the viewer is fixating on the correct positions at the right time in order to perceive the displayed information at that exact moment. Viewers do not fixate on correct positions at the right time and this leads to a loss in displayed information due to insufficient attention to the displayed visualisation (Dibiase et al., 1992).

Both these forms of blindness are important to consider when designing indoor visualisations. Effective indoor visualisations need to limit the effect of these phenomena by developing smooth visualisations that captivates the user resulting in no loss of information.

Figure 2.2 shows a 3D representation of a typical indoor mall environment with guided navigation.

Geovisualisation

Modern visualisation technologies offer new possibilities for geographical visualisation tasks. These visualisations may help to explore, understand and communicate different spatial phenomena (Nollenburg, 2010).

The definition of geovisualisation according to the 2001 research agenda of the International Cartographic Association (ICA) Commission on Visualisation and Virtual Environments is widely accepted and adopted today. It states that "Geovisualisation integrates approaches from visualisation in scientific computing, cartography, image analysis, information visualisation, exploratory data analysis and geographic information systems to provide theory, methods and tools for visual exploration, analysis, synthesis and the presentation of spatial data" (Nollenburg, 2010). In this definition, accounting for human needs is essential for effective geovisualisation techniques (Nollenburg, 2010).

The goals of geovisualisation are defined by the map-cube (see Figure 2.3). MacEachren and Kraak (2001) models the space of visualisation goals with respect to three-dimensions (Kraak and MachEachren, 2001):

- the *task* ranges from revealing unknowns and constructing new knowledge to sharing existing knowledge
- the *interaction with the visualisation interface* ranges from low-level to high-level where the user can influence what they see
- lastly, the *visualisation use* ranges from single to public to private audience

The four visualisation goals namely exploration, analysis, synthesis and presentation are placed diagonally in the map use cube. On one extreme, exploration can be found as private, highly-interactive task to prompt thinking generating new scientific insight. The other extreme is formed by presenting knowledge in low-interactive visualizations to a wide audience e.g. publication or public conference. Dibiase et al. (1992) describes these two extremes as "visual thinking" which creates and interprets graphical representations and "visual communication" which aims to distribute knowledge in an easy-to-use graphical display (Dibiase et al., 1992).

All the processes that are presented by the map use cube above are applicable to the visualisation and navigation of indoor environments i.e when a user interacts with an indoor environment, he/she has a task at hand resulting in spatial knowledge construction. The effectiveness of the knowledge construction is based upon the interaction with the visualisation.

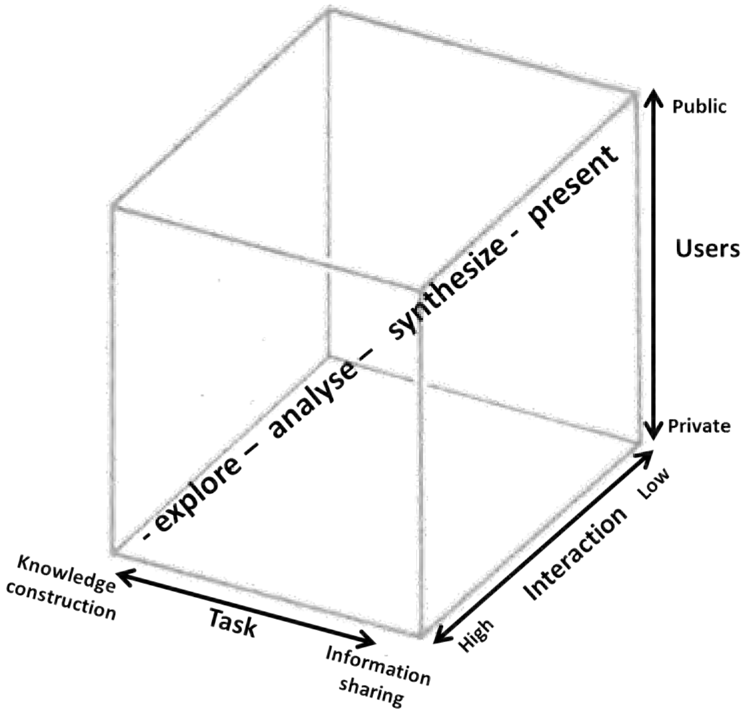

FIGURE 2.3: The map use cube defined by MacEachren and Kraak characterising geovisualisation in a three-dimensional space (Kraak and MachEachren, 2001)

There are three driving forces behind geovisualisation that has allowed this field to evolve and become relevant to indoor visualisation.

Firstly, advances in display and graphic technologies have made available low-cost 3D graphics hardware resulting in immersive, realistic environments. Maps historically have filtered out necessary details. The challenge is to find a medium between level of abstraction and realism in geovisualisation (Nollenburg, 2010).

Secondly, the purpose of geovisualisation is to analyse and explore increasing amounts of spatial data. According to Kraak and MachEachren (2001), 80% of data collected has spatial references (Kraak, 2003). The goal of geovisualisation is to combine the strengths of human-vision, creativity and general knowledge with modern computing systems in order to explore large datasets. Indoor environments have many spatial references thus showing the importance of geovisualisation (Nollenburg, 2010).

Thirdly, the rise of the Internet and its ability to broaden maps has provided the medium between the user/public and the geovisualisation (Nollenburg, 2010).

Computer-based geovisualisation has allowed for map interaction. This is the primary factor that distinguishes geovisualisation from traditional cartography. The two main

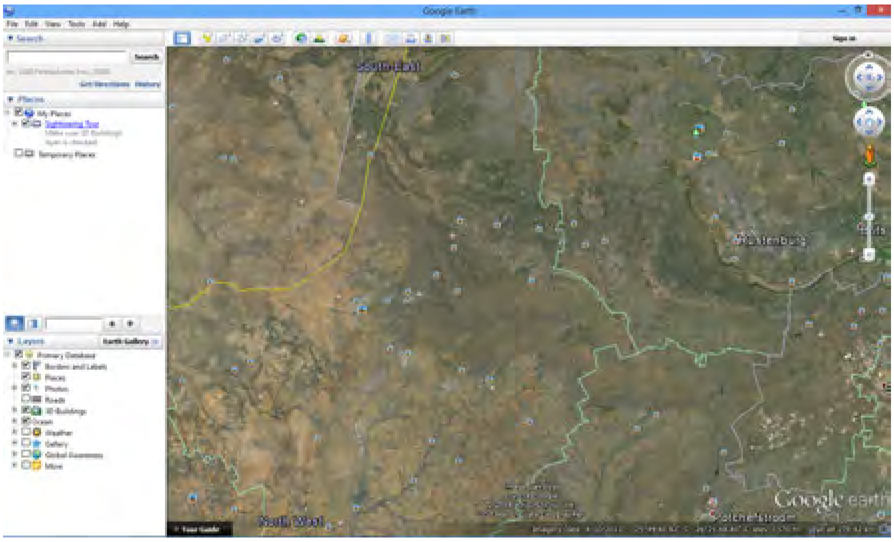

FIGURE 2.4: Google Earth software showing navigation tool and layers in view that can be toggled on and off (Earth)

interaction classes are focussing on individual views and linking multiple views (Nollenburg, 2010).

Focussing refers to any modification that selects what to see in a single display and how it is seen. It is compared to operating a camera: choosing a perspective, magnification decisions, details etc. Three-dimensional maps usually encompass a set of navigational controls that use scroll, shift or rotate a map or walking or flying through a virtual 3D environment. Furthermore, controls allow the user to zoom in and out thus controlling the level of detail. Once a perspective is chosen, the appearance can be modified further by switching layers on or off i.e. depending on the user's task, irrelevant and not useful information can be distracting (Nollenburg, 2010).

Another mode of interaction deals with the way in which the actual data items are displayed. The user must be able to select their attributes of interest and their desired visualisation type. Accessing attribute information of features using tool tip technique is useful to the user. Dynamic isolation is another technique which uses different symbols to depict different classes of data items (Nollenburg, 2010).

The full potential of interaction in geovisualisation lies in linking multiple views of the same data on the screen. Linking means to simultaneously highlight data in multiple views and it is usually combined with brushing. Brushing refers to the selection of on-screen objects by pointing at them or encircling them on the screen. (Nollenburg, 2010).

Figure 2.4 shows the interface of Google Earth. Google Earth is an example of an application that allows for user interactivity.

FIGURE 2.5: A collection of grocery shopping applications (Nossum, 2013c)

2.3.2 Sophie's Scenario 2

After high school, Sophie attends university and life becomes more complex. She finds that she has little time as she is rushing between classes, going to tennis or attending yoga. In addition to all these commitments, she needs to do grocery shopping at the giant store ReMart. After a couple of weeks of tiresome and laborious shopping, Sophie needed a solution to help aid her shopping experience to become more efficient and less time-consuming. Sophie found her solution in the form of an application that ReMart had that allowed her to enter her grocery list, suggest similar discounted items and display a map with all stores and their contents at their locations.

2.3.2.1 Sophie's Shopping Experience Application

The scenario above presents a typical, daily shopping experience. Several grocery stores have already implemented such systems (Bing Mall Maps 2011, Aisle411 2012, Rimi 2012) (Nossum, 2013c).

An important aspect that simplifies the visualisation challenges of indoor environments grocery stores is that the building layout usually covers only one floor. The interior is often designed as aisles with a single entrance and single exit. Visualisation solutions covering single floor layouts are most successful when using regular floor plan maps in comparison to maps being used in multi-storey environments (Nossum, 2013c).

Figure 2.5 shows various grocery shopping applications.

2.3.2.2 Discussion

The above application that Sophie uses for her shopping applies a dynamic visualisation. However, the application only addresses indoor visualisation in a navigation context. This can be extended to account for other forms of environmental interaction such as exploration or crisis occurrences.

Geovisualisation (discussed in the previous Section 2.3.1.2) allows for different levels of knowledge construction of the environment based on the user's task. Thus, different forms of environmental interactions can be accounted for.

2.3.3 Sophie's Scenario 3

During the holidays, Sophie often loves to travel abroad. She finds the current maps used for airports and indoor environments confusing and not user-friendly. Whilst travelling, she met a researcher who presented her with a new map that looked like a subway map. After a short introduction, Sophie realises it is a simplified and schematic map of the airport covering all terminals, different floors and gate information.

The following section outlines Nossum's (2013) solution to mapping in airports and indoor environments referred to as the IndoorTube map as well as alternative solutions.

2.3.3.1 IndoorTube Map

Harry Beck introduced a new way of depicting the London metro system in the 1930's. Beck was an electrical engineer and was inspired by the simple and schematic layouts of circuit diagrams. These diagrams are visually pleasing due to their regularity. The network only bends at certain regular angles such as 45 and 90 degrees and it aims at simplicity rather than geographical accuracy (Nossum, 2007).

Indoor environments are fundamentally different from transportation networks and underground lines. However, conceptually the similarities between the two are surprising. Multi-storey environments consist of:

- Overlapping and different floors
- Floors connected between elevators and stairs
- Floors are made up of corridors
- Each corridor has rooms

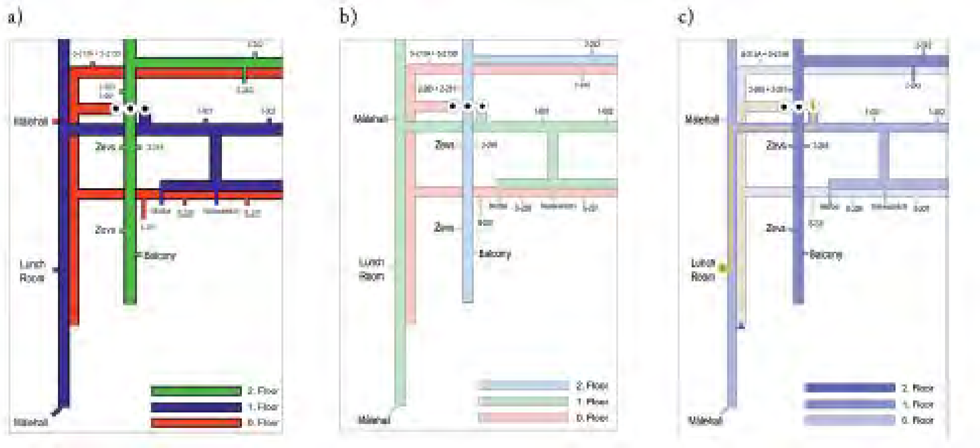

FIGURE 2.6: Illustration of three different colour schemes applied to an IndoorTube map (a) high contrast qualitative scale, (b) pastel qualitative scale and (c) blue sequential scale to indicate vertical dimension (Nossum, 2013d)

While underground networks/ lines have the following:

- Different lines
- Lines are connected by transfer stations
- Lines are geographically made up
- Each lines have stations

The IndoorTube map is an application of Beck's tube map on a multi-storey indoor environment. The process of digitisation on architectural plans allows for the aggregation of a single, two-dimensional visualisation. Many corridors and floors physically overlap but visual changes have been implemented to make it aesthetically pleasing. Metrical accuracy is sacrificed in return for better aesthetics and to avoid visual cluttering (Nossum, 2013d).

The colour scheme is essential to IndoorTube maps. Colours, similar to vertical colour maps, distinguish different floors and represent the vertical dimension. Two forms of colour scale can be used: quantitative or sequential colour scale. Figure 2.6 indicates different colour schemes applied to an IndoorTube map(Nossum, 2013d).

2.3.3.2 Alternative solutions

The IndoorTube map can be enhanced by using dynamic, three-dimensional components as well as geovisualisation (same as Vertical Colour Map).

The IndoorTube map can be extended to a visualisation that provides real-time updates of important information. Such a map can easily be designed for large, interactive displays as well as for mobile devices.

2.3.4 Discussion

The three scenarios that have been presented reflect different interactions with different forms of environments. However, the problems affecting indoor visualisation are consistent through all forms of indoor environments i.e. vertical dimension, limited field of view, occlusion, diversity etc.

Nossum's (2013) suggested mapping solutions for all three scenarios provided a platform that could be improved through the use of alternative solutions. Nossum's (2013) solutions were based on the following (Nossum, 2013c):

- *Colour*- to differentiate between different floors in a multi-dimensional indoor environment (human-perception theory)
- *Guided navigation*- way-finding in indoor environments
- *Two-dimensional representations*- all mapping methods were represented in two-dimensions
- *Simplifying the real*- metrical accuracy is sacrificed for visually pleasing representations

The use of alternative solutions such as dynamic/3D visualisations and geovisualisation allows for the visualisation of real-time, dynamic activity resulting in different levels of acquired spatial information. However, dynamic visualisations consist of issues such as inattentional blindness and change blindness. These issues identify the importance of the user-interface as these issues are solved through user interactivity i.e. brushing, linking etc.

The following section extends the previous discussion by looking at environmental interaction, human-perception theory, way-finding, navigation, spatial-cognition and human-computer interaction.

2.4 Understanding and Perceiving Indoor Environments

The average person spends 90 % of their time in an indoor environment. Many indoor applications have similar purposes to that of outdoor environments. However, due to the structure of indoor space and the types of users, the applications are diverse. The most common application is navigation through the environment (Worboys, 2011).

This section discusses the psychological approach during human-environmental interaction followed by perception in visualisation as well as defining and emphasising concepts such as way-finding, spatial-thinking and human-perception theory when navigating an indoor environment.

2.4.1 Environmental Psychology

The key variables behind human-environmental interaction are cognition and perception- “The internal mental processes by which individuals sense, perceive, interpret and make decision about their environment”(Burgess and Gold, 2015). The interaction between the human and the indoor environment is important to consider for indoor visualisation. The cognition and perception processes in the indoor environment can be used to enhance the indoor visualisation experience.

One theme of interest in environmental psychology is that of human-environmental optimisation. The concept of environmental optimisation is based on a cyclical, feedback model of human cognition and behaviour and pertains to human transactions with the socio-physical environment. The idea of environmental optimisation is to maximise the fulfilment of peoples needs and their accomplishment of their goals and plans (Yadav, 1987).
Extending on the optimisation theme, people tend to orient to the environment based on existing information, expectations and goals; they operate in the environment to achieve their needs and goals as well as to maintain desired levels of satisfaction; and they evaluate the quality of the environment for future interaction and goal attainment (Yadav, 1987). This theme is important to understand especially in the context of indoor environments.

The following section continues the discussion by investigating the perception process in visualisation. The perception process explains how humans handle information gained through sight and thus it is important in indoor visualisation.

2.4.2 Perception in Visualisation

Seeing (i.e.visual perception) is handled by the visual cortex located in the rear of the brain and this process is extremely fast and efficient. Thinking (i.e. cognition), which is handled primarily by the cerebral cortex, is much slower and less efficient. Good visualisations shift the balance towards greater use of visual perception so that advantage of powerful the human-visionary system can be taken (Few, 2014).

One of the earliest contributions to the science of perception was made by the Gestalt School of Psychology. The original initiative began in 1912 and it aimed to uncover how patterns, organisation and form are perceived. The founders uncovered that humans organise what is seen in a particular way in order to make sense of it. This observation resulted in a series of Gestalt principles of perception to be developed (Few, 2014). The seven fundamental principles are (Nossum, 2013a):

- **Proximity-** objects that are close together are perceived as a group
- **Similarity-** perceptual grouping of similar objects are based on elements such as colour, size, shape and pattern
- **Continuity-** Humans have the ability to search for, identify and perceive continuity between objects
- **Symmetry/ Order-** relevant to the principle of continuity and provides a powerful sense of surrounding objects or forming a visual whole
- **Closure-** inherent within human perception to search for closure of objects
- **Relative size-** the size of objects have an effects on perception. Smaller objects are perceived as a singular object instead of individual elements
- **Figure/ ground-** effects that differentiate the depth of graphics are commonly used or misused in cartographic maps

Figure 2.7 shows a visual representation of the Gestalt theory.

The theory states that the perceptive activity is subordinated to a basic factor of "Pragnaz" which means "good shape". An object is Pragnaz if it expresses characteristics in a strong and sufficient manner so that it can be easily evocative and understood (Dulclerci et al., 2004).

The Gestalt principles states above can used in the design of effective indoor visualisations. Different levels of perception can be achieved based on the implementation of the principles.

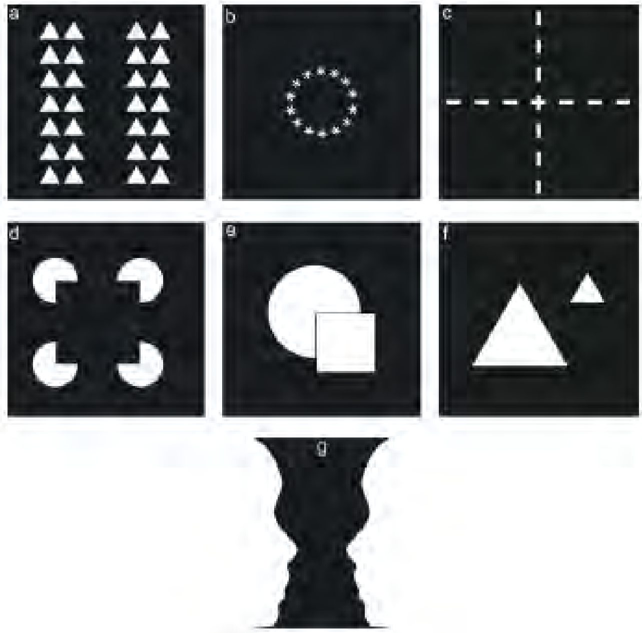

FIGURE 2.7: (a) *Proximity*- the proximity of the triangles creates two rows. *(b) Similarity*- the collection of stars are perceived as a circle. *(c) Continuity*- many small line segments are perceived as a cross and the lines are not even meeting. *(d) Symmetry*- square is perceived in the negative space. *(e) Closure*- the circle is perceived behind the square even if it is a partial shape. *(f) Relative size*- larger objects are perceived in the foreground of smaller objects. *(g) Figure/ground*- Rubin's vase is perfectly balanced between figure, ground and symmetry (Few, 2014)

Also, accounting for the perception of space is important due to the increase in three-dimensional visualisations. The perception of space is not associated to a particular sensory organ, it uses elements of visual, hearing and time perception (Dulclerci et al., 2004).

There are two factors that mainly affect the perception of space. These are the distance between objects in space and their relative size. The combination between these two factors with other agents can be useful in areas such as perception and simulation (Dulclerci et al., 2004). Based on this, the following is presented:

- **Vertical predominance-** a vertical line can look longer than a horizontal line even if they are the same size. This is due to vertical predominance being part of the human vision system
- **Parts and Totality-** the perception of parts does not only depend on individual stimulations; it is also affected by the totality of the relations established in the perceivable field

- **Surfaces-** the perception of surfaces is conditional to the heterogeneous composition of these surfaces. If these differences are not presented, then the surfaces are perceived but not realised. Neither is there space localisation

- **Volume and Depth:** In this case, there are peculiarities that need to be mentioned

  - *Overlapping:* if an object is overlapping another one, the last object is perceived as being further away
  - *Size:* between two objects with different sizes, the bigger is perceived as being closer
  - *Movement parallax:* the more distant objects seem to follow movement of the observer, while nearer ones seem to have movement in the opposite direction
  - *Relative clarity:* between two objects that have different clarity levels, the clearer one is perceived as being closer
  - *Light and Shade:* models using a combination of light and shade provide different depth indications
  - *Texture gradient:* a uniform texture is projected onto the retina in such a way that, however the distance is, the density texture in the image is greater

The resulting perception of space factors above are relevant to novel indoor visualisations due to these visualisations being three-dimensional and dynamic.

In addition to the above, there are certain other perceptual properties such as colour, texture, motion, and nonphotrealism that can be used in the design of indoor visualisations.

