USER EXPERIENCE OF ARCHITECTURAL DETAILING IN VIRTUAL URBAN ENVIRONMENT

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To my beloved parents, Zaini Oje and Juncy Abdullah.

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ABSTRACT

Architecture and urban design disciplines very much adhere to the use of representations as a tool to aid decision making process. As it is almost impossible to replicate environments in full-scale, both physical and digital representations are therefore restricted by the notions of scale and level of details. These notions are now challenged by the emergence of virtual reality (VR) technology, which allows architects to work with full-scale virtual environments (VEs). However, the taxonomy of architectural representations in VR is not properly defined as discussions in academia are mostly concerned about creating realistic impressions of space, rather than the operational side of different architectural detailing. Thus, in recognizing the operational dimensions of VEs in VR, it is vital to examine the influence of different architectural detailing on the legibility of VEs. This study aimed to suggest a guideline for users' experience of architectural detailing in a VE for a large-scale urban simulation. This study was executed as an experimental simulation study. In a total of N=96 respondents were divided into four different treatments with n=24 respondents in each VE with a unique level of architectural detailing. They answered the questionnaire surveys and drew cognitive maps after completed navigating within the VEs using VR. Analysis methods used were primarily of content analysis, Kruskal-Wallis H test, and one-way ANOVA. The first analysis phase was environment-specific and the second phase was route and point-specific. In the third phase, the findings from previous phases were triangulated. The most and the least legible VEs were established as per different abilities of interpreting VEs. The operational dimensions of the VEs were established based on the deconstructed architectural detail components namely 'geometric extrusion' and 'distinction' as the factors influencing legibility of VEs. The operational dimensions of each VE were synthesized based on various criteria derived from the abilities of interpreting VEs. Based on the statistically significant results, the criteria were reduced to 'understanding VE' and 'recalling VE', in that order. In conclusion, there are some influences of architectural detailing on legibility but only in regards to the two criteria. The operational dimensions were also established for each criterion, which was learned from the cognitive knowledge data. Firstly, is for tasks within one viewpoint. Secondly, is for linear navigation and lastly is for full-fledged virtual exploration. This thesis also proposed two main guidelines for the user experience of architectural detailing in urban VE to be used by architects and users in the associated domain.

ABSTRAK

Disiplin senibina dan rekabentuk bandar sangat bergantung kepada penggunaan representasi sebagai alat dalam membantu proses pengambilan keputusan. Disebabkan mereplika akan suatu persekitaran berskala penuh dikira hampir mustahil, maka representasi fizikal dan digital terhad oleh tanggapan skala dan peringkat keperincian tertentu. Kemunculan teknologi realiti maya (VR) telah mencabar tanggapan tersebut kerana arkitek kini mungkin boleh memanfaatkan penggunaan model persekitaran maya (VE) berskala penuh. Namun, taksonomi VE berskala penuh sebagai representasi senibina masih belum ditakrifkan dengan baik kerana perbincangan akademik hanya menekankan aspek gambaran realistik suatu ruang di dalam model VE dan bukannya dari sisi pengendalian yang berdasarkan peringkat keperincian senibina. Demi menilai aspek pengendaliannya, maka kajian ke atas pengaruh peringkat keperincian senibina yang berbeza ke atas kebolehbacaan model VE adalah penting. Kajian ini bertujuan untuk mencadangkan garis panduan bagi pengalaman pengguna terhadap keperincian senibina di dalam simulasi VE bandar berskala besar. Kajian ini berbentuk simulasi eksperimental. Sebanyak N=96 responden telah menyertai kajian dan dibahagikan kepada empat perlakuan berbeza, dengan n=24 responden di dalam setiap perlakuan. Setiap perlakuan mempunyai peringkat keperincian senibina yang berbeza. Mereka telah menjawab soalan kajiselidik serta melukis peta kognitif setelah memandu arah di dalam model VE melalui VR. Kaedah analisis utama yang digunakan adalah analisis kandungan, ujian H Kruskal-Wallis dan ANOVA satu arah. Fasa analisis pertama adalah khusus kepada persekitaran model VE dan fasa analisis kedua pula khusus kepada laluan dan titik. Dalam fasa ketiga, penemuan daripada analisis sebelumnya telah melalui proses penyegitigaan. Model VE dengan kebolehbacaan tertinggi dan terendah dikenalpasti berdasarkan kebolehan responden menginterpretasi model VE yang berbeza. Sisi pengendalian model VE telah dikenalpasti berdasarkan komponen keperincian senibina yang telah dirumuskan menjadi ‘penyemperitan geometri’ dan ‘penonjolan’ sebagai faktor utama dalam mempengaruhi kebolehbacaan model VE. Sisi pengendalian setiap model VE disintesiskan berdasarkan kriteria tertentu yang diambil daripada kebolehan menginterpretasikan model VE. Berdasarkan keputusan statistik yang signifikan, kriteria tersebut dikurangkan menjadi ‘memahami VE’ dan ‘mengimbau VE’, dalam tertib tersebut. Kesimpulannya, terdapat beberapa pengaruh daripada peringkat keperincian senibina ke atas kebolehbacaan model VE tetapi hanya berkaitan dengan dua kriteria berkenaan. Sisi pengendalian model VE juga dikenalpasti untuk setiap kriteria berkenaan berdasarkan kepada data pengetahuan kognitif. Pertama, adalah untuk tugas dari dalam satu titik pandangan. Kedua, adalah untuk navigasi linear dan yang terakhir adalah untuk eksplorasi maya yang menyeluruh. Tesis ini juga telah mencadangkan dua garis panduan bagi pengalaman pengguna ke atas keperincian senibina di dalam bandar VE untuk digunakan oleh arkitek dan pengguna-pengguna lain dari bidang yang berkaitan.

TABLE OF CONTENTS

3 RESEARCH METHODOLOGY 84

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

VE	-	Virtual environment
VR	-	Virtual reality
ORDK2	-	Oculus Rift Development Kit 2
MEMS	-	Micro-Electro-Mechanical Systems
HMD	-	Head-mounted display
DPOV	-	Display field of view
ANOVA	-	Analysis of variance
3D	-	Three-dimensions/ three-dimensional
2D	-	Two-dimensions/ two-dimensional
LRS	-	Landmark, Route and Survey
GIS	-	Geographic Information System
KMO	-	Kaiser-Meyer-Olkin

LIST OF SYMBOLS

n - Sample size

N - Population size

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background

Virtual Reality (VR) is a technology as described by Steuer (1992) referring to a particular technological system that uses computer generated real-time animation displayed on a head-mounted stereoscopic visual output. It is controlled typically with a system of wired gloves and position tracker. Brooks (1999) defines a VR experience as whenever a user is being effectively immersed in a responsive virtual world. VR in this sense overrides human senses to be absorbed into believing to be in another set of 'reality', which often are in digital format. Original works on VR was done by Ivan Sutherland when he was at Harvard University (Myers, 1998). He said in his lecture titled 'The Ultimate Display' in 1965, that the challenge for computer graphics is to create a virtual world that moves and responds to real time interactions, as well as feel, look and sound real (Brooks, 1999). This similar pursue towards achieving total immersive environment has become the main motivation for VR developers that today in delivering deliver real feeling, look and sound of an unreal environment. This is not too dissimilar from what Sutherland had come to predict.

As in the late 1980s and early 1990s, VR devices were becoming more widespread and slowly occupying video arcades and research laboratories (Boyen, 2009). However, the technology at that time was considered not capable enough in delivering a fully immersive environment due to limitations such as the weak display and limited software capabilities (Drettakis et al. 2005; Halley-Prinable, 2013; Zachara & Zagal, 2009), apart from economic constraints (Kahaner, 1994).