Colour is the most common feature used in visualisation. Sophisticated techniques using colour attempt to control the difference viewers perceive between different colours, as opposed to their positions in RGB space (Healey, 2012). This allows for:

- **perceptual balance-** there exists a perceptually uniform difference in colour along the colour scale

- **distinguishability-** within a discrete selection of colours, each colour is easily distinguishable

- **flexibility-** colours can be selected anywhere in the colour space

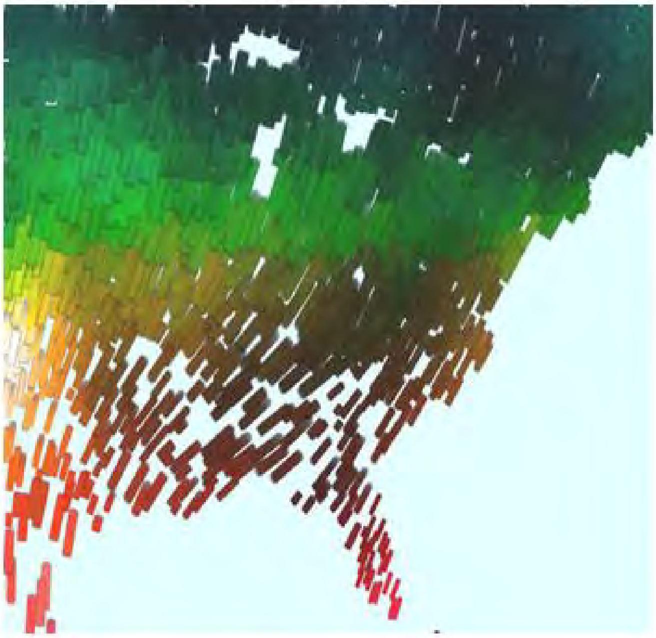

Figure 2.8: Map showing historical weather conditions over eastern part of the United States using colour to indicate temperatures (green to red) and luminosity to indicate wind strength (brighter for stringer winds) (Healey, 2012)

Figure 2.8 presents a map that shows historical weather conditions over the eastern part of the United States through the use of colour and luminosity. These visual elements indicate temperatures and wind strength respectively.

Texturing in visualisation uses perceptual texture dimensions to represent multiple data attributes. This results in a change in texture pattern based on an underlying dataset. Perceptual texture elements that varied in size, density and regularity showed that changes in size and density were perceptually salient (Healey, 2012).

Motion is the third visual element known to be perceptually salient. The use of motion in visualisation represents the direction and magnitude of a vector field (e.g. directions along a path). Motion techniques such as flickering, oscillation, divergence and movement along longer distances have proved to enhance the ability for a visualisation to be perceived (Healey, 2012).

The last visual element deals with the area of modelling and rendering. Although photo texturing is common, there are other nonphotorealistic visual methods. Nonphotorealistic renderings are considered more appropriate, effective and even more expressive than the conventional photographic way. Laidlaw (2011) extended the multi-layered approach for the visualisation of multidimensional data. He varied style properties such as lighting, direction, transparency and frequency to display multiple levels of information in a single display (Laidlaw, 2001). Ebert and Rheingans (2000) used nonphotorealistic techniques such as sketchlines, halos, and silhouettes to highlight important features in a volumetric dataset (Ebert and Rheingans, 2000). The aim of this visual element is to construct visualisations that are both aesthetic and effective (Healey, 2012).

2.4.3 Wayfinding behaviour, Navigation and Spatial Cognition

Novel navigation tools have attracted the interest of researchers concerned with their effect on the user's wayfinding and spatial learning. Axon et al (2012) stated that advanced, technologically driven maps were perceived different from conventional, traditional maps resulting in an impact on the user's wayfinding ability. Frean (2006) expressed concern towards advanced navigation systems stating that it might impact people's geospatial literacy and awareness negatively (Ishikawa and Takahashi, 2014).

Spatial cognition differentiates between navigation and wayfinding. Montello (2005) defined navigation as locomotion and defined wayfinding as involving planned movement in an environment. Navigation involves less decision-making/ cognitive processing than wayfinding due to a person needing to follow a series of prescribed directions without relying on internal representations of the environment (Ishikawa and Takahashi, 2014).

Spatial knowledge has conventionally always been expressed in terms of landmarks, routes and survey knowledge (refer to Section 1.2.2 for earlier discussion). Some people accurately acquire survey knowledge in a new environment and others stagnate at route and landmark knowledge even with continuous exposure to the same environment (Ishikawa and Takahashi, 2014). Montello (2005) and Dabbs et al. (1998) stated that when men give navigational directions they tend to use cardinal directions whilst women use landmarks and egocentric reference frames.

Ishikawa and Takahashi (2014) define another type of spatial knowledge in addition to landmark, route and survey knowledge. The additional knowledge type pertains to people's memories of scenes in travelled environments. A good and enjoyable travel experience comprises of having a good memory of the environment in contrast to heading to a destination without giving attention to the surroundings. Munzer et al. (2006) showed that users of mobile navigational tools do not remember locations and directions of intersections in comparison to paper-map users. Ishikawa (2008) showed that mobile users stopped more frequently and travelled longer distances than map users did (Ishikawa and Takahashi, 2014).

2.4.3.1 Enhancing Sensory Abilities and Cognition in the Spatial Domain

In order for the enhancement of sensory and cognitive abilities to take place, a functional change in which information is encoded, stored, utilised and represented is required. Information technology has directed its attention to the development of larger databases that can be used by smaller and smaller computers. Technological advancements have resulted in the accessibility of data in real-time via mobile devices and other wearable technologies. All of these advancements raise questions such as: How can humans absorb, access and use this data? How much of this data needs to be accessed? How best can humans access and use this data? The underlying concept that these questions are based on is how can human perception and cognition be exploited to aid this process (Golledge, 2002b).

Indoor environments consist of magnitudes of spatial information that cannot all be processed by the human. The challenge is to filter unnecessary information and only present relevant, useful information to the user.

Visualisation is the dominant component between human-IT interaction. The main reason for this is due to the sense of vision being so dominant especially in the spatial domain. Geo-spatial experiences are said to be biased. These biases are a result of cognitive filtering of sensed information and technical errors in the representations. The assumption of general spatial awareness is false. Basic geographic knowledge is minimal and the knowledge of rudimentary spatial concepts such as distance, adjacency, orientation and hierarchy is flawed (Golledge, 2002b). Golledge (2002) states that these biases include improper thinking, perceptual biases, inappropriate use of cognition and the distortion of cognitive maps (Golledge, 2002a).

The above biases are important to consider during the design of indoor visualisation. It provides the understanding of how cognitive filtering can affect the user's perception in an indoor environment.

2.4.3.2 Augmented Reality Visualisations Guided By Cognition

Augmented Reality systems have allowed for the user's perception of the real world to be enhanced by displaying information that the user cannot directly sense when unaided. An example of this is allowing for "X-ray vision" which enables the user to see through objects such as walls to see electrical conduits, a foetus in a womb or a hidden enemy solider. The ability to visualise occluded objects is useful in a variety of fields such as the medical, military, architectural and inspection industries. This technology is becoming extremely useful in urban environments where broad, angular surfaces limit one's field of view (i.e. indoor environments) (Furmanski et al., 2002).

Providing the user extra-sensory information has a wide range of applications. However, adding visual information also presents the user with perceptual complexities. The two main perceptual issues are: (1) conveying the difference between what is normally perceptible and what is extra-sensory (2) that is perceptually easy to visualise and understand in a complex and cluttered environment. Both these complexities are relevant to indoor visualisations as presenting the user with extra-sensory information can advantageous (Furmanski et al., 2002).

The primary problem with displaying rendered information in a AR system is depth ambiguity. Conveying the difference between what is visible and not visible can be ambiguous due to 3D information being represented on 2D planar surfaces (i.e. information about depth can be lost). In addition to this, AR systems with overlayed information can become visually complex and cluttered limiting the effectiveness (Furmanski et al., 2002).

In order to address these challenges processing methods have been used. Processing methods are divided into two categories namely image enhancement, which uses qualities such as brightness, contrast and transparency to improve visibility of features, and image understanding which aims to recognise structures and features and attempts to describe their contents (i.e. visual saliency) (Furmanski et al., 2002).

There are a host of perceptual phenomena that can disambiguate depth ambiguity within AR systems. The first visual cue that allows for this are monocular depth cues. These cues are robust and effective in static and dynamic environments. Examples of these cues are:

- *Transparency*- most common visualisation technique to distinguish between depths.
- *Occlusion*- the interposition of objects in depth is another intuitive monocular visual cue.
- *Size-scaling texture and gradients*- Another common visualisation technique involves the varying of size and detail as a function of distance. This takes advantage of perceptual bias to conceptualise that size changes with distance.
- *Shading gradients*- Along with size-scaling, altering an objects shade relates information about depth and size. The perceived contrast objects decreases as distance from the user to the object increases. (Furmanski et al., 2002)

In addition to the previously mentioned monocular depth cues another important class of perceptual cues that provide depth/distance information are motion-related cues. Two of the most useful and relevant motion cues are:

- *Motion parallax-* Objects that are closer move faster than objects in the distance. This leads to less confusion and limits localisation errors in the system.
- *Structure-from Motion (SFM)-* This cue ties shape and structure together. SFM in AR systems would reduce visual complexities thus reducing non-relevant information could be reduced from rendered models to vertices or simple outlines and when moved can gain its true form. (Furmanski et al., 2002)

All the above perceptual cues can be used in the design of effective indoor visualisations as they address the complexities resulting from depth ambiguity.

2.5 Emotion in Human-Computer Interaction

2.5.1 Introduction

This section discusses the human-emotional processes during human-computer interaction (HCI). This process contribute towards the visualisation experience of the user, making it important to consider.

Traditionally, HCI has been viewed whereby the user must discard all emotions in order to work efficiently and rationally with computers (Brave and Nass, 2003).
Recent psychological research states a different view of the relationship between humans, computers and emotion. Emotion plays a critical role in every computer related activity ranging from designing a three-dimensional model in SketchUp to doing calculations on a spreadsheet to using your GPS system on your mobile device. Psychologists state that it is impossible to perform these previously mentioned tasks without engaging some form of emotion (Brave and Nass, 2003).

Emotion and mood is discussed from a HCI context below.

2.5.2 Understanding Emotion

Damasio (1994) stated that in a HCI context, events and on-screen objects have the potential to activate primary emotions (e.g. joy, anger, fear etc.). For example, visual stimuli that are aesthetically pleasing include images that approach the user or move laterally on-screen. However, most emotions concerned with HCI are referred to as secondary emotions (e.g. pride, satisfaction, frustration) and require more extensive cognitive processes. Such processing occurs at different levels of complexities Brave and Nass (2003).

Emotion affects the navigation and visualisation experience of the user. Thus, visualisations need to be designed to support emotion (especially secondary emotion).

Emotion is distinguished from mood based on its object-directedness. Frijda (1994) states that emotions are intentional and involves directness towards a particular object i.e. a person gets scared of something or angry with someone (Frijda, 1994). Contrary to this, moods are nonintentional and not directed towards a particular object.

2.5.3 Effects of Emotion

Emotions have the ability to affect several cognitive processes that humans experience. These processes consist of attention, memory, performance and assessment.

Attention

One of the most important effects of emotion lies in the ability to capture attention. In an HCI context, this attention-getting function is important to consider in order to be utilised advantageously i.e. a sudden beep is used to alert the user or can be distracting (Brave and Nass, 2003).
An interface that is capable of detecting or predicting a user's emotional or mood state could assume an affect-regulation role by helping and guiding towards positive stimuli. For example, a frustrated user could guided to take a break (perhaps visiting an online entertainment website) (Brave and Nass, 2003).

Performance

Moods have been found to have an effect on cognitive processes and performance. The most resounding find is that even mildly affected states have the ability to profoundly affect thinking, performance and problem solving. Positive affect have been found to stimulate and increase heuristic processing. Thus, keeping a user happy may result in not only satisfaction but may also lead to efficiency and creativity (Brave and Nass, 2003).

Assessment

Mood has also shown to influence judgement and decision making. If a user is in a certain mood, he/she will pursue stimuli associated with their current mood state. This infers that users in a good mood will judge an interface in a positive light regardless of any direct emotional effects. Positive moods also decrease risk-taking due to the likelihood of preserving the positive mood. Users in a positive mood tend to be more cautious (Isen, 2000).

2.5.4 Factors that Stimulate Emotion

The factors that stimulate emotion is important to consider during the design of indoor visualisations especially the user-interface component. There five factors are briefly outlined below:

Needs and goals

A user interacts with a computer system hoping to achieve an application-specific goal. The degree to which an interface facilitates or hampers this process has a direct effect on the emotional state of the user. The ideal interface would be capable to detect the user's current emotional state and adjust it's behaviour if the user's goals are not being met (Klein et al., 1999).
For example, a new user needs to feel comfortable and supported whilst an expert is more focussed on aesthetic appeal of elegance and efficiency. Maslow (1968) stated that it is important to account for these abstract goals during interface design and identified the following individual needs (Maslow, 2013):

- **Aesthetic**- order, symmetry and beauty
- **Cognitive**- understanding, knowing and exploration
- **Esteem**- gain approval, be competent and to achieve
- **Physiological**- thirst, hunger, bodily comforts etc.
- **Safety/security**- staying out of danger
- **Self-actualisation**- realising one's potential, self-fulfilment
- **Social**- be accepted, to fit in
- **Transcendence**- helping others realising their potential and reaching self-fulfilment

In an HCI context, interfaces have shown to directly address a user's basic needs. For example, a spelling-check interface is an approach that acknowledges a user's esteemed needs. Such interfaces, enhance the user's affective state and as a result are viewed as more intelligent and likeable interfaces (Brave and Nass, 2003).

Appraisal Theories

Appraisal theories provide greater predictive power than hierarchy-schemes by specifying the critical properties of preceding events that lead to a particular emotion (Smith and Lazarus, 1990). In an HCI context, slow and unclear response to an interface generally reflect a problem. One of the most common mistakes in interface design is to leave the user in this state of uncertainty. Users tend to fear the worst when the application is at a standstill or appears to be loading for too long. Such uncertainty leads to a state of anxiety that can be avoided through the use of a state indicator or a well-placed informative message. Providing the user with immediate feedback on their actions reduce anxiety and promote positive affective state (Norman, 2002).

Ellsworth (1994) states that obstacles and control play an important role in stimulating emotion. High control can lead to a sense of challenge in positive emotion, but stress in negative emotions. However, lack of control leads to frustration resulting in desperation and resignation. In an HCI context, providing the appropriate level of controllability based on the user's abilities and the task at hand is critical for avoiding negative affective states (Ellsworth, 1994).

Contagion

Emotions experienced through interfaces can also be contagious. For example, when an online character experiences excitement when a certain product appears can make users feel more excited (Brave and Nass, 2003).

Moods and sentiment

Moods and sentiment can also be biased towards emotions. For example, interaction with an object to which a sentiment is already attached can evoke emotion either in memory of past interaction or anticipation of the current interaction. Thus, interfaces that were frustrating in the past, may elicit frustration again without any user interaction (Brave and Nass, 2003).

Previous Emotional State

A user's previous emotional state can affect subsequent emotions and lead to excitement transfer and habituation. Excitement transfer is the experience caused by residual activation of a particular emotion during the return to normal state. Habituation is the opposite of the excitation transfer in that the intensity of the emotion decreases over time. Repeated pleasurable experiences gradually loses intensity (Frijda, 1994).

2.5.5 Factors that Stimulate Moods

Emotion is the primary cause of moods. Repetitive or intense emotional experiences result into moods. A user who is repeatedly being frustrated will likely result in a frustrated mood while the converse if a user is happy. Moods, however, can be anticipated based on sentiment. For example, if a user knows that they must interact with an application they dislike, they may be in a bad mood from the beginning (Brave and Nass, 2003).

Contagion

Moods, similar to emotion, can exhibit contagious effects (Neumann and Strack, 2000). In an HCI context, moods exhibited by on-screen characters or objects may directly transfer to the user's mood. On-screen moods can also lead to perceived contagion effect whereby one smiling character can influence the user's perceptions of other characters in a positive light (Brave and Nass, 2003).

Colour

Colour can be designed into an interface with mood influencing properties. For example, utilising warm colours evoke active feelings whilst cool colours are less likely to cause extreme reactions (Levy, 1984). Carefully designed colour schemes complimenting other design elements can produce specific and reliable influences on mood (Brave and Nass, 2003).

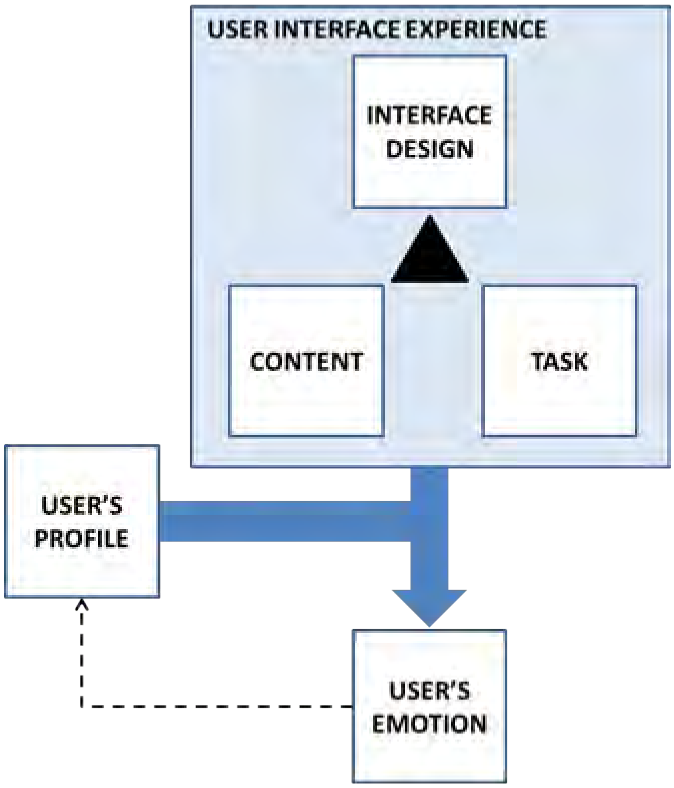

Figure 2.9: Model of User Interface Emotion (Lockner and Bonnardel, 2014)

2.5.6 Emotional Interface Design

The previous discussion of emotions, moods and sentiments have allowed for the design of user-interfaces that evoke positive judgements and improves attentions.

Lockner and Bonnardel (2004) proposes the above model which states that the specificities of an interface is a product of design (Lockner and Bonnardel, 2014).

In the model, Figure 2.9, the user's profile consists of the baseline on which the current interface (external) is appraised in order to give rise to certain emotions.
The user interface experience (light-blue block) accounts for two considerations. Firstly, experience refers to the continuous interaction with the product. Secondly, the user interface consists of three components (Lockner and Bonnardel, 2014):

- The content refers to the information and data that wants to be communicated to the user. It consists of pictorial elements (e.e illustrations, photographs, diagrams) and textual elements (e.g. journals, titles, articles).
- The interface design consists of the layout and presentation strategies of the content and the functionalities. "Information design" refers to information display

strategies and "interaction design" refers to the way in which users interact with the interface.

- The task refers to the purpose of the interface which has to be handled by any users.

The user's profile refers to the specifications of the user at the moment of interaction. This functionality could potentially gather information such as cultural background, previous content related knowledge, mood personality etc. (Lockner and Bonnardel, 2014).

In order for a user interface to evoke positive emotions there has to be an element of "fun" involved during the user-interaction. Ben Shneiderman (2004) defines three goals that result in "fun" interaction.
Firstly, the user interface needs to provide the right functions so that the user can accomplish their tasks. Secondly, usability and reliability of the user interface needs to prevent frustration which can detract from the fun element. Thirdly, engage users with fun features (Shneiderman, 2004).

Shneiderman (2004) states that fun consists of "alluring metaphors, compelling content, attractive graphics, appealing animations and satisfying sounds" (Shneiderman, 2004). However, he states the importance of not over doing it and reach a balance between completing a task and an element of fun during user interaction (Shneiderman, 2004).

Lastly, Hassenzahl (2004) stresses the need for designers]s to understand the context in which the users are situated. The satisfaction of different needs of users within a certain context can create positive emotions for a user. New design methodologies have attempted to meet the challenge of designing interfaces that have a balance between cognition and emotion (Hassenzahl, 2004).

2.6 Related works

2.6.1 Introduction

The following section presents novel, innovative outdoor/ indoor visualisation applications used for navigation and exploration. The first example discusses the sport orienteering and its extension to indoor environments. The remaining applications are augmented systems.

2.6.2 Orienteering

Traditionally the sport of orienteering has always been outdoors. However, the sport is slowly moving indoors in order to avoid unstable weather conditions and unequal conditions for the athletes. Orienteering is dependent on one crucial facility, the map (Terje, 2013).

Indoor orienteering offers new possibilities and new challenges both when it comes to making of the map and the competition. The handling and presentation of several floors is the most challenging aspect of indoor navigation. Usually maps consisting of different floors are illustrated side by side thus it is important to indicate how the horizontal positions of the different floors are related. Figure 2.10 shows example of one of the campuses on a Norwegian University where vertical reference points are included (Terje, 2013).

The coloured circles in the corners are used as vertical points. Circles of a certain colour have identical horizontal coordinates. However, even with this depiction, it is a challenge to do a “mental movement” between floors when time is an issue.

The three-dimensional extension of orienteering also introduces new possibilities. When navigating between controls, orienteers will have to select between two or more possible routes in an horizontal plane. In a multi-level environment, it is possible to choose routes between different levels and Figure 2.10 presents the vertical dimension challenge (Terje, 2013).

All orienteering maps are a generalised picture of the real. Scale is an important factor when different generalisation parameters are set. Typical indoor maps have a scale in the range of 1:500 - 1:1000. Larger complexes would have 1:1500 and micro-orienteering would have 1:100 - 1:500. It is important to not show superfluous information to the orienteer and details inside inaccessible areas need to be strongly de-emphasized or even removed (Terje, 2013).

FIGURE 2.10: Map over NTNU Dragvoll including vertical reference points (Terje, 2013)

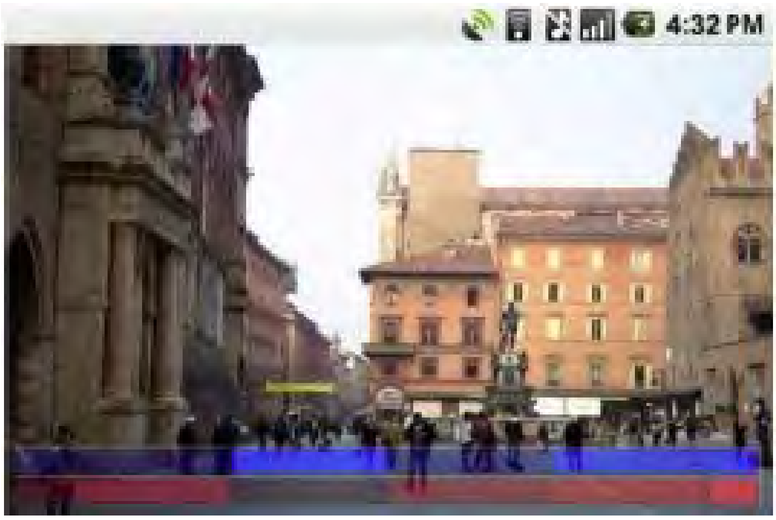

FIGURE 2.11: Screenshot of the Framy-AR application showing two colour strips at the bottom of the screen. The intensity of colour indicates the amount of data available and the different colour indicates two different points of interest i.e. hotels and restaurants (De Chiara, 2012)

FIGURE 2.12: Copenhagen Airport's MAR application that assists passengers in navigating the airport's interiors (Chionna et al., 2015)

FIGURE 2.13: Augmented reality navigation application (Alnabhan and Tomaszewski, 2014)

2.6.3 Framy-AR: Beyond The Screen Map Exploration

The Framy-AR application uses augmented reality. The application aims to overcome screen size limitations of mobile devices by representing, through qualitative metaphors, the geographic locations of objects outside of the visible space. The idea is to visualise a frame along the border of the device, where the colour intensity of each frame indicates a visual summary of data located besides the visualised map area (De Chiara, 2012).

Framy-AR aims to enhance user's navigation activities using augmented reality. The main advantage of the application is that users gain instantaneous hints about objects surrounding them, independently of the visual modality they are adopting. This system targets the support of user navigation be defining a geovisualisation technique where a geospatial data representation is included in a real scenario enriched by visual metaphors (De Chiara, 2012).

Figure 2.11 shows an example of this application.

2.6.4 Indoor Way-finding MAR app

In 2011, Copenhagen Airport (CPH) became the world's first airport to use Mobile Augmented Reality (MAR) to aid passengers to navigate the interiors. GPS positioning is typically used for external geo-location applications and thus cannot be reliably used indoors. The CPH application uses the exiting Wi-Fi infrastructure for tracking (Chionna et al., 2015).

Look at Figure 2.12 for an example of this application.

2.6.5 INSAR: Indoor Navigation System using Augmented Reality

INSAR or Indoor Navigation System using Augmented Reality uses the Wi-Fi fingerprinting method to determine the user's position, augmented reality to relay real-time navigational information and a directional compass to determines the direction of the destination (Alnabhan and Tomaszewski, 2014).

Figure 2.13 shows an example of this application.

Chapter 3

Method

3.1 Introduction

This chapter presents the method used to investigate the elements of design for indoor visualisation. The implemented processes resulted in a set of indoor visualisation renderings that aimed to address the challenges facing indoor environments.

The chapter is divided into two sections.
The first section defines the Elements of Design framework that can be used as best practices for the design of indoor visualisations. The second section outlines the development of the visualisation renderings that were developed. This includes the creation of the model, the texturing as well as the added elements of design for indoor visualisation that was based on the Elements of Design framework.

The visualisation renderings were generated using a virtual, three-dimensional environment.

3.2 Elements of Design Framework

The Elements of Design Framework establishes a set of visual perception variables and their relevant properties. The variables were based on the theoretical component in the indoor visualisation approach (particularly the human-perception theory component).

The visual perception variables consist of:

- *Colour*- use of colour to enhance visual perception (particularly saturation)
- *Contrast*- use of contrast to enhance visual perception
- *Shape*- use of geometry to enhance visual perception
- *Scaling*- use of dynamic sizing to enhance visual perception
- *Glow*- use of glow effect to enhance visual perception
- *Motion*- use of movement to enhance visual perception
- *Directionality*- use of direction to enhance visual perception
- *Texturing*- use of texturing to enhance visual perception
- *Contextual*- use of contextual visualisation to enhance visual perception e.g. transparency, grayscale, depth of field etc.
- *Depth of field*- use of depth perception to enhance visual perception
- *Projection*- representation of a three-dimensional object
- *Acquisition*- the attained spatial cognition by the user

The aim of the framework is to provide a robust process to address indoor visualisation for different user needs and goals in the environment.

The Elements of Design framework is shown in Table 3.1 and 3.2 below.

Table 3.1: Elements of Design Framework for indoor visualisation

Visual variables	Design elements/ Properties
Colour	- Tint (light colours), shade (dark colours) - Complimentary colours (opposite on the colour wheel) - Anagolous colours (next to each other on the colour wheel) - Neutral colours (don't show on the colour wheel)- e.g. black, white, grey - Warm colours (made up of red, orange, yellow or a combination of these) - Cool colours (made up of blue, green, purple or a combination of these)
Contrast	- Colour contrast (low to high contrast) - Size contrast (small to big) - Shape contrast (basic to extreme) - Positional contrast (basic alignment to extreme alignment)
Shape	- Geometric shapes (regular & precise) - Free-form/ organic shapes (found in nature or man-made items) - Abstract shapes (recognisable form but not real) e.g. icons, symbols, glyphs - Positive and Negative shapes (positive- contains subject matter, negative- background)
Scaling	- Relative sizing (e.g. emphasise dominance, focal points, balance etc.) - Typographic scale (textual elements)- not legible to legible
Glow	- Dim to bright - Small to large
Motion	- Time (rate of change- slow to fast) - Sound (soft to loud) - Space (positioning)
Directionality	- Lateral (left-right) - Vertical (top-bottom) - Longitudinal (front-back) - Common fate (objects appearing to move in the same direction)
Texturing	- Real texture (real images) - Visual/ implied texture/ Hyper-realism (invented or simulated)

Table 3.2: Elements of Design Framework for indoor visualisation contd.

Visual variables	Design elements/ Properties
Contextual	- Anti-occlusion - Directional Reduction - Grayscale - Vignette - Section-cut - Environmental Blur - Focus - Level of detail
Depth of field	- Distance between user and object of interest - Distance between object to background
Projection	- Parallel projection- orthographic, pictorial, axonometric, isometric, oblique - Perspective projection- three-dimensional objects are viewed in a picture plane
Acquisition	- Poor to excellent spatial cognition

3.3 Modelling and Rendering

This section shows the processes that resulted in the indoor renderings. The rendering designs are separated into two phases namely the model creation phase and the texturing and elements of design phase.

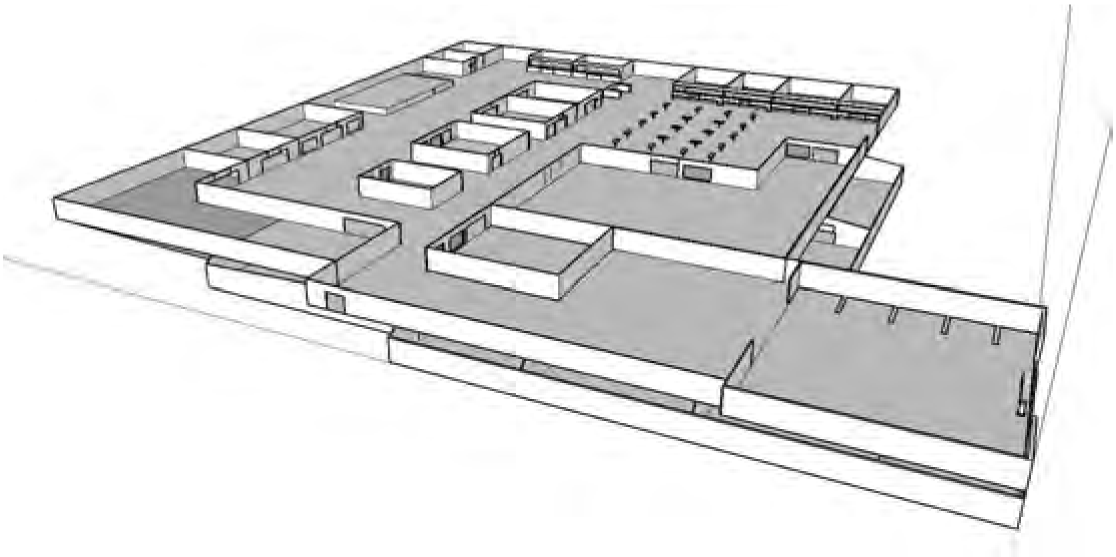

FIGURE 3.1: Three-dimensional representation of the raw, conceptual two-storey shopping mall environment in the Trimble SketchUp framework

3.3.1 Model Creation

The model creation phase represents the creation of the three-dimensional model. The model comprises of a conceptual, two-level shopping mall environment that consists of various shop types, elevators, emergency exits and various relevant environmental objects. The purpose of the design is to represent an indoor environment that reflects the complexities and challenges i.e. multiple floors, limited field of view, occluding objects etc.

Figure 3.1 above shows the raw, three-dimensional model in Trimble SketchUp.

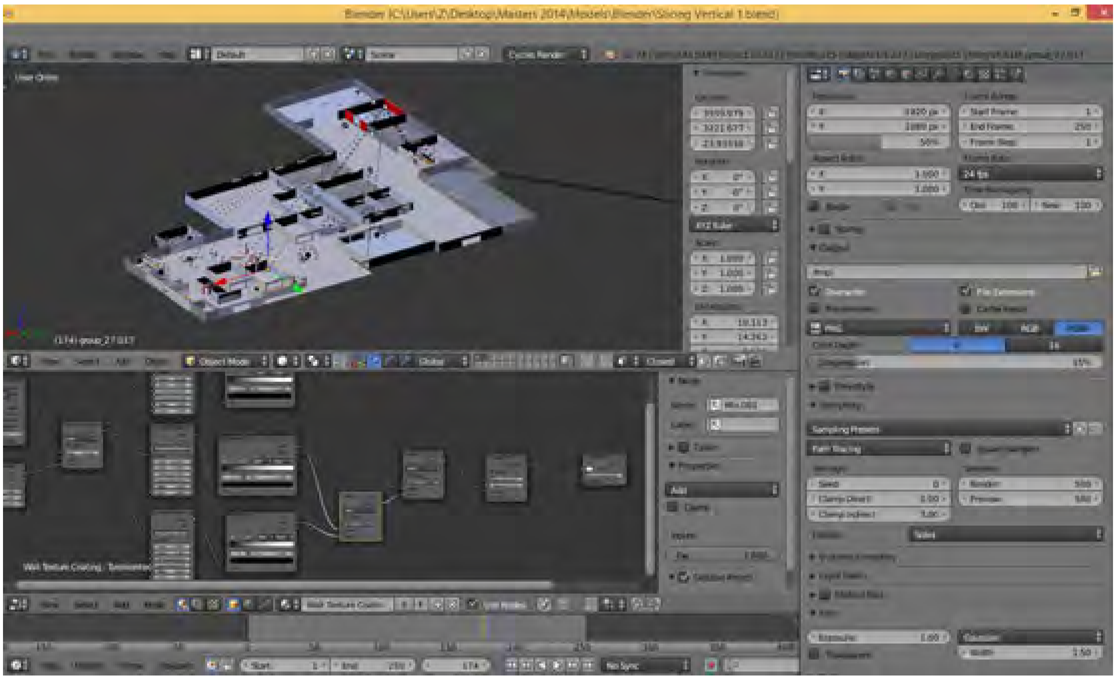

FIGURE 3.2: Three-dimensional model in the Blender framework

3.3.2 Texturing, Elements of Design and Realism

Blender was the graphic software used to render the various forms of visualisation. Blender also allowed for the texturing and the addition of lighting and modelling props to the model which further enhanced the realistic appeal of the model.

3.3.2.1 Aesthetic Appeal

The texturing of the model was implemented using different shaders through the cycles renderer in Blender. The cycles renderer is a path tracing engine designed for animations. It is a backwards path tracer as it traces light rays by sending them from the camera instead of from the light source. Cycles actually simulate light so results are similar to what is seen in the real (Sons et al., 2015).

The shaders that were used for texturing included wall paint, granite, wood, gloss effect etc. These shaders were downloaded and used accordingly. Also, emission and point lighting was added to the environment to allow for the creation of shadows and proper illumination. The various store logos were designed conceptually in Microsoft Powerpoint and used as image textures to represent store signage in Blender. Modelling props such as cars, water features, humans and fire extinguishers were added to the environment in order to enhance further realism.

The above processes resulted in a fully textured, three-dimensional model with modelling props, advanced lighting and shadows that simulated a realistic, conceptual two-level shopping mall. Figure 3.2 above shows the textured model in the Blender framework.

3.3.3 Elements of Design for Indoor Visualisation

The visualisations were rendered to simulate a 1st person perspective. Each visualisation addressed different visual perceptions. Seventeen different visualisation techniques were simulated. The visualisation techniques were based on the properties/design elements of the different visual variables in the Elements of Design framework.

3.3.3.1 Grading Visualisation Techniques

Each visualisation technique was graded using a parallel chart that compared variations of the same visualisation technique against each other. However, certain techniques were scaled singularly with no comparison. The parallel charts do not show that one visualisation is better than another. They merely show the different in elements like colour or contrast for example.

The x-axis of the chart reflected the different visual variables i.e. colour, contrast, shape etc. The y-axis represented a nominal scale from 0 to 1. The effectiveness of the different visual variables applied in different visualisation techniques were compared against each other. Certain contextual visualisations such as the vignette and grayscale techniques were used in conjunction with other visualisation techniques in order to demonstrate the ability for them to be combined. If a certain contextual visualisation was used for a visualisation technique, it was added to the x-axis so it could be scaled accordingly. The tables below summarise the scaling of the different visual variables as well as the different contextual visualisations (Table 3.3 and Table 3.4).

An example that shows the layout and format of the rendering results is presented after the tables below. The results consist of screenshots showing the visualisation technique, a parallel chart that scales the technique and description of the technique and how different visual perception variables were utilised.

TABLE 3.3: Scales/Ranges of the different visual variables

Visual variable	Scale/Range
Colour	Unsaturated - Saturated
Contrast	Low contrast - High contrast
Shape	Poor shape - Very good shape
Scaling	Poor scaling - Very good scaling
Glow	No glow - Strong glow
Motion	No motion - Very good motion
Directionality	Poor directionality - Very good directionality
Texturing	Real texturing - Hyper-realistic texturing
Contextual	Refer to Contextual table (Table 3.4)
Depth of field	Shallow - Deep
Projection	Poor projection - Very good projection
Acquisition	Poor cognition - Very good cognition

TABLE 3.4: Scales/Ranges of the different contextual visualisation renderings

Contextual	Scale/Range
Anti-occlusion	Opaque - Full transparency
Directional Reduction	0 - 100 %
Grayscale	Light shade - Dark shade
Vignette	Small - Large
Environmental Blur	Low - High
Focus	Shallow - Deep
Level of detail	Near - Far
Section Cut	0 - 100 %

3.3.4 Example: Line for Route Rendering with Yardstick distances

The example below presents the layout of the results which show the different rendering results. The figure graphically demonstrates the visualisation technique, the parallel chart grades the technique and a description and other relevant information to the discussed technique is also presented.

FIGURE 3.3: Path renderer used to facilitate guided navigation using saturated colours to distinguish between paths

FIGURE 3.4: Path renderer used to facilitate guided navigation using unsaturated colours to distinguish between different paths

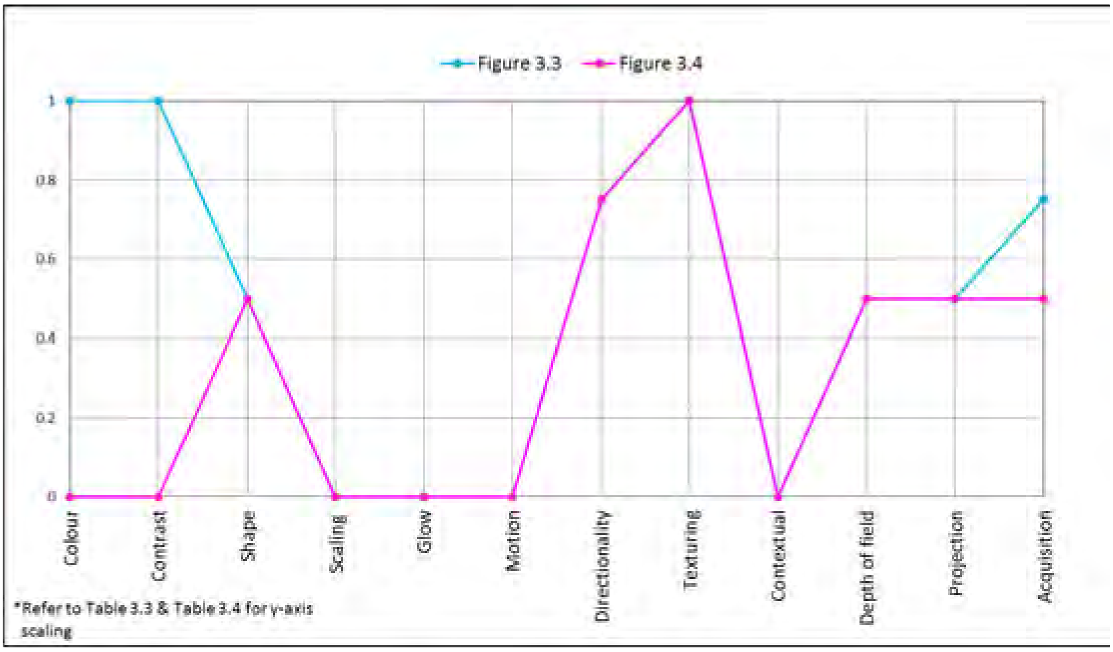

FIGURE 3.5: Parallel chart shows that saturated colours result in higher contrast resulting in better acquisition

The path renderer and yardstick distances is the most conventional approach in guided navigation systems. The yardstick distance adjusts in real-time according to where the user is in relation to the end destination.

Figure 3.3 and Figure 3.4 above uses colour to distinguish between the different paths presented to the user. Colour is a widely used component in perceptual visualisation. Figure 3.3 uses saturated colours with resulting in high contrast and Figure 3.4 uses unsaturated colours resulting in lower contrast. The different types of colour used allows for a degree of distinguishability between the different paths. According to Dulclerci et al.(2004), the implemented visualisation technique, particularly 3.3, applies the Law of Prägnanz whereby colour has been used in a strong manner so that the differentiation between the paths can be easily understood (Dulclerci et al., 2004).

The following section shows the results of the remaining visualisation renderings.

Chapter 4

Results and Discussion

4.1 Introduction

The remaining results of the different visualisation techniques used and tested are presented below. As stated previously, these techniques were developed using the indoor visualisation theory framework (in Chapter 1.6) and the previously established Elements of Design for indoor visualisation framework. Each technique is shown in the same format as the example in the previous section (Section 3.3.4). The different visualisation techniques are then discussed further in relation to different applications/contexts in which they can be used. These applications/contexts include commercial, navigation, exploration, hazard and combination setting. Lastly, a sample user interface on which the visualisation renderings can be viewed is presented as well as including the emotional processes that result from human-computer interaction.

The scaling of the presented visualisation techniques are not based on experimental evidence but rather subjective comparison. For example, a technique that used saturated colours instead of unsaturated colours resulted in a better visualisation due to high levels of saturation and contrast inferring better acquisition and clarity. The acquisition visual variable is the most important variable as it represents the user's cognition and spatial understanding of the environment. The grading of this variable is based on the scaling of the other visual variables.

Refer to Appendix 6 for the storyboard that uses scenarios. Each scenario is addressed by the most suitable visualisation technique.

4.2 Conceptual Visualisation Rendering Results

The aim of the renderings is to determine alternative ways to present as much spatial information in a scene to the user without causing cognitive dissonance, spatial disorientation, confusion and fatigue. The amount of spatial information is dependent on the user's task and the context in which he/she is traversing through the environment. In some cases, spatial information needs to be filtered in order to reduce the amount of unnecessary spatial information that the user receives. The ideal is to determine a balance between excess and too little information based on the user's task.

The remaining visualisation renderings use and manipulate the visual variables differently. The results aim to prove that the indoor visualisation experience for a user can be enhanced through the application, manipulation and combination of the defined visual variables.

The y-scaling for each visual variable can be found in Table 3.3 and Table 3.4 above.

4.2.1 Line for Route Rendering with Thickness and Transparency

The route rendering used in Figure 4.1 and Figure 4.2 below is based on the fundamentals of the previous visualisation technique (Figure 3.3).