In a much recent development, capabilities of electronic components and software have been vastly improved. This has triggered the interest of innovators such as a man named Palmer Luckey to capitalize on the idea of improving the VR technology using components available in the generic technology of today (Stein, 2015). The prototype uses MEMS sensing and video display technology that are already available in modern smartphones. High-fidelity VR contents and wide-angle viewing capability makes Oculus Rift's level of immersion better than its predecessors (Lavalle et al. 2014). Since then, giant technological corporations, as well as other small companies, have invested their interests in developing similar VR products for the masses. The biggest change in current VR technology is the rapid improvements on software capabilities (Halley-Prinable, 2013). As the software development is more advanced, the physicality of recent VR devices has fairly preserved a similar design as the previous hardware, as shown in Fig. 1.1. Almost all VR hardware designs are becoming similar which most of the available VR products in the market have retained similar method of displaying the VEs. The position reorganization is made possible usually by gyroscopes and accelerometers (Boas, 2013), which is almost similar to all VR products from different companies.

Figure 1.1: Similar HMD designs in Oculus Rift DK2, Project Morpheus and HTC Vive *(Image source: PCMag.com; http://venturebeat.com/2016/01/12/htc-vives-year-of-uncertainty/; http://www.extremetech.com/gaming/178867-sonys-project-morpheus-prototype-is-a-hit-bodes-well-for-the-future-of-virtual-reality)*

The competition of creating more capable VR system has become one of the major pursues in technological development recently. As this may lead to more discoveries in terms of its practical prospects ahead, this leaves a myriad of existing and new potential studies pertaining VR system and contents. From the earlier version of VR products and up until today, the technology is heavily anchored to gaming and entertainment purposes. VR functionalities are slowly being adapted into activities that otherwise were at all unthinkable before. Film production, website building, and product manufacturing are just some real-world, non-gaming activities that are slowly adapting VR technology. Many studies were done in hoping for discovering possible practical uses of VR from various perspectives. This is an advantage for both the academia and technological community, as principally the performance and usability limit of the VR technology is still unknown.

As architectural practice is much involved in spatial evaluations, VR is set to be more relevant as a mean of architectural or insofar, territorial representation. As the decision making in the practice often involves representations that would eventually require much time and cost, the need of recognizing VR as a valid architectural representation tool has become more profound. A virtual environment (VE) in VR can be perceived as the second set of reality that users can interact with, whether they are a small or a large environment. Similarly, the nature of architectural practice itself has no standard of how small or how big does a design decision making should take place. Architects have the liberty to metaphorically construct anything as VEs and this is not just limited to small spaces. A VE in VR in this sense may be treated as a tool to assess small architectural space or even an urban scale environment. The optimal operational dimension of VR, therefore, should be learned through the small concerns such as architectural details to larger components such as the aggregate of buildings in an urban scale VE.

VR system relies heavily on the computing power, which will later affect the fluidity and fidelity of the VE representations. Apart from this, the concern of perfecting the VEs realism and richness in VR has always been the primary concern among industry players as well as academics. However, as highlighted by Balfour (2001), appropriating the tool for the pursue towards creating a richer and realistic hypothetical VE than the real one is simply idiotic. Furthermore, this thesis argues that a VR system should not be more than just an operational representation tool to evaluate space and the environment it represents. This requires the concerns regarding VR as a tool for urban scale architectural representation should be viewed from the system’s operational side for architectural purposes. Researchers should not neglect the importance of architectural details in VEs while maintaining the best quality and fluidity of the VEs in VR.

Using a conventional way of constructing a 3D model of the VEs, this study examined the influence of the different levels of architectural detailing on 3D buildings upon the legibility of the VEs itself. In other words, this study is based on the concern of leveraging the level of architectural detailing in creating a workable VE as a form of large-scale urban representation in VR. Through this, VR, therefore, can be envisioned to be an operational representation tool for architecture and urban design by appropriating the most legible level of architectural detailing in VEs for architectural design and evaluation.

1.2 Statement of Problem

For ages, architects have been using scale representations such as models to aid design process (Stavrić, 2013). It is an economical solution considering constructing buildings may take years to complete and unexpected circumstances and decisions could come into play in the interim. Using representations in the form of scale models, in particular, allows architects to manage the risks of possible errors and discrepancies in the final design product. However, the operational use of these models may vary depending on the scale and the level of details (Stavrić, 2013). The selection of scale generally depends on the actual size of objects, the size of the workspace and the project stage that is to be illustrated. Another critical consideration for scale models is the selection of the level of details. Reducing the scale of models thus will increase the level of details and vice versa, to the level of their geometric primitives. As presented in Table 1.1, a highly detailed model of a house on a scale of 1:25 may be useful for an interior design study as it bears a realistic resemblance to the real house. A 1:1000 scale model of a city environment may be represented in prismatic blocks and is often monochromatic, as it is laborious to produce huge models with architectural details and colour and therefore, deemed as not effective enough for gathering valid information.