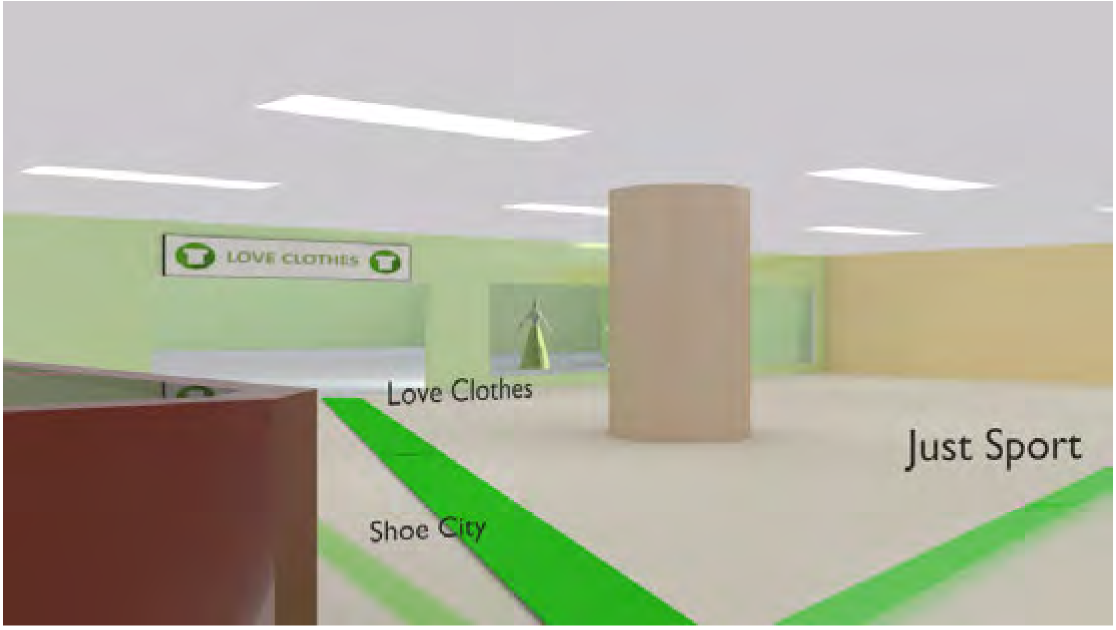

FIGURE 4.1: Path renderer with varying thickness and transparency used to facilitate guided navigation

FIGURE 4.2: Path renderer with varying thickness, transparency and scalable text used to facilitate guided navigation

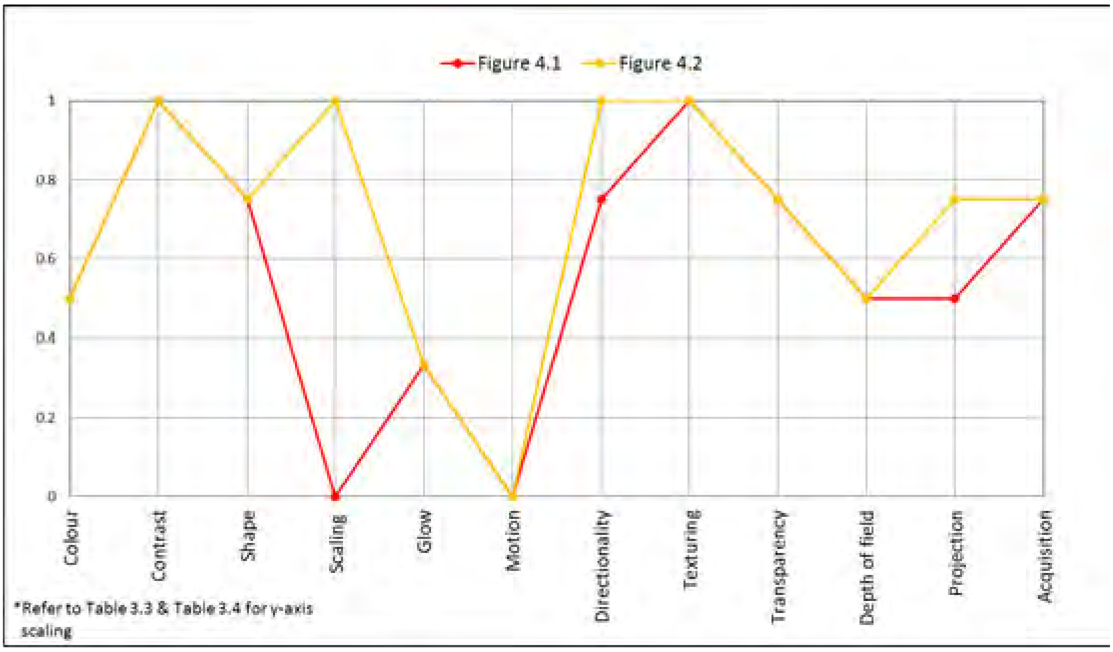

Figure 4.3: The scalable and directional text used in Figure 4.2 result in a better projection

Figure 4.1 and Figure 4.2 represents a modification of the conventional approach towards route-rendering. Instead of using colour to differentiate between varying paths, it uses a singular saturated colour, transparency, path thickness and adjustable font size to define paths and relate their pertaining distances. For example, paths that are rendered thick, bright and have large font sizes result in closer destinations than paths rendered thinner, lighter and smaller font sizes.

The use of a line as a path helps direct the eye and creates a sense of movement. The varying path thickness creates emphasis and enhances the contrast between the paths. Lastly, the transparency element further enhances contrast between the paths in a striking way (Stribley, 2016).

Figure 4.2 differs from Figure 4.1 in that it uses type hierarchy to order and orientate text. Figure 4.2 uses the relative size component of the Gestalt theory that states that the relative size between objects have an effect on perception i.e. Larger font size, closer the destination. It also orientates the textual elements in the direction of the path in order to emphasise directionality (Nossum, 2013a).

The challenges facing this visualisation technique are (1) rendered paths may not be as clear if there is poor lighting, (2) adjustable font sizes will become too large when location names are long and (3) if several paths wanted to be displayed, recognising the varying width and transparency levels between the different paths will be challenging.

4.2.2 Line for Route Rendering Displayed Towards the Ceiling

The route rendering technique seen in Figure 4.4 and Figure 4.5 shows the change in vertical positioning of the rendered routes. In this case, the routes are rendered towards the ceiling of the environment.

FIGURE 4.4: Path for route-rendering displayed towards the ceiling using saturated colours and directional text

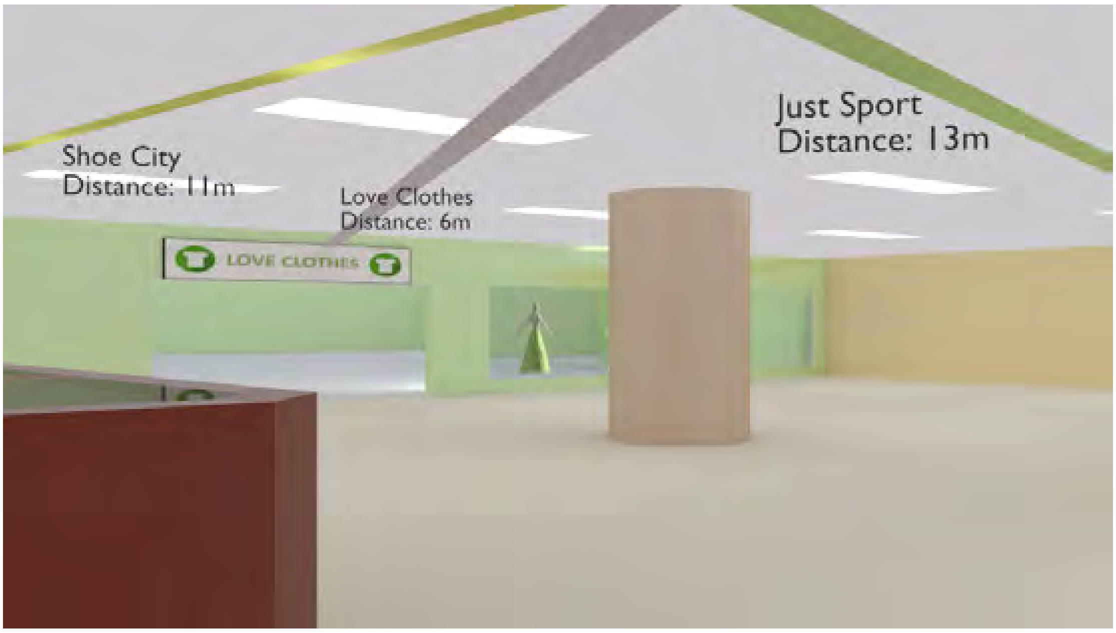

FIGURE 4.5: Path for route-rendering displayed towards the ceiling using unsaturated colours with poorly directed text

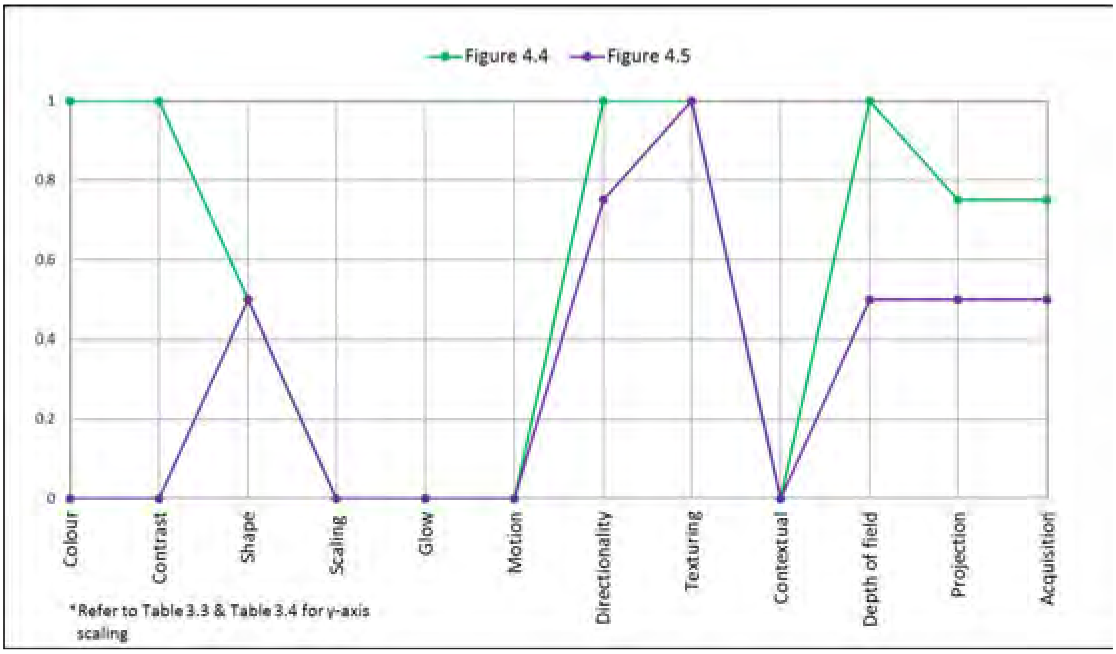

FIGURE 4.6: The ceiling route-rendering technique that uses saturated colours and directional text results in better contrast, directionality, depth of field, projection and acquisition

The focus of humans during indoor navigation is below the horizon (eye-level) (Zlatanova et al., 2013). This results in the ceiling being visual dead space. Visual dead space plays an important role in visualisation. Elevating the paths and text towards the ceiling (visual dead space) removes visual clutter from the floor area (Parmar, 2013). As the floor draws most of the viewer's interest, it is desirable to keep it as free of captions and visual elements as possible. This also infers the proximity component of the Gestalt theory whereby the distances between elements in a visualisation have an effect on perception. In order for visual clutter to be reduced, the entire visualisation space needs to be utilised (Nossum, 2013a).

Figure 4.4 also uses saturated colours to distinguish between the different paths and directional text to facilitate the guided navigation process.

This approach improves on existing navigation systems such as the Copenhagen Airport's MAR application (Secion 2.6.4) by changing the vertical positioning of the path and utilising visual dead space more efficiently.

However, the primary challenge is that rendered paths may be affected by foreshortening due to the angle at which the paths are displayed to the user (Seddon and Shubber, 1985).

4.2.3 Dynamic and Adjustable Arrows for Path Rendering

Figure 4.7, 4.8 and Figure 4.9 use directional arrows to guide the user through the environment. It is based on the previous path rendering technique (Figure 3.3).

Figure 4.7: A series of arrows are rendered along the path direction. The arrow closest to the user is rendered most clear and bright

Figure 4.8: The size of the arrow enlarges as the user approaches the destination

FIGURE 4.9: The series of arrows are rendered upon a grayscale environment in order to further enhance the contrast and place emphasis on the arrows

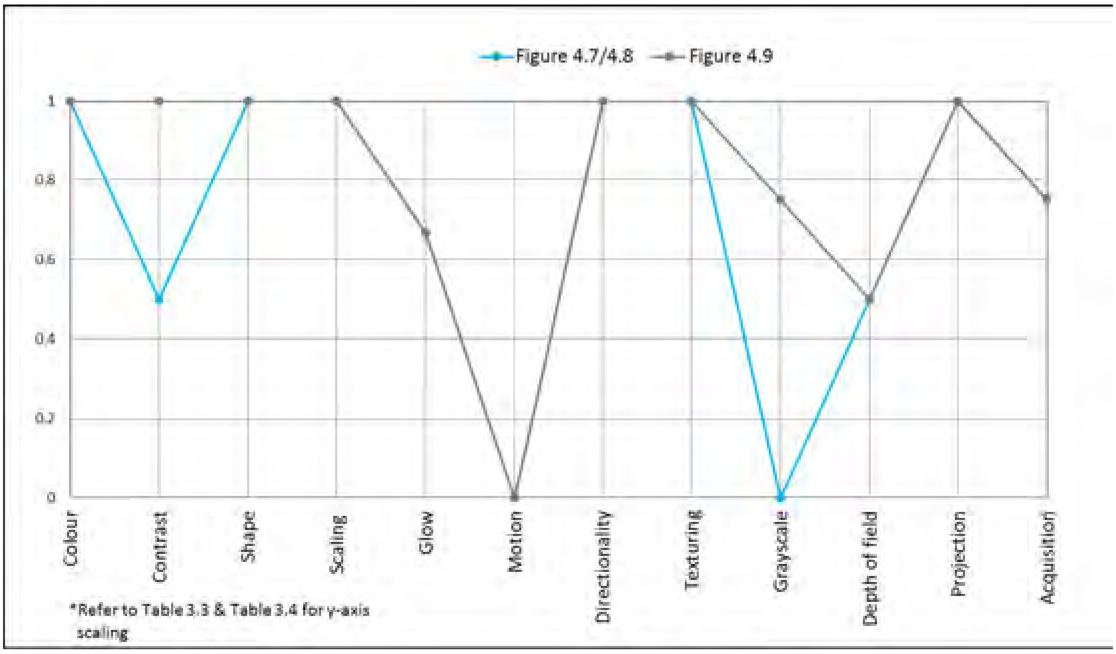

FIGURE 4.10: The use of the grayscale contextual rendering allows for a higher contrast between the environment and the arrows resulting in easier perception

Breaking a path/route into a series of symbols (arrows) enhances the sense directionality (Figure 4.7). It also applies the continuity and common fate principles of the Gestalt theory whereby the perception of shapes (arrows) will continue beyond their end points and elements that are in the same direction are perceived as related. The added element of transparency used in the series of arrows creates a clean sense of movement for the viewer (Stribley, 2016). Long/large unbroken symbols (Figure 4.8) use the focal points principle of the Gestalt theory whereby attention will be drawn to the large and strongly coloured shape (large arrow) (Stribley, 2016).

Figure 4.9 uses a contextual technique that renders the environment in grayscale. This enhances the contrast between the arrows and the environment (light vs dark) (Nossum, 2013a). It also applies the figure/ground principle of the Gestalt theory whereby the arrows are perceived as the figure and the grayscale environment as the ground. This allows for the viewer to focus on the smaller shape (arrows). Combining more Gestalt principles results in better synergy in the visaulisation (Bradley, 2014).

4.2.4 Top-down, Superimposed Overview Map

The approach shown in Figure 4.11 and Figure 4.12 above allows the user to toggle a top-down/ overview map. This serves as a useful tool as it relates a different perspective of the environment to the user.

FIGURE 4.11: Top-down/ Overview Map over three-dimensional environment to provide a different perspective

FIGURE 4.12: Top-down/ Overview Map over three-dimensional environment to provide a different perspective combined with a vignette effect to allow better contrast

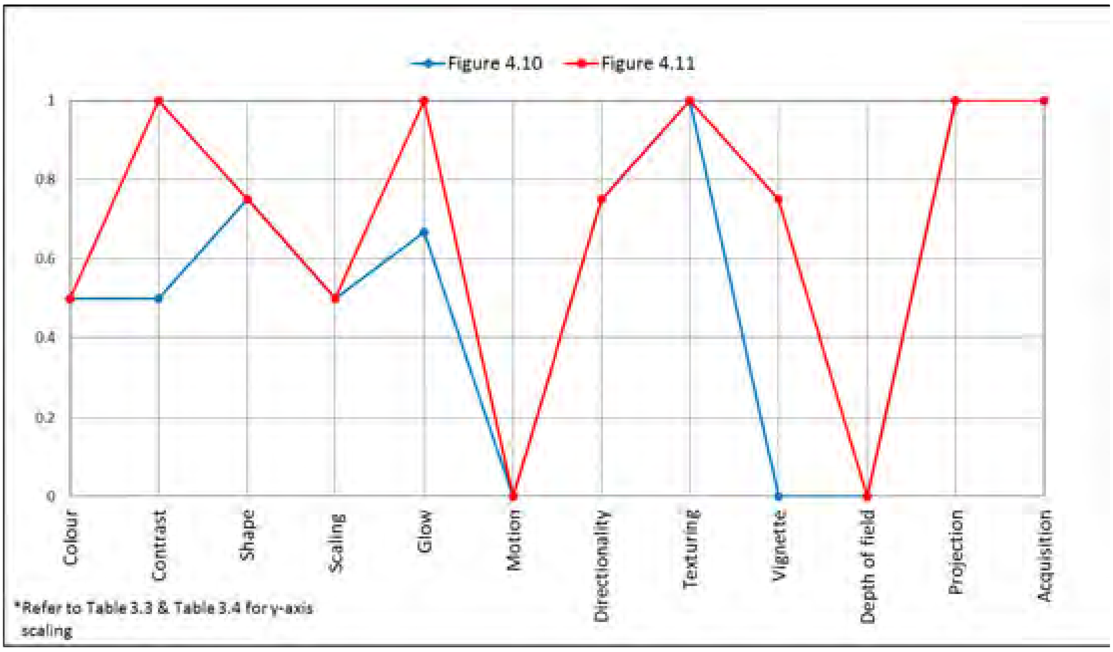

Figure 4.13: The addition of the vignette effect results in better contrast between the environment and the overview map so that it can be easily perceived

The technique shown in Figure 4.11 and Figure 4.12 combines previous work such as the Vertical Colour Map (Section 2.3.1.1) and the IndoorTube Map (Section 2.3.3.1) together with dynamic/3D visualisations. These previous mapping methods are two-dimensional, top-down approaches. The resulting technique allows for a two-dimensional, top-down perspective to be superimposed upon the 3D environment.

Both figures use the framing principle in design theory to emphasise and draw attention to the inset, superimposed map (Stribley, 2016). Also, the figure/ground principle of the Gestalt theory is used to distinguish between the figure (inset map) and the ground (3D environment) (Bradley, 2014). Figure 4.12 uses a more stark frame and the vignette effect brings attention to the centre of the display and it isolates the superimposed overview map for better focus (Vig, 2016)

The combination between a three-dimensional and two-dimensional perspective allows for better depth perception and acquisition of the environment due to the holistic understanding of the environment.

4.2.5 Camera Extension

While moving towards a destination, the user may want to know what is happening at the destination. A decision based on knowledge of the present and the future can be made using the Camera Extension technique. Figure 4.14 applies this technique using virtual cameras that have been placed in the scene. The camera view becomes active when the user selects the camera symbol on the rendered path. The camera view provides a front-end perspective of the destination of interest.

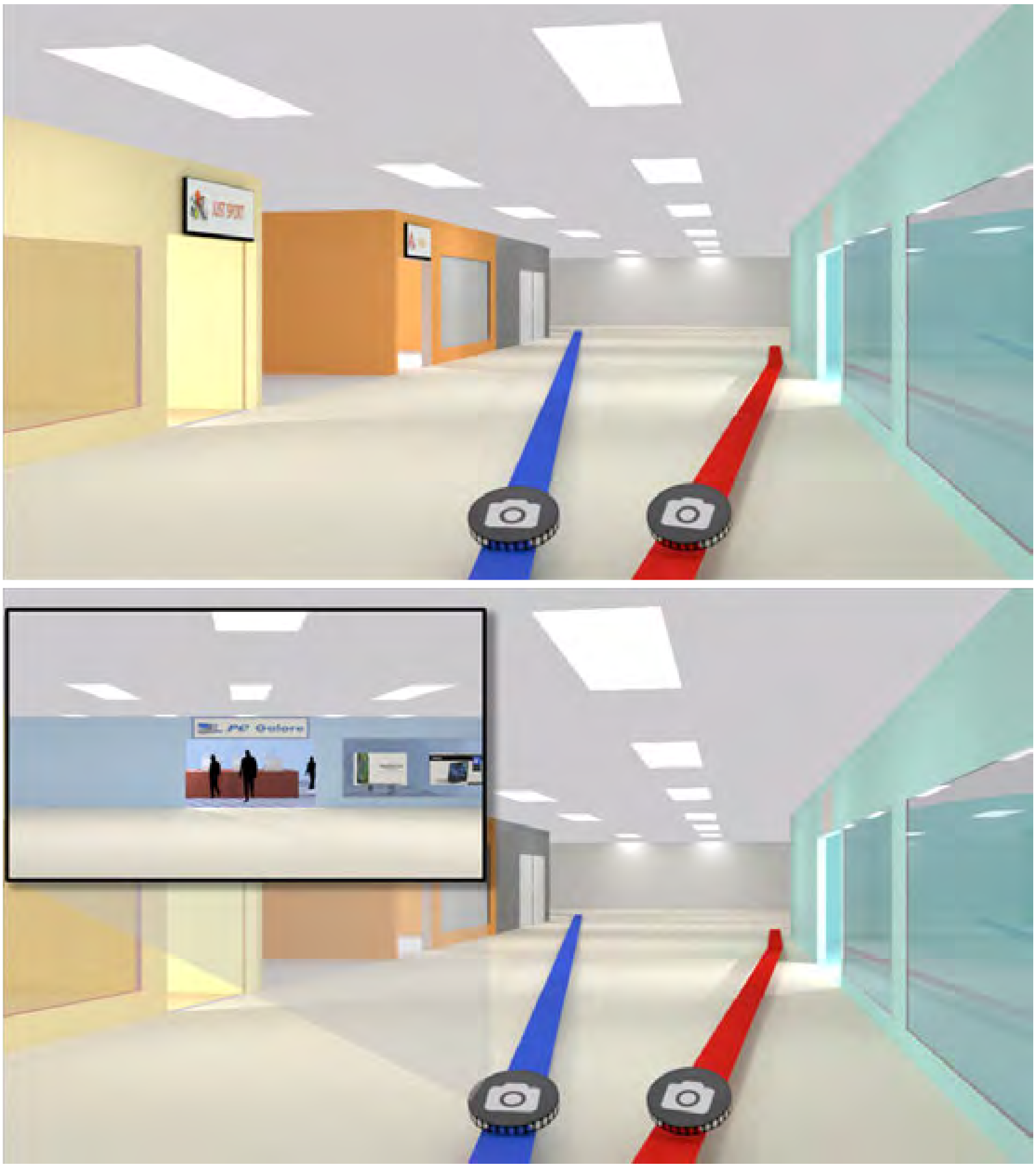

FIGURE 4.14: Camera icon on path that extends visualisation to provide a front-end perspective of the store when clicked

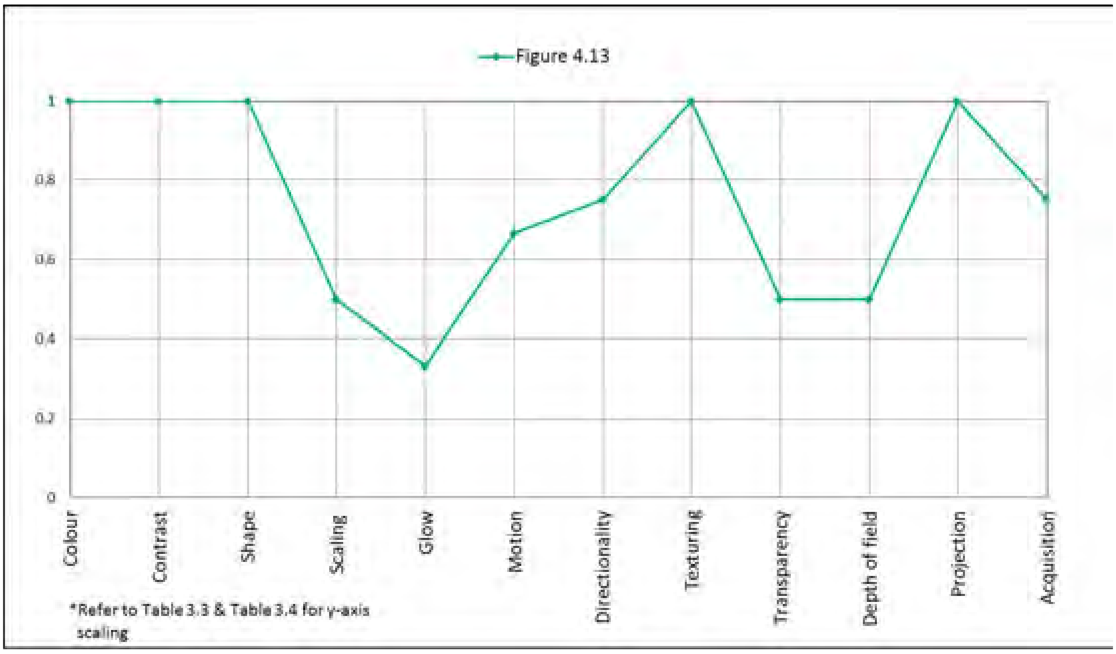

Figure 4.15: Cameras on path technique utilises saturated colours, shape, elements of transparency, good projection to provide good acquisition and cognition

The technique in Figure 4.14 builds on previous work by applying user interactivity (in this case it is the brushing technique) (Nollenburg, 2010). The inset, modal window is enhanced using the framing principle from the design theory (Stribley, 2016) and the figure/ground principle from the Gestalt theory (Nossum, 2013a). Also, the location of the modal window is towards the ceiling (visual dead space) resulting in less visual clutter (Parmar, 2013). The transparent connection between the modal window and the camera symbol applies the uniform connectedness principle from the Gestalt theory whereby connected elements are perceived as being related (Bradley, 2014). Lastly, the symbology used for the camera symbol uses a pictogram. The pictogram represents a logical relationship between the symbol and the resulting action (Campbell and Shin, 2012).

Possible usage of this technique consist of allowing the user to see the windows of shops, see how busy they are or see if there are any specials for example without having to physically navigate to them etc.

4.2.6 Points of Interest

A limited field of view is a primary challenge in indoor environments. Visual cues are required to reveal hidden information. The Point of Interest technique seen in Figure 4.16 addresses this challenge by using on-screen visual cues to attract the user's attention towards objects or locations that are not in the viewers field of view.

FIGURE 4.16: Visualisation technique to visualise points of interest in the environment using a dynamic and conforming rectangular bar

The implemented technique shown in Figure 4.16 uses a saturated rectangular shape that is located on the top/bottom/left/right extremities of the screen depending on where the point of interest is located. As the user turns towards the rectangular shape, the shape scales towards a square indicating that the point of interest is almost in the field of view. A square shape superimposed upon the point of interest indicates that the point of interest is in the field of view. The arrows indicated on the rectangle emphasise the direction of the point of interest.

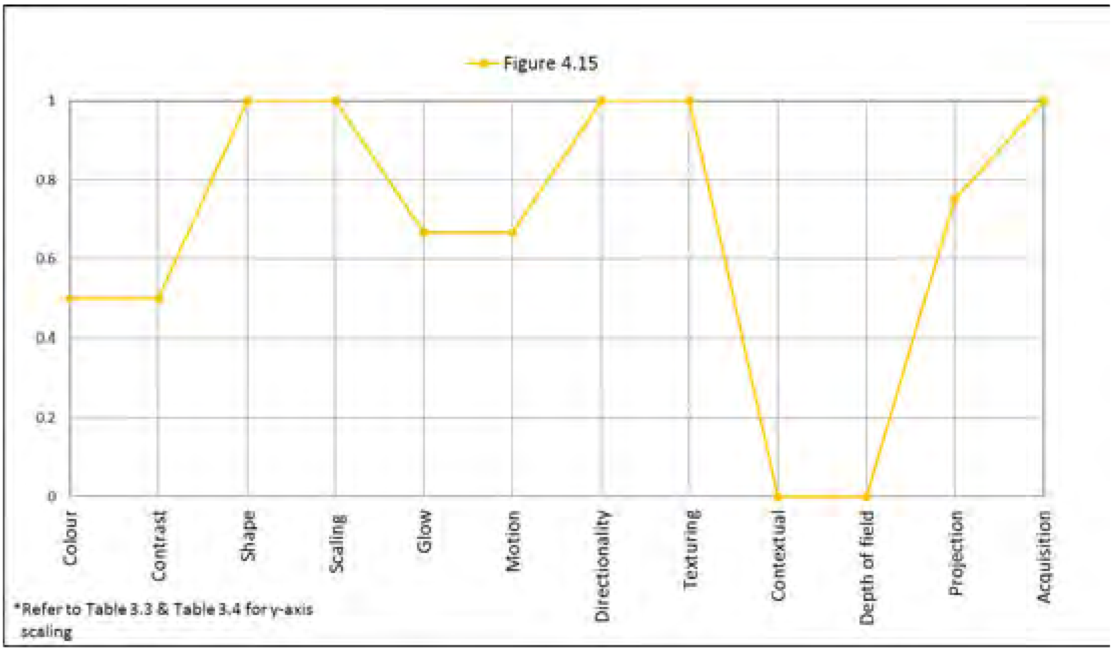

FIGURE 4.17: The dynamic and conforming rectangle uses shape, scaling and arrows to provide very good directionality and acquisition of the environment

This technique builds on the previous Framy-AR application which is a outdoor AR application that uses similar methods to visualise points outside the visible space (Section 2.6.3). The use of the saturated rectangular/square shape uses the focal points principle from the Gestalt theory. This is further enhanced by using a drop shadow in the shape. Also, the arrows that are in the same direction use the common fate principle of the Gestalt theory to further enhance perception (Bradley, 2014).

4.2.7 Descriptive Symbols and Call-outs of Information

The visualisation technique used in Figure 4.18, Figure 4.19 and Figure 4.20 simplifies the environment through the use of symbology. In addition, textual elements pertaining to the symbols are used to provide additional, hidden information to the viewer.

FIGURE 4.18: Visualisation that displays store category type using symbols

FIGURE 4.19: Call-out information has no order resulting in a cluttered display

FIGURE 4.20: Call-out information is positioned orderly and in close proximity to each other making it easier to perceive

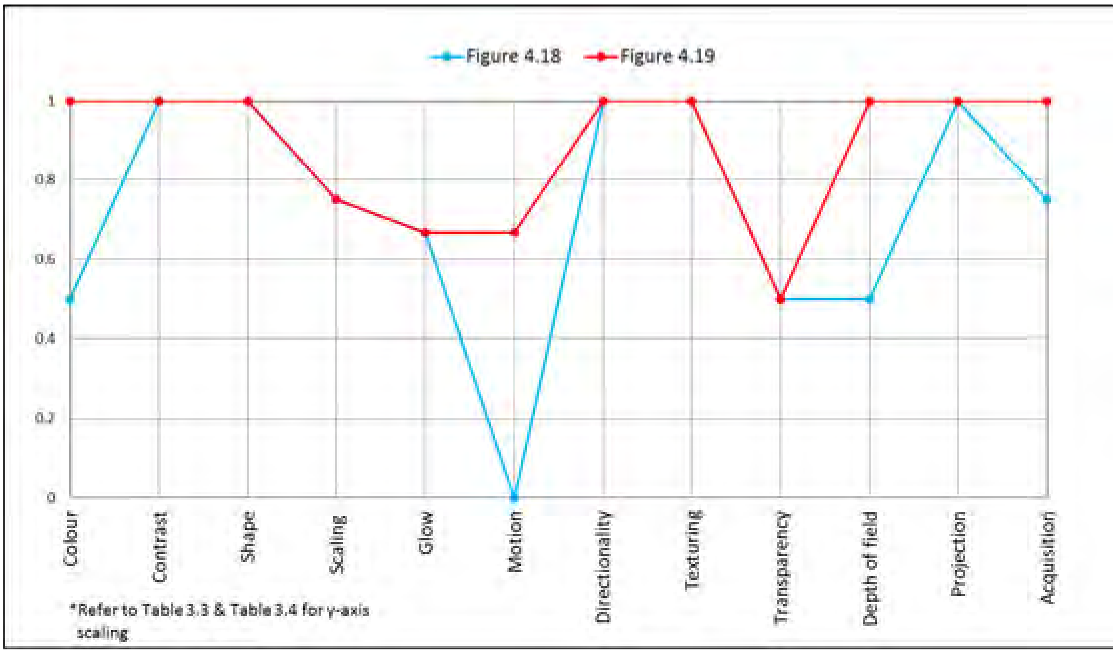

FIGURE 4.21: Figure 4.20 uses colour, motion and depth of field more efficiently than 4.19

The presented visualisation techniques shown in Figure 4.18, Figure 4.19 and Figure 4.20 constitutes of a few visual elements. The symbols represent the store category e.g. t-shirt icon represents clothing stores, the knife and fork symbol represents food stores. The legend located at the bottom of the screen explains the meaning of each symbol. The dial located on the top-right provides a top-down view of the environment and the surrounding symbols. The dial also indicates the line of sight of the user. The user is also able adjust the symbol buffer region allowing the user to control the number of icons he/she sees.

The symbology is consistent throughout all three representations. The symbols are represented as pictograms and they clearly denote the features of interest and do not require interpretation by the viewer (Campbell and Shin, 2012). The symbols are also three-dimensional and used in a 3D environment. The relative size between the symbols provides a sense of depth perception i.e. larger symbols are closer to the user in comparison to small symbols (Figure 4.18).

The placement of the textual elements has an effect on the rendered visualisation shown in Figure 4.19 and Figure 4.20. Figure 4.20 positions textboxes towards the ceiling making use of the visual dead space resulting in less visual clutter (Parmar, 2013). The textboxes also apply the symmetry/order and proximity principles from the Gestalt theory to convey a sense of consistency, stability and structure in the visualisation (Few, 2014). Also, textual elements are only displayed for symbols in close proximity thus providing another cue for depth perception. Lastly, the legend displayed in Figure 4.20 greys out irrelevant symbols that are not featured in the field of view. This allows the user to only perceive relevant information at that point in time.

4.2.8 Hidden Information

The visualisation technique in Figure 4.22, Figure 4.23 Figure 4.25 and Figure 4.26 use degrees of transparency as a contextual visualisation and allows for the viewer to "see-through" the occluding objects. Occlusion impedes the use of landmarks in indoor environments. This results in the use of transparency to limit the effect of occluding objects/ walls in the environment.

FIGURE 4.22: Lower range use of transparency and colour used to facilitate normal navigation by highlighting the top three search locations

FIGURE 4.23: Higher range of transparency and colour used to facilitate normal navigation by highlighting the top three search locations

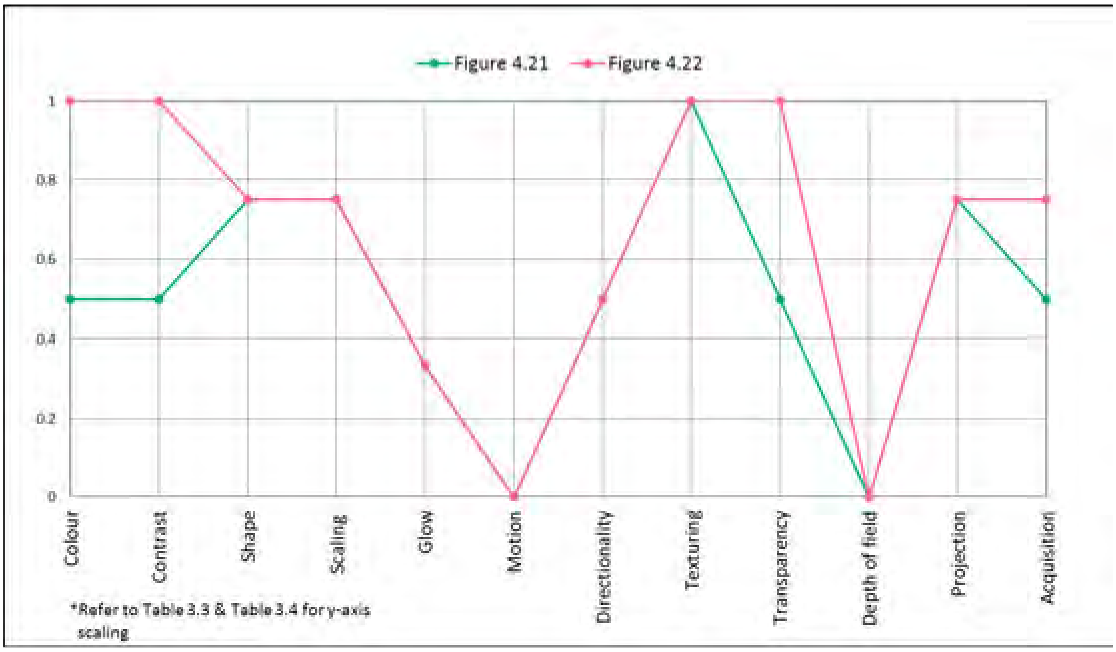

FIGURE 4.24: Greater transparency and effective use of colour results in a better visualisation experience as seen in Figure 4.23

The use of transparency improves the visibility of features in the environment. This is relevant in indoor environments due to the limited field of view because of occluding surfaces. Transparency is a type of monocular depth cue that can be used to distinguish between different depths (Furmanski et al., 2002). Transparency changes perceptual elements such as colour, contrast and depth perception.

Figure 4.23 uses saturated colours to compliment the transparency approach. It applies the similarity principle from Gestalt theory whereby the textual element, the symbol and the location wall colour share the same colour property inferring that they are related. Figure 4.22 and Figure 4.23 use a cylindrical projection from the floor above to the ground floor in order to facilitate depth perception of locations on another floor.

The use of transparency is also adaptable to multiple situations besides for navigation. Figure 4.25 and Figure 4.26 use transparency to search for a car in the parking or looking for a child in a store respectively.

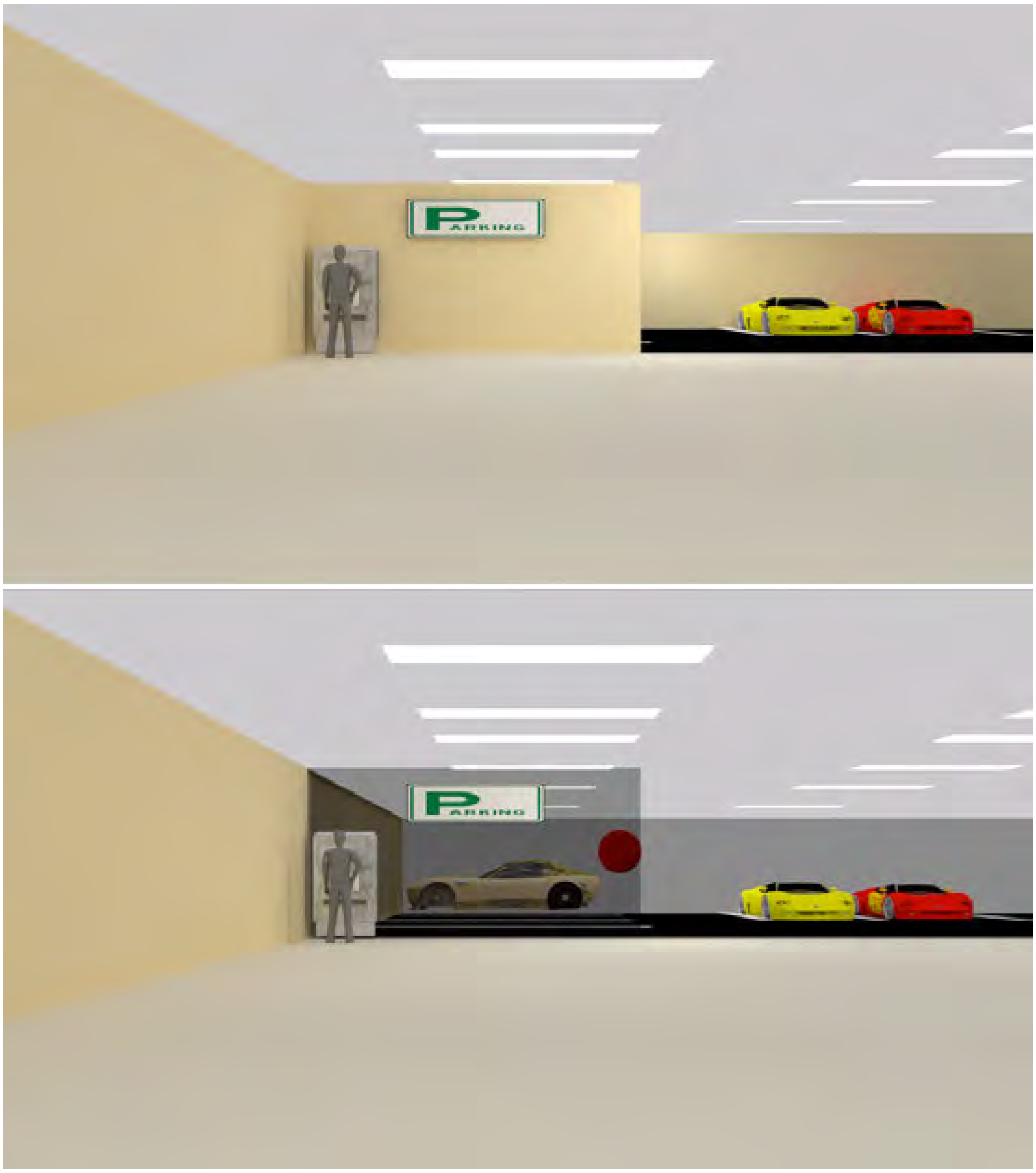

FIGURE 4.25: Transparency used to find a car in the parking by making the wall slightly transparent allowing the user to see through

FIGURE 4.26: Transparency used to make a certain store transparent so that the user can see through allowing him/her to locate their child inside

4.2.9 Environmental Blur

Figure 4.27 is a contextual visualisation that blurs the environment to enhance and place emphasis on certain objects. With reference to the Figure 4.27, the single navigational arrow is the object that emphasis has been placed upon. However, the applied technique could be used to emphasise various other objects in the environment as well.

FIGURE 4.27: Blurring of environment to emphasis certain objects i.e. in this case, the single, dynamic arrow is the object of interest

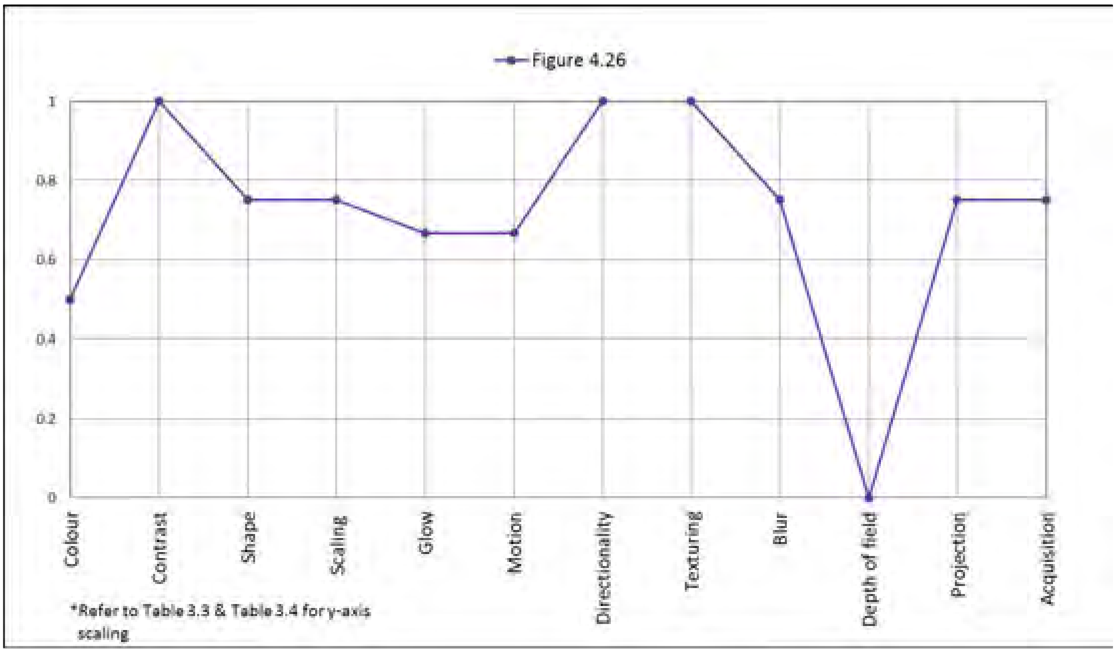

FIGURE 4.28: Environmental blur results in high contrast between the arrow and the blurred environment

The blur technique works similarly to the previously presented grayscale rendering (Figure 4.9). Blurring allows for the de-emphasis of parts of the scene in order to place focus on a particular object. In this case it is the environment that is de-emphasised and focus is placed on the navigational arrow (Held et al., 2010). It also applies the figure/ground principle from the Gestalt theory to place focus on the navigational arrow (Bradley, 2014).