Table 1.1: Common type of scale models (Stavrić, 2013).

Type of scale model	Scale
Detail model	2:1 or 1:1
Interior/ furniture model	1:25
Conceptual/ development model	1:50, 1:100, 1:200 or with no specific scale
Exhibition model, model of constructed objects	1:100, 1:200
Site model	1:250 or 1:500
City/ landscape model	
Small environment	1:250 or 1:500
Large environment	1:1000 or 1:2500

The practice of using representations historically contributed to the existence of the discipline itself (Losciale, Lombardo, & De Luca, 2012). Architects from the earlier days until now still build scale models to actualize ideas through smaller and therefore, manageable pieces of information. Architects have always relied on representations in communicating design intents to the stakeholders, and sometimes representations are central to architects to establish intimate wanderings through one’s thoughts as a dialogue in the design process (Aroztegui, Solovyova, & Nanda, 1997). As it is impossible to foresee implications of the decision taken during the design process, representations play a critical role for architects in the decision-making process before taking a stake in the end product. Architects often work with 2D representations and would eventually utilize 3D format of representations such as isometric and perspective drawings to explain the designs even further. All these physical representations either in the form of drawings or models are always inadequate in some areas as compared to the digital representations.

Frequently produced in smaller scales, physical models are not suitable agencies for allowing architects to gain spatial experience. Thus, digital 3D models are used by architects and urban designers to explore virtual spaces. The scale of digital models, however, are not accessible in computing and digital models often worked on through interchangeable scales as a scale translation from the VE displayed on the screen to the real world has to be made by the user (Richardson, Montello, & Hegarty, 1999). Metaphorically, all digital models exist within the digital realm are in a full-scale, it is just what is being displayed to the users may not. Additionally, in the end, they are going to be viewed as 2D representations through the computer screens or to be printed on the physical outputs such as papers. This pushes architects or the system itself to reduce the level of detailing in the 3D models as per what the computer screens can display or depending on the size of the physical outputs they intent to produce on. Either physical or digital format, the level of details and scale remain as two factors distinguishing the operational quality of one representation to another.

In the architectural design process, 3D buildings are usually built with an optimal level of detail. Whereas for a larger scale environment such as a city environment, highly detailed representations are rarely, if not impossible to be built in full-scale. As for the scale models of cities and urban areas, physical models are typically small that it is unlikely for certain vital information to be obtained from studying one. It might also be uneconomical, laborious and just nearly impossible to build physical models in full-scale with adequate detailing.

In a recent development, the vision of making VR be available and affordable to the masses has paved the way to the so-called second wave of VR revolution (Stein, 2015). VR is therefore sought to be more capable and advanced, as it could present the VEs in full-scale through a more intuitive and immersive manner. Digital reinterpretation of the reality itself may trigger some interesting subjects within the architectural realm. As architecture and urban design are major fields involved with the concerns regarding spatial assessments of small to large environments, VR system is envisioned to be a capable tool that may aid these assessments at many levels.

VR systems of today can potentially allow large, full-scale VEs to be explored while maintaining the merit of architectural details. A Higher number of polygons and meshes are required in preserving architectural details on 3D buildings, and this, in turn, demands the diminution of the quality of VEs. Some techniques are already introduced by scholars in reducing the complexity of models in VEs to increase their performance. As highlighted by Gao (2013), commonly used techniques are mesh simplification and through using model simplification algorithms. These techniques, however, are mainly putting emphasis on the fidelity of the model while ignoring the importance of architectural characteristics and principles.