4.2.10 Focus

The visualisation technique in Figure 4.29 is an extension to the previous blurring technique (Figure 4.27). This technique uses a gradual blur that is based on the depth of field. Objects that are closer to the viewer are rendered in higher definition than objects that are further away. The further away the object is, the greater the blurring. Figure 4.29 uses a 3D humanoid to demonstrate this.

FIGURE 4.29: Focus technique uses depth of field to render objects at different clarity based on their distance from the viewer

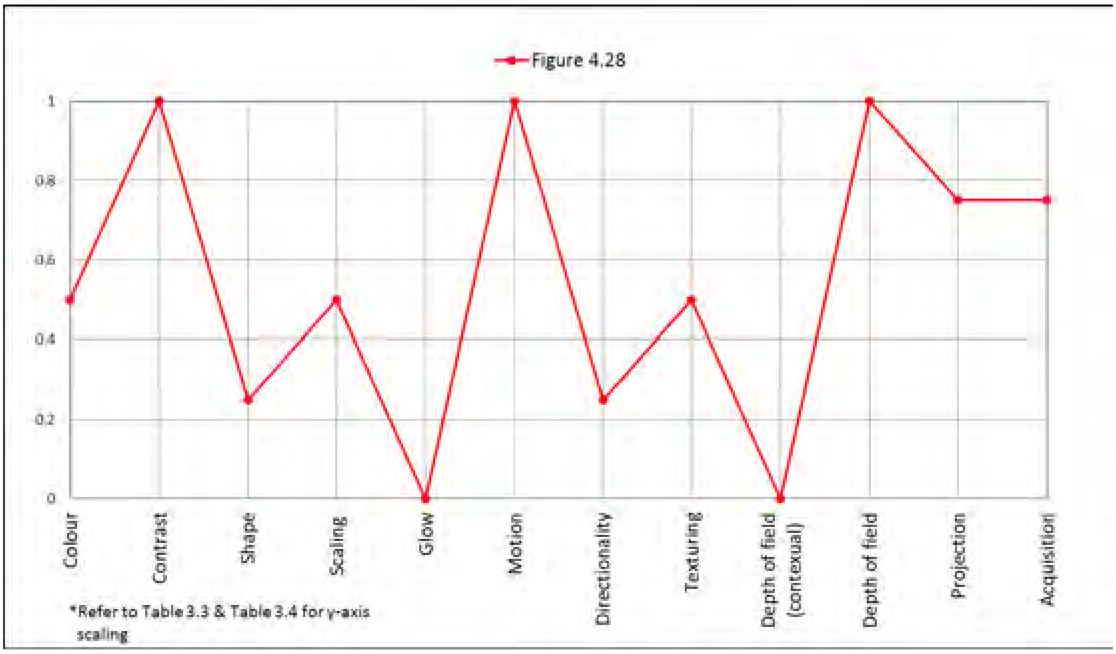

FIGURE 4.30: Focus technique rendering the closer object in full definition. Definition decreases as distance from the user increases. Provides a good sense of contrast and allows for the user to easily distinguish between different depths in the environment

Unlike the previous blurring technique that used strong blurring (Figure 4.27), this technique uses blur softly, selectively and gradually to convey other forms of visual communication such as depth perception (Held et al., 2010). Like the blur technique, it also applies the figure/ground principle in the Gestalt theory to distinguish between the figure (3D humanoid) and ground (environment) (Bradley, 2014).

The Focus technique can be used in other applications and not only in navigation. It can be used to de-emphasise regions that are further away from the viewer resulting in the limitation of unnecessary information being presented to the viewer 4.27.

4.2.11 Binocular Vision

The visualisation technique in Figure 4.31 is a visualisation tool that allows the user to zoom onto objects that he/she is interested in. It works on the same basis as a real-life binoculars. Figure 4.31 shows the user zooming onto a toilet sign. It allows for knowledge construction without having the viewer to physically traverse towards the object of interest.

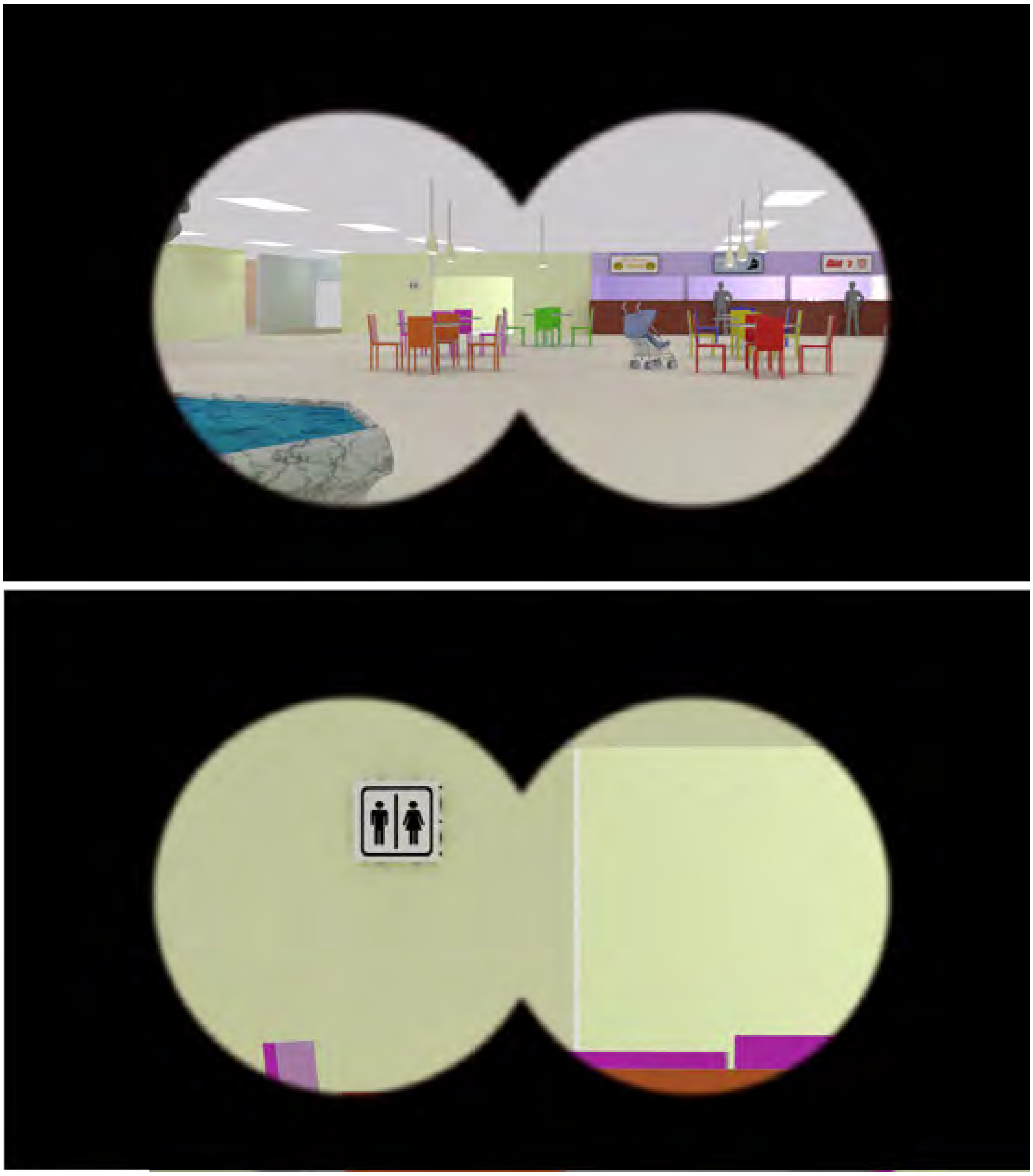

FIGURE 4.31: Binocular vision allows for zooming onto objects in the environment

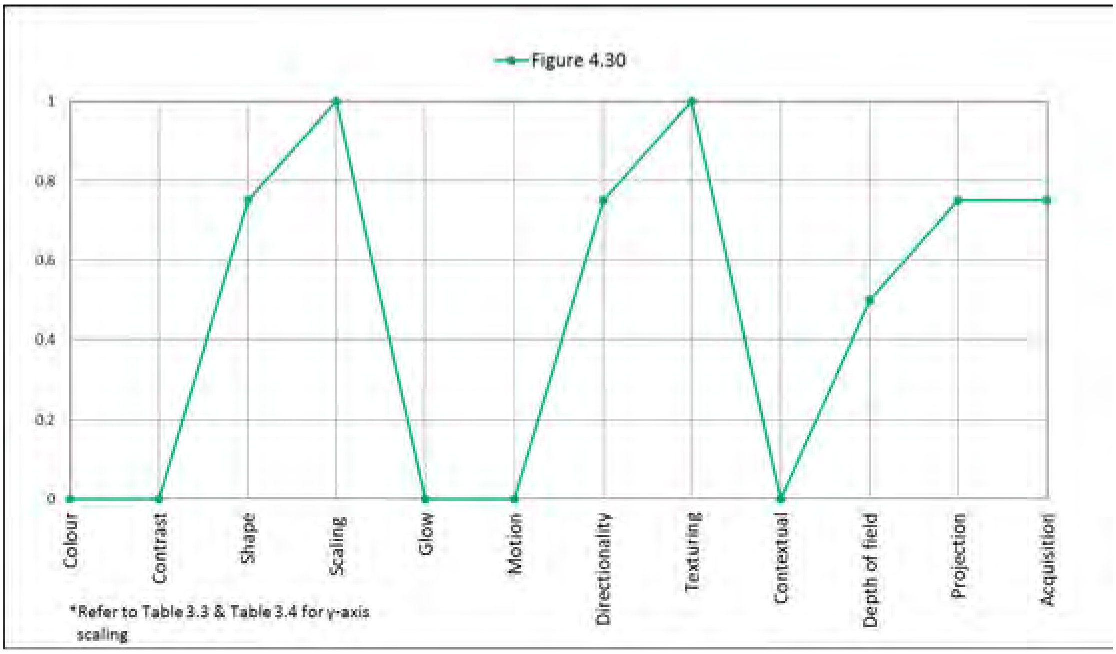

FIGURE 4.32: The Binocular Vision technique is a useful tool that provides the ability to provide good acquisition of details in an environment

This technique superimposes a cut-out of a binoculars texture onto the screen to block out unnecessary information and place focus on a region/object of interest. Also, the cut-out texture adds a sense of realism and increases the association to a real binoculars. Lastly, this technique also provides interactivity which allows the user to control their display (Nossum, 2013a).

4.2.12 User-oriented Signage

The visualisation technique in Figure 4.34 addresses the limited field of view problem in indoor environments by orientating store signage towards the user based on the location of the user.

FIGURE 4.33: User-orientated signage allows store signage to orientate towards the user

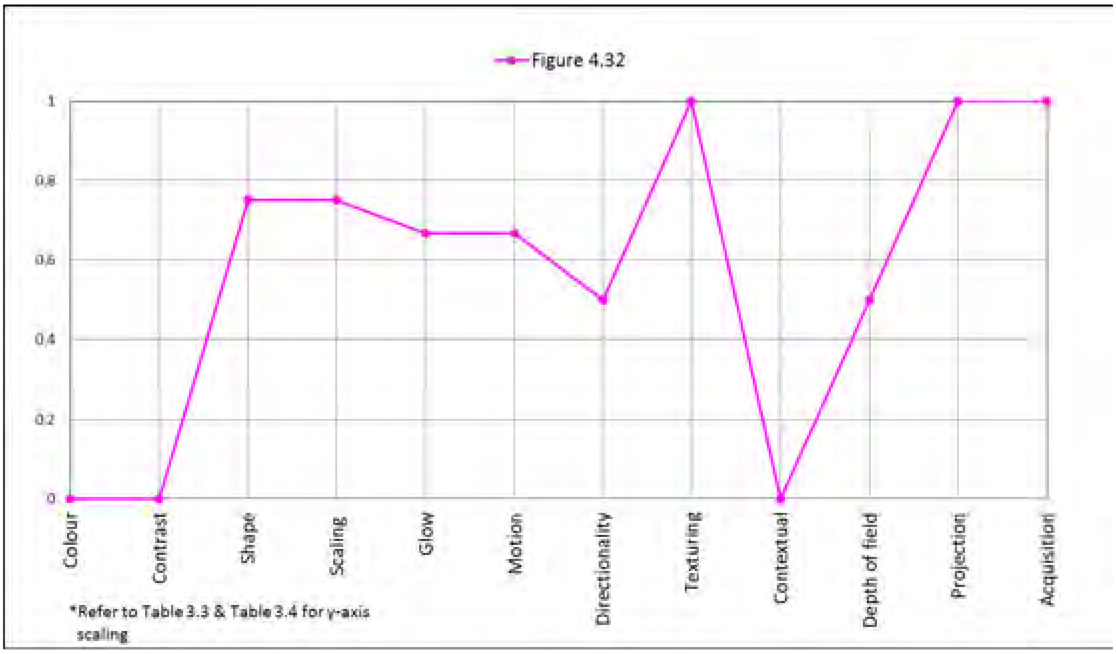

FIGURE 4.34: User-orientated signage technique uses good sense of shape, scaling and directionality to provide good depth perception resulting in very good excellent acquisition of the environment

As stated previously, this technique is dependent on the location of the user in the environment. For example, if a user is situated perpendicularly to a row of stores, the user is unable to see what stores they are due to the angle at which the user is at. In order to address this, the store signage orientate towards the user. As the user moves towards the orientated signs and the user can see the real store sign, it orientates back into its original position.

The orientated store signage is situated towards the ceiling. Again, this uses the visual dead space effectively alleviating visual clutter (Parmar, 2013). The signage applies symmetry and order from the Gestalt theory to provide balance and order in the visualisation (Bradley, 2014). It also applies scale from the design theory whereby there is a consistent scale between all signage resulting in all of them to be perceptually as important (Stribley, 2016).

4.2.13 Directional Reduction

The visualisation technique in Figure 4.35, Figure 4.36 and Figure 4.38 addresses occlusion by allowing the user to "slice" through occluding surfaces in order to reveal what is behind these surfaces. The technique can be applied vertically or horizontally. Essentially, this technique reduces the heights or widths of stores so that the user can perceive the surroundings behind these stores.

FIGURE 4.35: Technique applied in a vertical direction allowing for the user to slice through occluding surfaces revealing what is behind these surfaces

FIGURE 4.36: Technique applied in a horizontal direction allowing for the user to slice through occluding surfaces revealing what is behind these surfaces

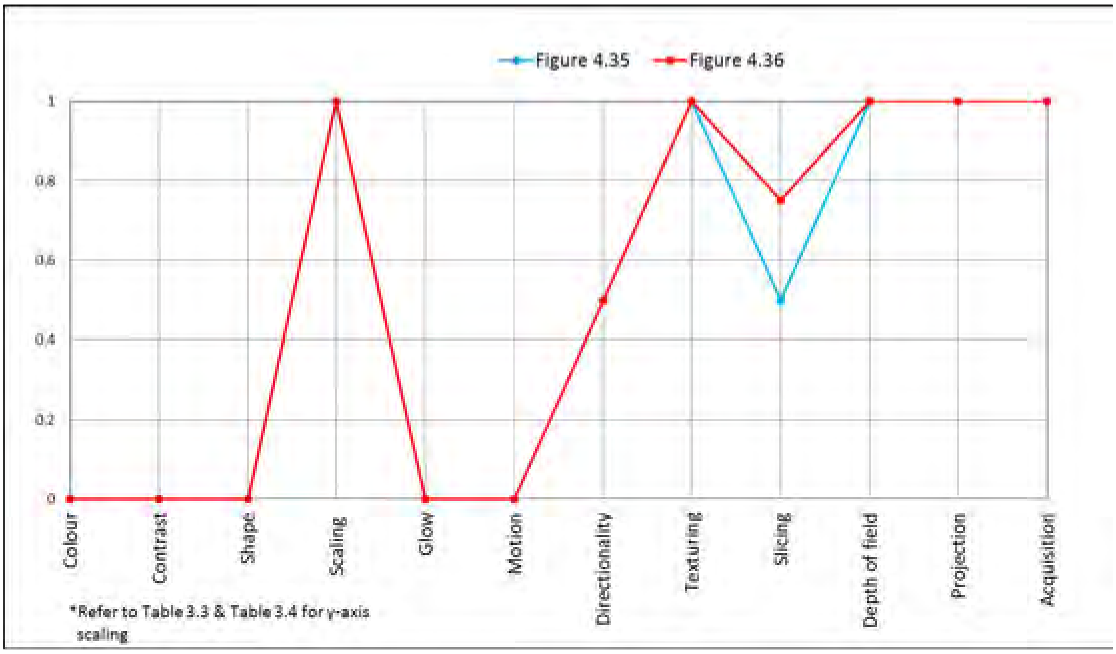

FIGURE 4.37: Parallel chart shows the percentage of slicing is greater in Figure 4.38

This technique provides interactivity so that the user can control their display (Nossum, 2013a). It allows the user to gain a better understanding of their environment by limiting the effect of occluding objects on the user's field of view. Figure 4.38 uses a larger percentage of slicing to reveal more information related to the environment.

FIGURE 4.38: A larger percentage of slicing applied in a horizontal direction

4.2.14 Section-cut

The visualisation technique in Figure 4.39 clips through the environment so that only regions that are close to the user will be rendered. As the user moves towards the clipping plane, the rest of the environment will be revealed. Figure 4.39 shows this process.

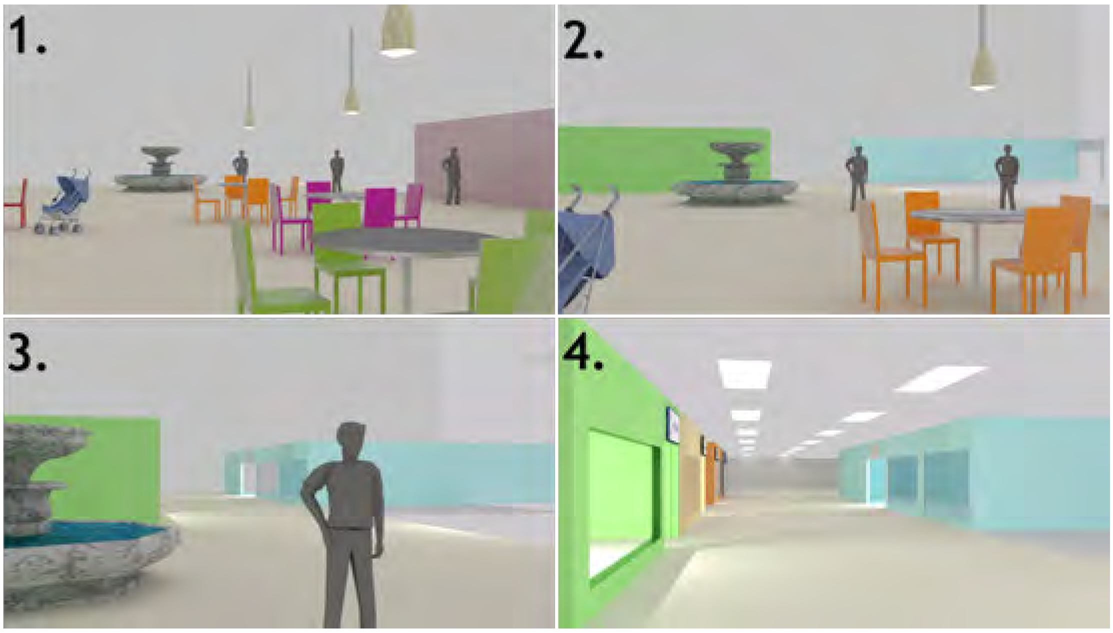

Figure 4.39: Section-cut allows for only close surroundings of the environment to be rendered and as the user travels towards the unknown, more of the environment will be revealed

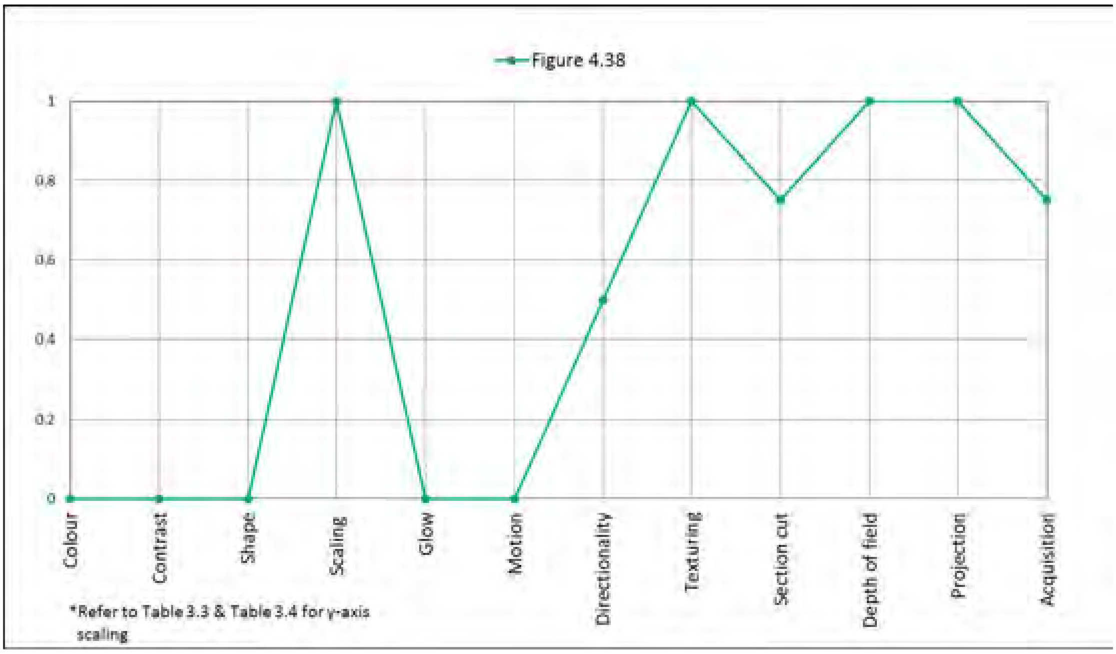

FIGURE 4.40: Section-cut visualisation technique uses effective scaling, depth of field and projection to provide good acquisition

This technique is similar to the previous Focus visualisation technique (Figure 4.29). It is only effective when the viewer is interested in close surroundings and it prevents unnecessary information being presented to the viewer. This technique also applies a shading gradient that provides a good sense of depth perception (i.e. grey colour distinguishing section-cut) (Furmanski et al., 2002).

4.2.15 Hot-spots

The visualisation technique in Figure 4.41 and Figure 4.42 is a useful tool to the user. It uses the previous Top-down, Superimposed Overview map (Figure 4.11). However, in this technique, hot-spots are used to indicate tables that are free as well as fast food stores that have a little or no queue. Although the use of hot-spots are demonstrated in a particular context, it can be used in a diverse array of applications.

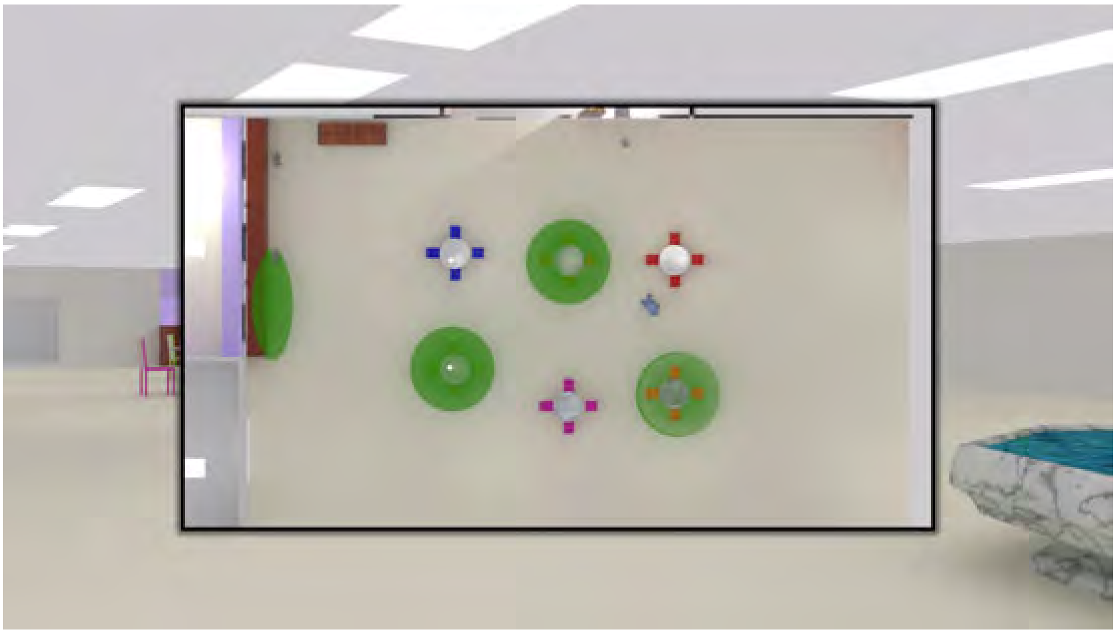

FIGURE 4.41: Hotspot technique being represented by shapes having less glow and no vignette effect

FIGURE 4.42: Hotspots technique with vignette effect to enhance the superimposed overview map as well as shapes with strong glow

Figure 4.41 and Figure 4.42 both use the Top-down, Superimposed Overview Map (refer to Section 4.2.4 for details relevant to this technique). However, Figure 4.42 uses a vignette effect. The vignette effect brings attention to the centre of the display and it isolates the superimposed overview map for better focus (Vig, 2016).

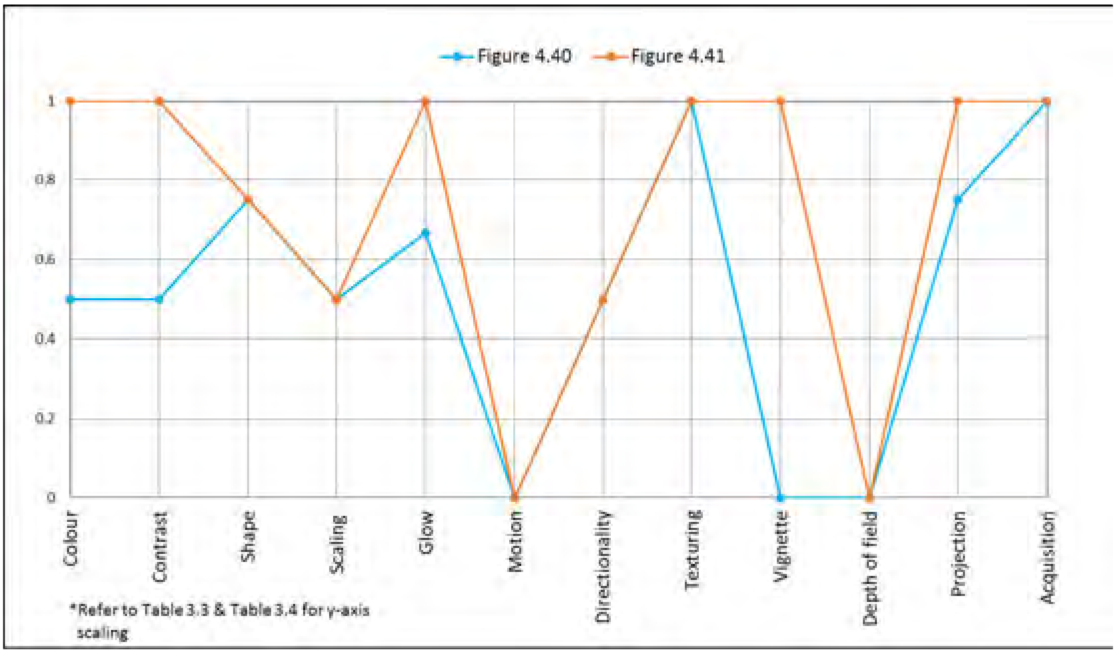

Figure 4.43: The Hot-spot technique using the vignette and strong glow effect enhances the superimposed overview map and make the areas of interest more clear

The actual hot-spot representation uses the similarity principle of th Gestalt theory due to the shapes being of a similar shape and colour thus inferring that they are related (Bradley, 2014). Figure 4.42 uses additional lighting in the form of spotlights to further enhance appearances of the hot-spots.

4.2.16 Level of Detail

The visualisation technique in Figure 4.44 represents the level of detail that the environment is rendered to the user. The level of detail is dependent on a distance factor whereby the closer the user is to the area of interest, the greater the detail.

FIGURE 4.44: Series of images that show how the level of detail in the scene increases as the user moves closer to the store

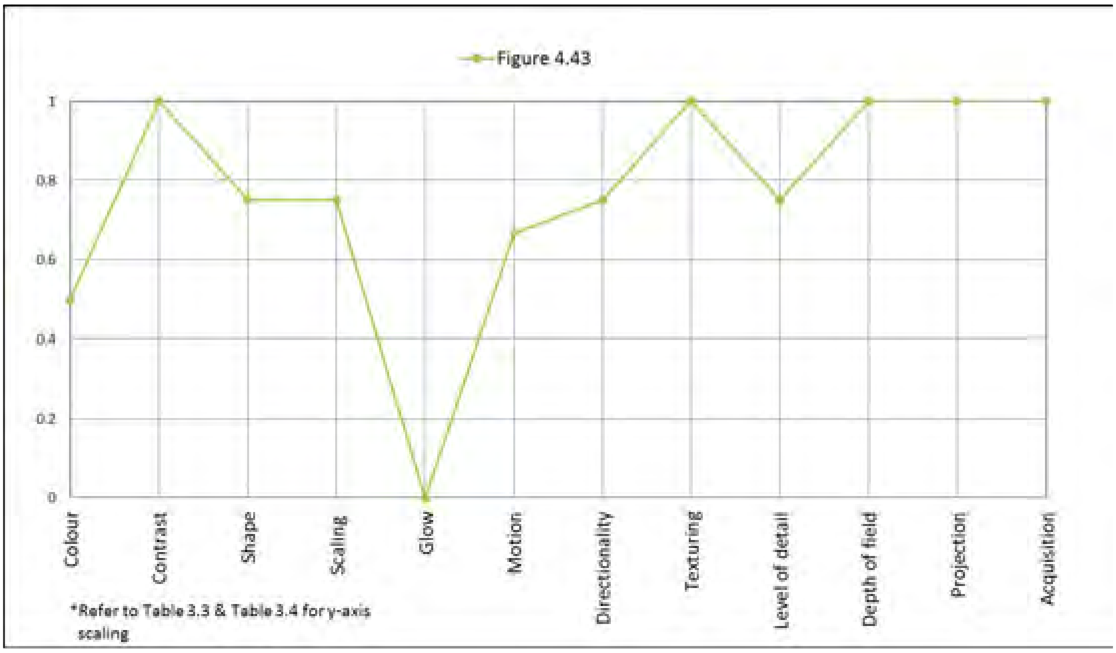

FIGURE 4.45: Level of Detail visualisation technique facilitates depth perception and uses good projection resulting in very good acquisition of the environment

The applied technique provides a good sense of depth perception due to regions further away from the viewer being rendered in less detail in comparison to regions that are closer. This technique is similar to the previous Section-cut (Figure

4.2.17 Interface Colour Display

The visualisation technique shown in Figure 4.46 and Figure 4.47 is applicable during crisis or hazardous situations. The technique differentiates between safe and unsafe zones during these situations through the use of colour and text.

FIGURE 4.46: Interface colour display using blue and red respectively to covey safety status. Both are strong, saturated colours that evokes correct emotion/reaction

FIGURE 4.47: The displayed technique shows the importance of colour when conveying information. The chosen colours depict a poor representation of the situation

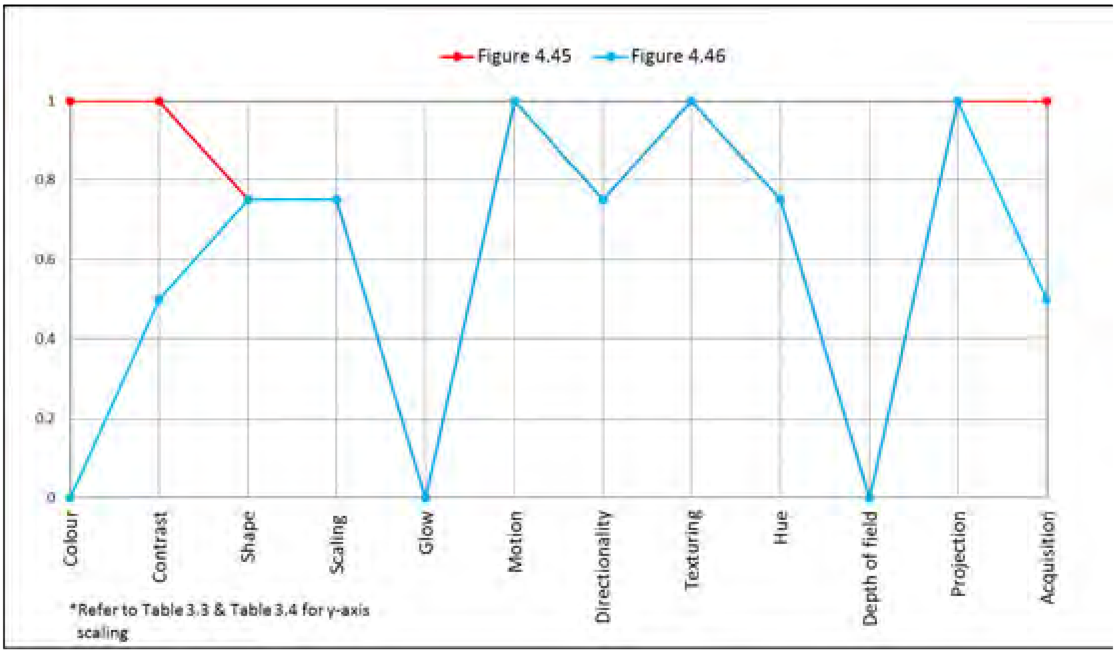

FIGURE 4.48: Figure 4.46 uses strong, saturated colours resulting in better acquisition

The implemented technique uses the entire screen real-estate to convey important information to the viewer. This limits the effects of change and inattentional blindness due to the entire screen real-estate being used (Nossum, 2013a).

It also shows the importance of colour and how it can be influential and evoke different messages. Figure 4.46 uses blue and red to convey different levels of information. Light-blue is a cool and calm colour that represents a state of safeness and stability. Red is a warm, emotive and vibrant colour that represents warning or danger. Thus, these two colours are applicable for the current situation that needs to account safe and unsafe zones during the crisis/hazardous situation. However, 4.47 uses poor colours that do not convey as strong information as the previously mentioned colours. The associated meaning to these colours are not as strong or clear as the previous (Agoston, 2013).

In terms of the textual elements that state the safety status, it is positioned below the horizon so that it must consistently be in the viewers field of view. Also, the colour of the text matches the interface colour display in order to further enhance visual communication. Lastly, the weighting used is thick in order for it to stand out and for its importance to be highlighted (Cousins, 2014).

4.3 Application

The previous section showed the different visualisation renderings using different visualisation techniques applied in an indoor environment. This section aims to show the applicability of the previously discussed visualisation techniques in different environmental settings/contexts. These contexts consist of:

- Commercial
- Navigation
- Exploration
- Hazard/ Crisis
- Combination

The best suited visualisation technique is determined by the contexts stated above. Each context results in different levels of information needing to be conveyed to the user.

Refer to Appendix 6 for the storyboard that uses scenarios based on the contexts above. Each context is addressed by the most suitable visualisation technique.

4.3.1 Commercial Setting

The commercial setting refers to traversing through the indoor environment with the purpose of gaining commercial information relevant to the environment using various visualisation techniques. An example of this would be stores wanting to convey sale or discounted items to the user.

The commercial setting provides the ideal platform for the stores within the environment to connect with the user and be able to convey information related to the stores without having the user to physically enter the store. It allows for a platform on which stores can market and advertise themselves to their clients in a digital manner.

The best suited visualisation techniques that aid this process are:

- Points of interest
- Descriptive symbols and call-outs

The above two visualisation techniques allow for effective visualisation from a commercial perspective. They allow for the stores to relate information to the user easily and efficiently. For example, stores can provide sales information using call-outs or attract a users attention to a specific window of a store using the points of interest technique.

4.3.2 Navigational Setting

Navigation is defined as the process of ascertaining one's relative position accurately and planning and following a route in an environment (Shen et al., 2011). The navigational setting allows for the user to be guided in the environment based on user's input using various visualisation techniques.

The most relevant visualisation techniques for guided navigation in an indoor environment are:

- Lines for path-renderings (along ground and towards ceiling)
- Line with thickness and transparency
- Dynamic, adjustable arrows
- Hidden Information

The visualisation techniques above facilitate the process of navigation and allow for the user to be guided in the environment. The techniques that do not follow the orthodox, conventional approach towards path-rendering have resulted in visualisation techniques that utilise multiple visual variables effectively.

4.3.3 Exploration Setting

The exploration setting differs from the navigational setting in that it allows for the user to be able to travel through an familiar/ unfamiliar environment in order to discover and develop spatial knowledge relevant to that environment. The user is not guided through the environment as the user does not have a defined end point.

The following visualisation techniques facilitate exploration within the indoor environment and promote the development of spatial knowledge:

- Binocular Vision
- User-orientated signage

- Directional Reduction
- Hidden Information
- Level of Detail
- Descriptive symbols and call-outs

The visualisation techniques above allow for the user to explore the environment and develop a better understanding of their surroundings.

4.3.4 Crisis Setting

The crisis setting results from the occurrence of a crisis/ hazard in the indoor environment. The simulated crisis in the rendering system was a fire located in east wing of the ground level.

The crisis setting allowed for the investigation of context-awareness concepts to be determined. The concepts were directed from a visualisation perspective whereby different visualisation techniques can aid a user during a crisis (Fahy and Clarke, 2004).

The best suited visualisation techniques that can be used during a crisis are:

- Line for path rendering with yardstick distances
- Line rendered towards the ceiling
- Dynamic, adjustable arrows
- Interface colour display

The visualisation techniques above are most effective when the user is confronted by a crisis. Strict, guided navigation to particular objects or relevant destinations needs to take place. These include fire extinguishers, first aid kits, emergency exits etc. The lines used for path rendering are ideal for strict navigation and limit the user from varying off-path. The environmental blur technique provides a solution to allow the user to focus on certain objects in the environment. Lastly, the interface colour display is an effective visualisation because it allows for the safety status of the user to be easily determined.

4.3.5 Combination Setting

The combination setting refers to the combination of the different environmental settings stated above. It represents the transition from one environmental setting to another. For example, the user might be navigated through the environment using a path-renderer and then decides to rather explore the environment due to the navigation destinations not catering to his/her needs. The combination setting needs to facilitate this process by providing a smooth transition between environmental states.

There are no defined visualisation techniques for the combination setting. This setting involves the interface of the visualisation system. The user must easily be able to switch between different environmental settings smoothly and it must not lead to disorientation of the user or a loss in information.

4.4 Quality of Rendering

The different visualisation techniques shown above are depicted through a virtual environment. However, if the environment was to be rendered as an augmented environment, the elements superimposed upon the scene will use non-photorealistic/ hyper-realistic texturing.

Non-photorealism is the counterpart of photorealism as it uses artistic styles such as drawings and cartoons (De Boer et al., 2009). The utilised map elements such as line renderers, arrows, icons etc. have a cartoonish/hype-realistic aesthetic appearance to them. These elements aim to synthesise in unison with the environment so that they feel "part" of the environment. For example, in Figure 4.14, the line reflection of the line renderer is seen in the window of the store. The synergy between the environment (augmented scene) and the non-photorealistic elements is important to result in a smooth visualisation experience for the user.

The cartoonish design of the elements contribute towards the element of "fun" that was discussed earlier in the human-computer interaction section. The elements style and design aim to evoke positive emotion by using strong, bold colours and by appearing bright and big. The elements also create shadows which further enhance the realistic appeal of the visualisation without limiting the aesthetic appeal of the elements.

4.5 User Interface and Screen Real-Estate

This section looks at two important components namely the user interface and the screen real-estate. Both these components are important in the sample user interface design for indoor visualisation system and represent the medium through which the user interacts with the visualisation renderings.

The visualisation system needs to have a simplistic UI that maximises the screen estate in order not to detract from the visualisation experience. It also needs to be dynamic to allow for deployment on varying screen estates. It needs to be deployable on three platforms namely:

- Cellphones
- Tablets
- Desktops

The user interface of the system plays the primary role in evoking positive emotions when the user interacts with the system. It is essential to emphasise feature content of the interface that will contribute towards a positive experience. The user interface also needs to accommodate for varying user capabilities i.e. be simplistic enough for new users and non-tedious for advanced users.

With the above in mind, the sample user interface design is based on the following:

- Maximising the screen estate by applying the idea that ”less is more”
- Simplistic panel positioned at the top of the screen containing relevant drop-down lists and icons
- GUI aesthetics and controls have a transparent look in order to minimise from the visualisation experience of the user
- Using the entire horizontal screen estate as using vertical screen estate would be more distracting to the user
- The controls provide the user with freedom and choice allowing for user preferential visualisations

4.5.1 Sample User Interface Design

Figure 4.49, Figure 4.50 and Figure 4.51 below provide a sample user interface design for the visualisation rendering system.

The components of the sample user interface are:
Firstly, the scene represents the virtual or real representation of the environment through the user's device. In the case of the demonstrated system (as seen in Figure 4.49) it is rendered as a virtual representation.
Secondly, the GUI controls represent the controls that the user interacts with to bring about a certain change in the display. These controls are located at the top of the screen. They comprise of drop-down lists, icons, a checkbox and sliders.
Thirdly, the rendered scene represents the superimposition of any elements on-top of the original scene rendered through the use of the GUI controls. Figure 4.50 shows rendered paths based on user input.

The detailed workings of the visualisation system using the sample interface is based on ordered user input. The user first needs to determine the preferred environmental setting. Based on this input, the visualisation techniques will be updated accordingly due to certain visualisation techniques being better suited for different environmental settings.

Figure 4.49 shows the navigational environmental setting being selected. The user can then select his/her preferred visualisation technique. If the navigational setting is selected, the user can then also select the item of interest that the user will be navigated to.

There is also a toggle button adjacent to the visualisation technique drop-down list that allows for an overview map to be superimposed onto the screen providing the user with a top-down perspective. Lastly, the two icons depicted by the eye and spanner represent the modification of the visual variables and contextual renderings respectively. When these icons are selected, modal windows are displayed.

Figure 4.50 shows the modal window of the visual modifications. These modifications are based on the ability for the user to manipulate the visual variables to his/ her preference. The modal window as seen in Figure 4.50 shows the grouping of the visual variables i.e. saturation and contrast, shape, scale and directionality etc. These groupings use preset values. These preset values are based on the environmental setting selected. If the user wants to manipulate the visual variables further, he/she can select the drop-down list and select another preset value (Figure 4.50 shows the example for Saturations and Contrast). The preset values allow for the user to manipulate multiple visual variables simultaneously resulting in a less tedious approach in comparison to if the user manipulated each visual variable individually. Also, in addition to this, there is also an intensity slider that represents the intensity of the manipulation of the visual variables e.g. a too high intensity for saturation and contrast could mask and neglect a too low shape, scale and directionality intensity.

Figure 4.51 shows that when the user selects the spanner icon, he/she can use contextual visualisations to further enhance the user's visualisation experience. The different contextual visualisations are listed together with a slider that allows the user to choose the preferred intensity of the contextual visualisation.