Studies with the objectives of pursuing legible VEs are commonly from the computer graphics point of view. The entire field of computer graphics has grown out of the tension between realism and speed, between fidelity and frame rate, between rich, highly detailed VE and smooth animation (Luebke, et al., 2003). Many studies are governed by the concern of how complex and realistic VEs should be presented, or at least, perceived. Attentions were given to pursue the aesthetic qualities of VEs towards creating more complex, therefore more realistic looking VEs. Thus, techniques such as photogrammetry are widely used as a reliable method to record parts of reality into a 3D model, but this approach often neglects the geometric quality of architectural details.

The problem with deciding the level of details in representations is mainly controlled by the scale, other than the question of production capability, time and cost (Hudson-Smith, 2007; Kobayashi, 2006). Therefore, deciding on what scale must go concurrently with determining the level of details. In an urban scale VE, the question of the level of details and scale can be more ambiguous, as there are no rules on dictating how to detail a VE this large should be built. For architectural decision making purposes, it is more logical for a higher level of architectural details to be preserved. Additionally, as other cues such as smell and touch are less possible to be recreated in VEs, the information expected to be properly displayed in VR are primarily of visual cues alone. As the actual environment is messy and complex, the relevant components that should be preserved in VEs are left with the visual cues containing the architectural characteristics of the buildings, thus the notion of legibility has to become relevant for this study.

The full-scale VEs in VR will require a high level of details as visual information in VR should be delivered sufficiently, especially for architectural and urban study assessment. Thus, the VEs should be made legible visually and cognitively. It is also important for the disciplines to learn about the operational level of different level of details. This ambiguous boundary of defining how detail buildings in VEs should be represented while maintaining the operational side of the representations for VR has become the gap that needs to be defined. As discussed by Oxman (2008), *"One way in which the clarification of the uniqueness of digital design media can be established is to define a taxonomy for digital design models,"*. This study is a continuation of this process, induced by the belief that the concern of defining the taxonomy for VEs with different detailing should be primarily based on architectural attributes rather than polygons, mesh numbers and textures. Thus, the term 'architectural detailing' (referring to different levels) and 'architectural details' (referring to certain detail components) are deemed to be more appropriate to be used rather than the traditional term of 'level of details'.

1.3 Aim and Objectives

The research aimed to suggest a guideline for the user experience of architectural detailing in a VE for large-scale urban simulation. This expands the possibility of VEs in VR to become a valid urban scale architectural representations. This study was centralized on the notion of legibility of the VEs, achieved through these objectives:

1. To measure differences in the degree of legibility of all VEs;
2. To evaluate the influence of different levels of architectural detailing upon the degree of legibility of VEs;
3. To compare the differences in cognitive knowledge of respondents from all VEs.

1.4 Primary Hypotheses

The primary null and alternative hypotheses that have been established for this study are as follows:

1. Null Hypothesis/ H_0 – The level of architectural detailing on 3D buildings has no observable influence on the degree of legibility of the VEs;
2. Alternative Hypothesis/ H_a – The level of architectural detailing on 3D buildings influences the degree of legibility of the VEs.

1.5 Scope of Research

The scope of research was set to describe the boundaries and limitations for this study, which was limited to these parameters:

1. Concerns were only limited to outdoor space legibility evaluation, not including the internal spaces of 3D buildings in the VEs;
2. The study utilized VR system as a tool and not focusing on the technicality of VR technology extensively;
3. The study did not compare the VEs representation with the reference site;
4. Only the data from the respondents who have not been to the reference site were considered for analysis;
5. Explorations within VEs during the data collection process were limited to certain paths as free explorations would only contribute to data redundancies and other unnecessary circumstances. However, a certain degree of freedom in explorations was allowed as discussed later in Chapter 3.

1.6 Outline of Research Methodology

To be elaborated in Chapter 3, the research methodology is the backbone of this study. Prior to the data collection, it is also vital to explain the research methodology briefly as to highlight the basic structure of how this study was executed. In warranting more valid and diverse findings, the research has the data taken through combined research strategy from both quantitative and qualitative approaches, within the post-positivist system of inquiry. This study is mainly of an experimental simulation study, with the primary data are of perception, cognitive and observation data. Thus, questionnaire surveys were used extensively as one of the main research instruments, combined with the data gathered from observations and cognitive maps drawn by the respondents. These were all done through respondents from different VEs with different level of architectural detailing. Overall, there were six main stages of work accomplished in completing this thesis accordingly as illustrated in Fig. 1.2.