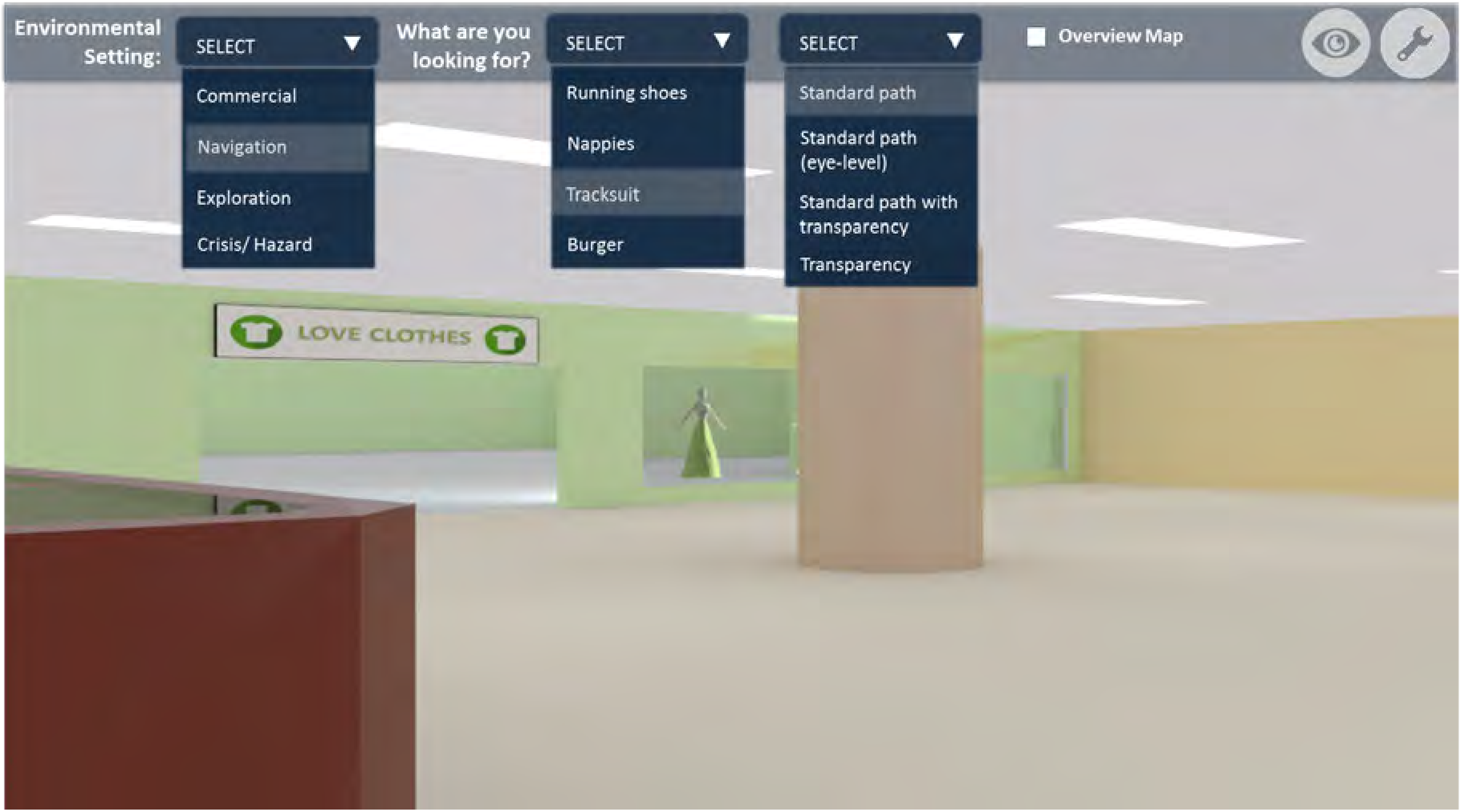

FIGURE 4.49: Interface design of visualisation system for navigation setting

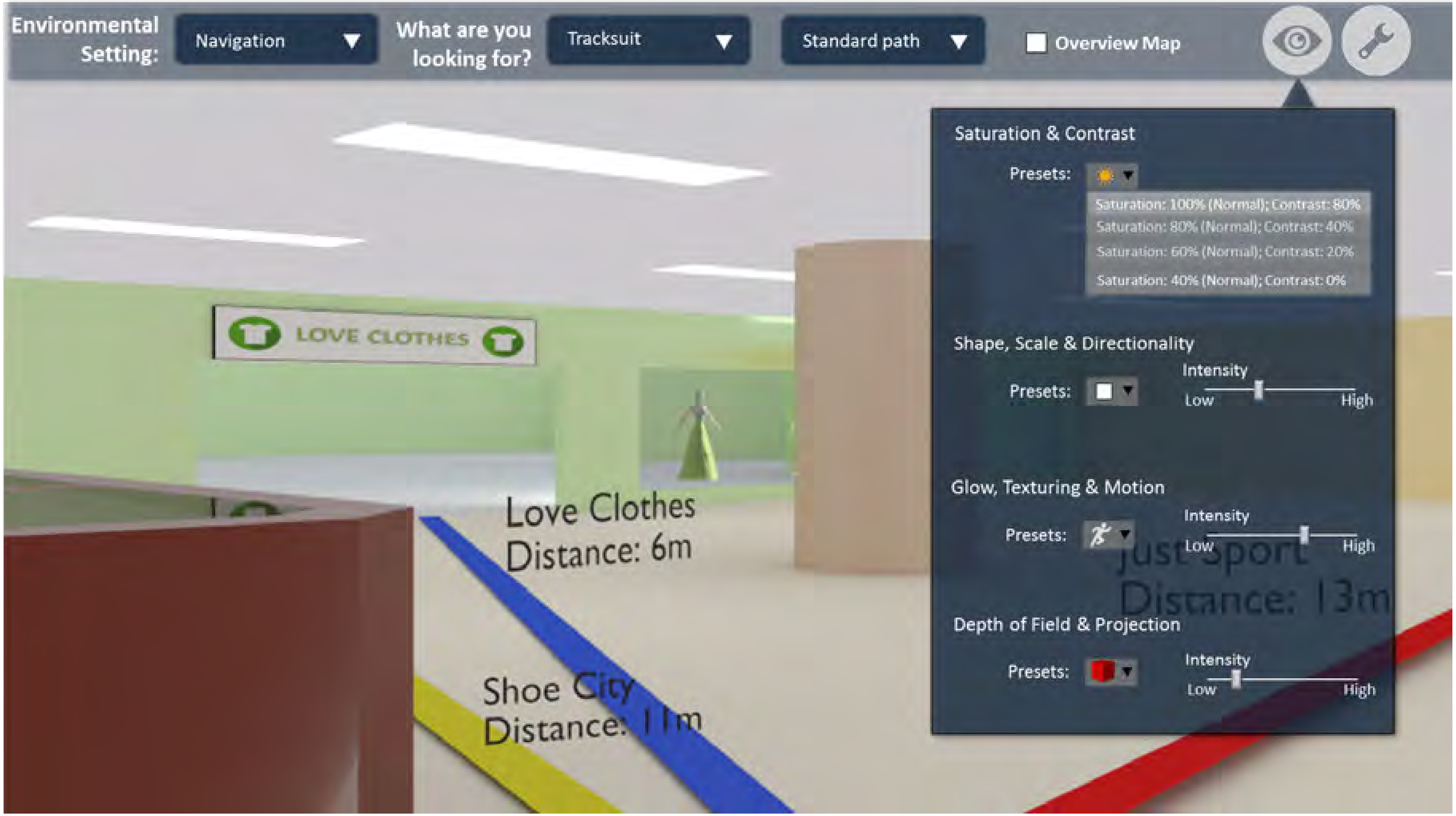

FIGURE 4.50: Modifying visual variables through the use of a drop-down lists and sliders

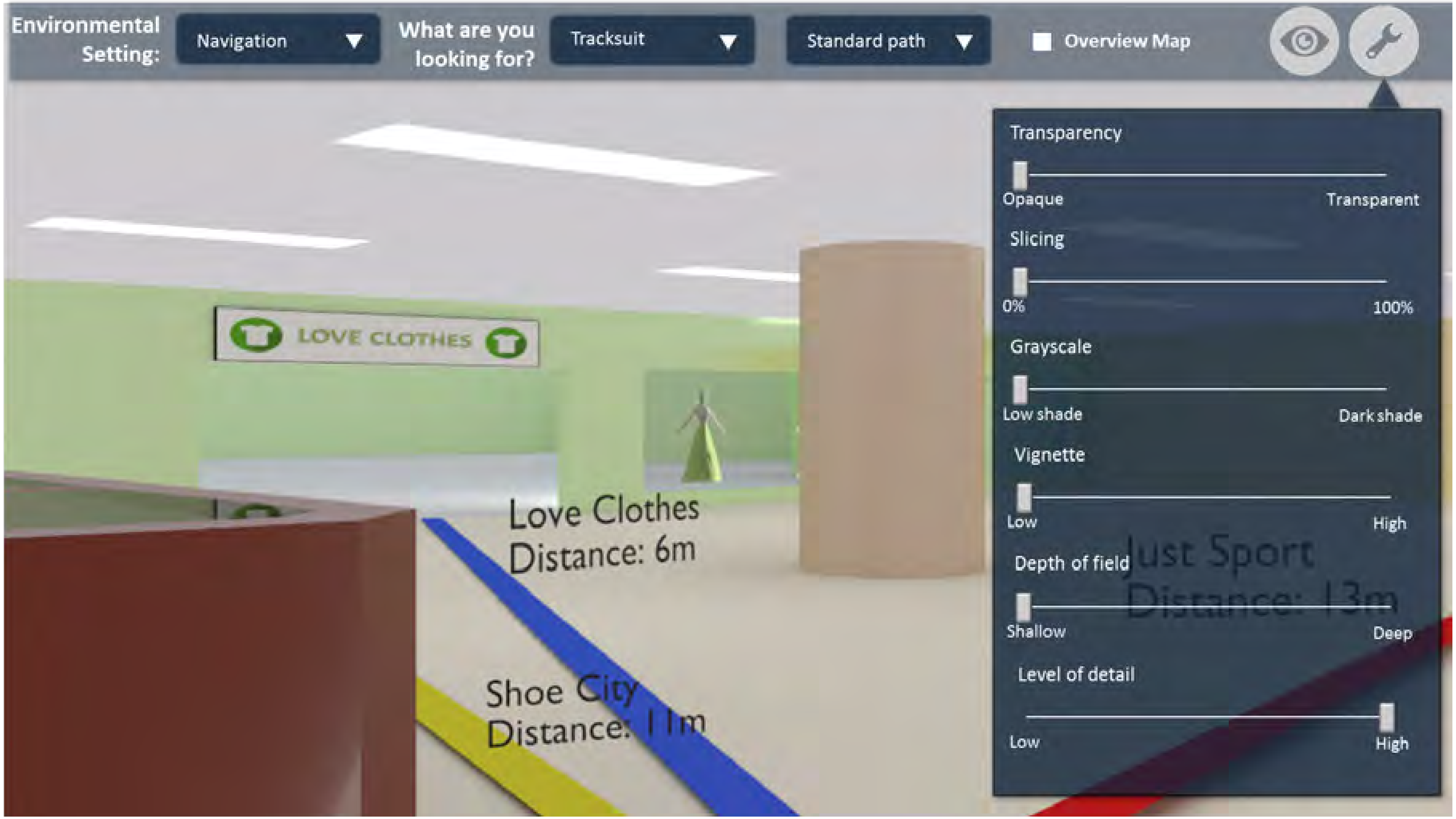

FIGURE 4.51: Modifying contextual renderings through the use of a slider

Chapter 5

Conclusion

5.1 General Discussion

Indoor visualisation has been at the forefront of discussion for the past thirty years. The complex and intricate nature of indoor environments have limited progress in this field.

This dissertation has aimed to provide an holistic approach for indoor visualisation and representation. This holistic approach consisted of the (1) Indoor Visualisation Theoretical framework and (2) Elements of Design framework.

The theoretical framework (Figure 1.1) comprised of several different disciplines such as cartography, geovisualisation, dynamic environments, human-perception theory etc. These different disciplines were merged and the best practices from each different discipline was extracted. The theoretical framework provided the fundamentals on which the Elements of Design framework could be based upon.

The Elements of Design framework (Table 3.1 and Table 3.2) represent a set of visual variables and their design properties. These variables were based on the previous theoretical framework.

The different visualisation techniques were based on the Elements of Design framework. The techniques utilised the visual variables in different ways in order to enhance the visualisation experience for user and ultimately improve the user's acquisition and cognition of the environment. The techniques were applied to different environmental settings in order for the applicability of different techniques for different contexts to be determined i.e. navigation, exploration, crisis, commercial settings.

Lastly, a sample user interface was proposed for the indoor visualisation rendering system. The user interface has a simple and clinical feel with the focus on efficiency resulting in positive experiences.

The following are the implications of this work:

1. The generated renderings have resulted in better quality visualisation elements for augmented scenes. The elements that were superimposed upon the virtual model had a hyper-realistic visual appeal to them. This appeal contributed towards an element "fun" that results in a pleasing visual experience for the viewer.

2. The different visual elements that were used for the different techniques were based on the Gestalt theory and other design theories. As stated previously, accounting for human-perception during design is important to effectively convey information to the user. For example, the use of colour, shape, contrast and orientation and size of textual elements all have an effect on what the viewer perceives.

3. The use of parallel charts for scaling the different techniques has provided a basis for benchmarking and comparing the different visualisations. Visually it is easy to understand how each technique uses the different visual elements.

4. It has been identified that human emotion and moods needs to be accounted for in user interface design as they have ability to influence user interface experiences. A poorly designed user interface can result in a prolonged negative association to an application or system.

5. The system has been designed for user personality whereby the system adapts (self-regulating) to different user needs and goals. This is accomplished through the user interface design.

5.2 Recommendations and Future Work

The following suggested recommendations and future work aim to extend and improve the quality of the research.

The recommendations and future work are:

1. The visualisation rendering system is represented as a virtual system. The ideal platform would be an augmented system. Thus, extending the visualisation system to be augmented upon the real would greatly enhance the realistic appeal and increase the scope of the system.

2. The results of the visualisation techniques are derived subjectively. The different visualisation techniques should be tested using multiple people and can then be scaled accordingly resulting in experimental evaluation. Also, eye-trackng is an important feature to account for. It will determine the focus areas of different users when using the visualisation system.

3. The platforms that were investigated for the deployment of the proposed visualisation system were mobile devices, tablets and desktops. However, this should be extended to allow for deployment on optical head-mounted displays e.g Google Glass, MicroVision, Lumus, Toshiba Glass.

4. Combine the indoor visualisation approach with the indoor localisation framework to provide a holistic approach that addresses the challenges facing indoor environments. Accurate indoor localisation in both VR-based and AR-based systems is important in providing sound indoor applications.

5. Investigate ways to extend the framework to account for the visually impaired i.e. using aural and haptic cues.

Chapter 6

Appendix: Storyboard

The Storyboard shown in this section presents a sequence of figures that depict a scenario based in the conceptual, two-storey mall environment. The figures represent the best suited visualisation technique for a particular event in the scenario.

The implementation of a storyboard demonstrates the elements of design in a practical method and shows how it can facilitate a user in an indoor environment when confronted with varying situations.

6.1 Scenario

Adam decides to go to the newly developed shopping mall in his area on a Saturday morning. He is unfamiliar with the environment. He is interested in getting a new pair of running shoes as he is training for the upcoming Two Oceans marathon.

6.1.1 Event 1

He parks on the first level parking relatively close to the entrance of the shopping mall. Upon entering the mall, he inquires about the top three stores known for selling running shoes. He then proceeds to these stores and has a look to see what they offer. Once satisfied what he has found, he then purchases the running shoe.

6.1.2 Event 2

Adam realises that he has some time to waste, so he decides to explore the mall for a bit without having anything in particular that he needs to find. He spends this time walking through the mall and entering stores that interested him.

6.1.3 Event 3

He then realises that his elder brothers birthday is coming up soon. After pondering about what he should get for him, he decides a PS4 game would be the most suitable gift. He goes to the nearest gaming store and purchases the game.

6.1.4 Event 4

All this walking around made Adam hungry. He proceeds towards the food court. He decides to get something quick, easy and that doesn't take too long. After he got his food he sat down at the a table and ate his food.

6.1.5 Event 5

Suddenly, an alarm sounds in the mall and Adam hears people shouting and running. He starts seeing smoke emerging from the computer store a couple of stores away from him. One of the fireman came up to him asking where a medikit and can be found. He aided the fireman and then proceeded towards the emergency exit.

6.1.6 Event 6

Once the crisis situation settled, Adam made his way back into the mall. He decided to treat himself to an ice-cream after all the drama but he did not feel like standing in a queue. Luckily, there was no queue and he got himself an ice-cream.

6.1.7 Event 7

Adam then proceeded towards the parking. However, he couldn't remember exactly where he parked. Once he found his car, he went home after a eventful day at the mall.

The following illustrations show the pertaining visualisation techniques that Adam could have used during his experience at the mall:

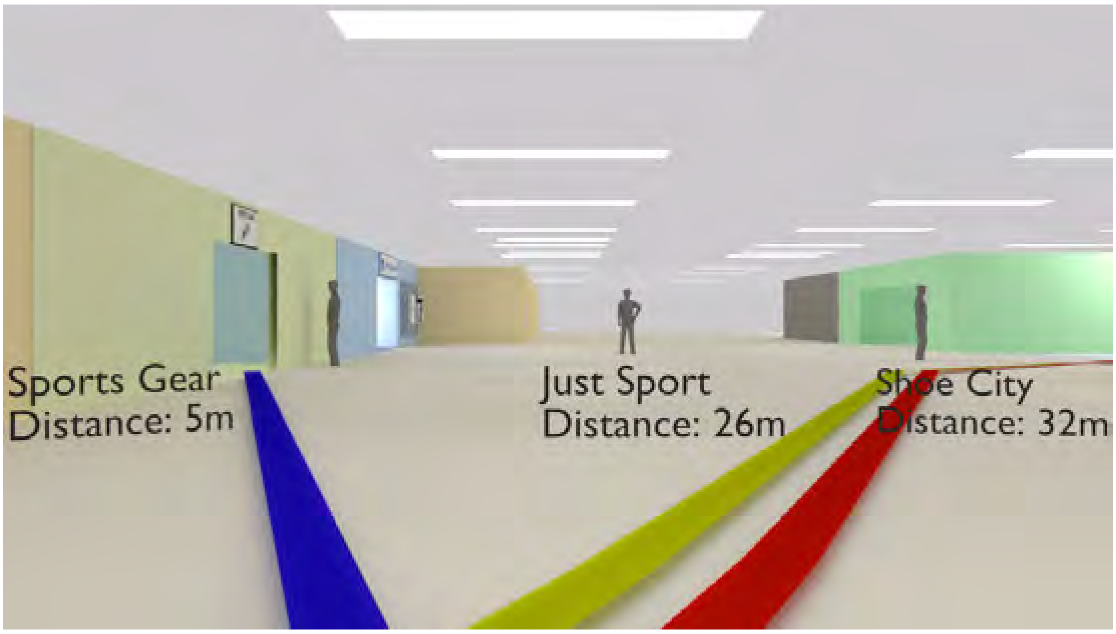

FIGURE 6.1: Standard path renderings used to display the top three stores known for having running shoes (Event 1)

FIGURE 6.2: Overview map used to provide an additional perspective to facilitate navigation. Allows for better distance perception (Event 1)

FIGURE 6.3: In order to facilitate the exploration of the surrounding indoor environment, the Icons and Call-out technique was used. The technique uses icons that shows the store category as well as pertaining commercial information (Event 2)

FIGURE 6.4: The directional arrow visualisation technique was used to facilitate navigation to a specific store (Event 3)

FIGURE 6.5: The direction arrow adjusts it size according to the distance from the location. In this case, the arrow is represented as being large due to the end destination being so close (Event 3)

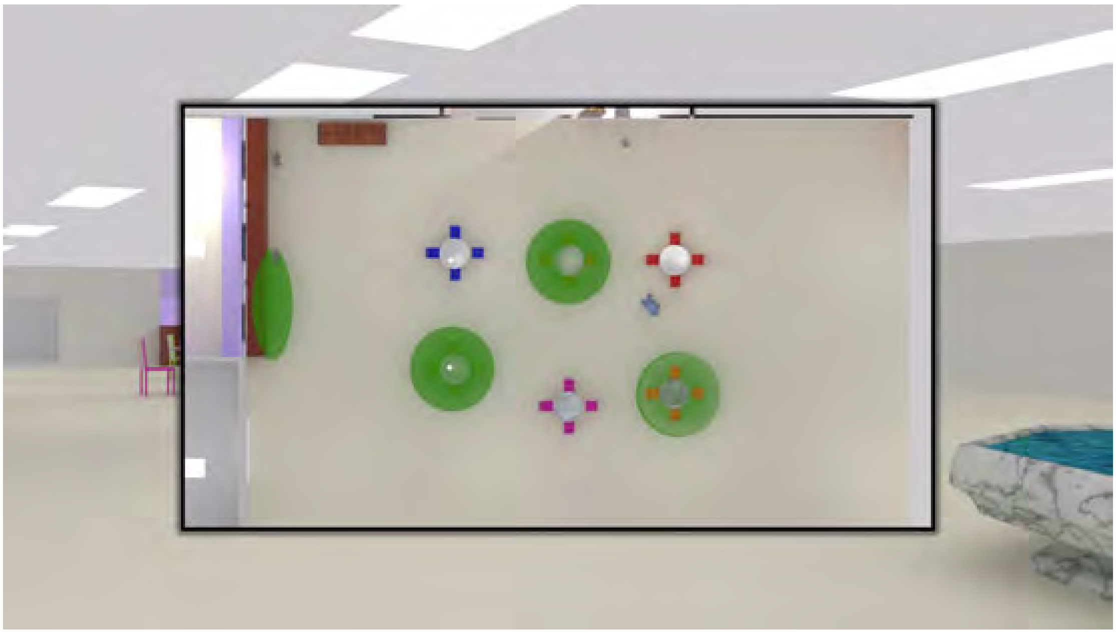

FIGURE 6.6: The Hot-spot technique is used to establish empty tables and food stores that have no or minimal queue (Event 4)

FIGURE 6.7: The Interface colour display identifies the presence of a hazard/crisis. The interface changes to a reddish colour indicating that Adam is in an unsafe zone (Event 5)

FIGURE 6.8: The Grayscale visualisation technique used to enhance objects of interest in the environment especially when visibility is not great due to the hazard (Event 5)

FIGURE 6.9: The Interface colour display becomes blue as he re-enters the mall environment indicating that Adam's current status is safe and it states that the crisis has been resolved (Event 6)

FIGURE 6.10: The Cameras Icons on Path visualisation technique allows for Adam to see the business of the store of interest without having to physically traverse towards the store (Event 6)

FIGURE 6.11: Transparency visualisation technique used to locate Adam's car that had been parked on the 1st level (Event 7)

Chapter 7

Appendix: Assessment of Ethics in Research Projects form

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