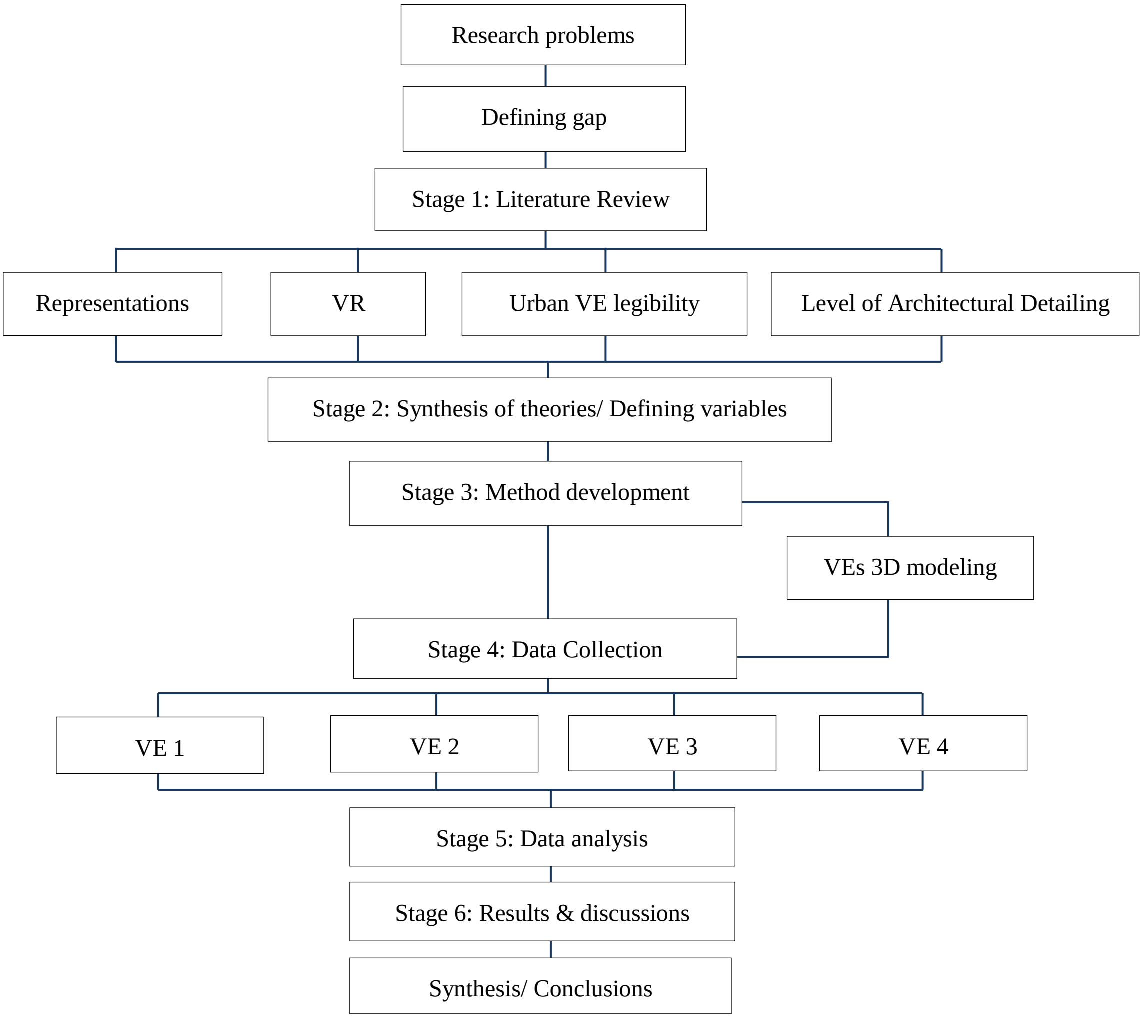

Figure 1.2: General outline of this study.

1.6.1 Stage 1: Literature Review

This is a preliminary stage of accumulating and reducing all the needed information discussing the related subject from a large body of literature sources (Groat & Wang, 2013). The sources were gathered from the works primarily discussing architectural representations, VEs, VR, computer graphics, the level of details, urban legibility, wayfinding and cognitive knowledge.

1.6.2 Stage 2: Synthesis of Theories and Definition of Variables

From the knowledge and discourse in the previous stage, the theories were synthesized into becoming the basis for the ongoing discussion of this research. The variables for the data collection were developed based on the dimensions that have been established through the theories. The next stage of method development and the data collection process were mainly of proving these theories.

1.6.3 Stage 3: Method Development

The hypotheses were established and research objectives that have been discussed earlier developed into the operational guidelines. The theories formulated became the basis of how the 3D model of the VEs was constructed. The work of preparing the VEs went concurrently with the development of research method. Determining the level of architectural detailing was also established based on the formulated theories. The tactics for collecting data including the way the navigation simulation was strategized and the tasks are given to the respondents were also based on these theories.

1.6.4 Stage 4: Data Collection

Taking precedence from the methods used by scholars such as Lynch (1960) and Appleyard (1981), cognitive knowledge data were gathered through cognitive maps as the respondents attempted to recall urban elements in the VEs within the realm of VR they have experienced. As this study is of ‘between subjects’ tests, each respondent was assigned into a unique group and therefore each respondent was independent of another. This was to discourage the preconceived idea of a place that they may have recognized earlier. The questionnaire survey questions were completed by the respondents after they have completed the cognitive mapping exercise.

1.6.5 Stage 5: Data Analysis

The data collected from the previous stage were analyzed separately in three primary phases. The first phase is the environment specific analysis of the quantitative data gathered from the questionnaire survey and observations. The second phase is the route and point-specific analysis using primarily qualitative cognitive knowledge taken from the cognitive maps, alongside the additional perception and observation data. Various analysis methods including statistics techniques were implemented. The results from the analysis stage are discussed in the third phase, which is the triangulation of the findings from the previous phases.

1.6.6 Stage 6: Results & Discussions

As the analysis of data is separated into three phases, the results from each phase are presented and discussed separately. At the end of this stage, the findings from both phases were triangulated, and the results of the triangulation were synthesized and presented as the conclusion. The established theories and hypotheses from the previous stages are the prelude to the conclusions in the final chapter.

1.7 Significance of Study

The architectural practice itself is an embodiment of multidisciplinary skills and talents. Architectural knowledge is stemmed from disciplines layered from anthropology, economy, engineering, history, geography, environmental psychology, philosophy etc. The assertion of new knowledge into an already rich discipline is, therefore, would not just empower the disciplines itself, but also encourage different disciplines to become mutually relevant over time. Thus, to study a new technological system into an already established concept of architectural representation can be a great commencement towards a total digitization of the concept generally, and the architectural practice mainly. In a long run, more efficient society can be created and more sustainable approach towards implementing architectural ideas can be achieved.

VR has begun to be used by architects as a representation tool. Through innovative integration technology, the architectural 3D software can now be supported with VR capabilities. At the same time, VR system itself can be acquired easily by the masses and the industry must keep up with this sophistication of the society. This inclusion of VR into architectural practice, especially as a form of representation should be validated through theories and empirical data. Evaluating the influence of architectural detailing upon the legibility of VEs will not only enable this validation but also will become the basic guidelines of which operational level of detailing should be achieved in any architectural representation in VR. This study will be one of the studies that touch on this matter, synthesized mainly from architectural and urban design knowledge and hoping to get to impeccably developed further. The taxonomy of architectural representations can be enriched to include VR as one of the tools apart from limited to just digital and physical models. This opens the way of how architects can contribute certain knowledge to the disciplines and technology that are not architecturally related.

This study defines operational levels that will be beneficial especially in maintaining architectural concerns related to computer graphics discourse. Software developers and 3D modelers can refer to the findings from this study to determine the optimal level of details for architectural purposes in future. Urban scale environments in VR with a high level of details may consume much work, time and cost, thus architects and urban designers can work within an optimal boundary set by this study.

As the actual reality and VR are two dichotomous dimensions, evaluating the legibility of a VE in VR is not just critical for architectural representation, but it also opens broader philosophical stance on the reality itself. As the real environment is already complex and messy with details, the schematized representation of that reality in VR based on architectural knowledge will make architects and scholars recognize the concept of redundancy and adequacy of details. While this study maintains the argument of schematization may influence the degree of legibility of VEs, it also highlights the operational side of it.

Apart from this philosophical stance, this study is also relevant to urban theories in general. The adoption of new technology in the digital era will pave the way for architectural and urban design disciplines to be resonant to this technological development. There are numerous urban legibility studies done in the past decades, and digital intervention may change the way people evaluate these studies and architectural decision process as a whole. There were no possible means to manipulate building details in evaluating how far do architectural details can influence legibility of a large urban environment. This so far can only be done in VR, as it can simulate a full-scale environment where observers can navigate within it. This study explores this possibility and urban theories in future can be built upon the relevant findings.

1.8 Organization of Thesis

This thesis is divided into six main chapters. To highlight the direction of this thesis more clearly, the outline of each chapter as a precursor to the entire thesis are as follows:

- Chapter 1: Introduction
- Chapter 2: Literature Review
- Chapter 3: Research Methodology
- Chapter 4: Results of Experiment
- Chapter 5: Discussion
- Chapter 6: Conclusions

The current chapter (**Chapter 1**) discusses the preliminary details and the direction of the thesis as an introductory discussion. The problems, especially regarding the emergence of VR technology and architectural representations, are discussed as the background of this study. The research gap is then discussed further in **Chapter 2**. Academic and other references especially relevant to the topics of VR, VEs, level of architectural detailing and cognitive study are discussed. The research method is discussed in **Chapter 3**, which presents the development of the research methodology including the system of inquiry, strategies and tactics as a preparation to proceed to the data collection stage to the next chapter. **Chapter 4** presents the results from the data analysis while **Chapter 5** discusses the findings from the data collection stage. The findings then used to confirm the theories that have been synthesized in the previous chapters, whether the level of architectural detailing has some influence to the legibility of VEs. After the findings were triangulated, the final chapter (**Chapter 6**) concludes the influence of the level of architectural detailing on the legibility of VEs, using the researcher’s own remarks. The synthesized operational dimension of the level of architectural detailing is also proposed and finalized into guidelines.

1.9 Chapter Summary

This chapter serves as the point of departure to the overall thesis. It presents the introductory background to the problems that lead to the formation of the research objectives, scope and hypotheses. The objectives and hypotheses are essential to compare and find differences between VEs which reflected through the different architectural detailing. Brief explanations of the research methodology and data collection stages involved are also presented in the introduction chapter. Based on the objectives, it is certain at this point this research would use combined method strategy to gather and analyze the data. The significance of this study is highlighted with the discussion focusing on its possible contributions to various parties. The significance of study was discussed in an optimistic tone that it requires further discussion and actual data analysis to support it. There is also a discussion on the outline of the research chapters that are expected to be in this thesis. The issues regarding VR technology and architectural representations are discussed with regards to the concern of the VE contents and architectural details. Thus, this study is likely to utilize VR system to simulate large-scale VEs for the data collection process. In this chapter, these are only elementary discussions to establish the problems in setting out the framework. This study requires various references touching on the subject matter, thus the arguments and claims are discussed more thoroughly in next chapters.

REFERENCES

Abrams, J. B. (2010). Wayfinding in Architecture. University of South Florida.

Afrooz, A. E. (2009). Assessing Wayfinding of Users in Unfamiliar Large-Scale Urban Places. Universiti Teknologi Malaysia.

Altürk, E. (2008). Architectural Representation as a Medium of Critical Agencies. The Journal of Architecture, 13(2), 133–152.

Appleyard, D. (1969). Why Buildings are Known: A Predictive Tool for Architects and Planners.

Appleyard, D. (1970). Notes on Urban Perception and Knowledge. EDRA 2: Proceedings of the 2nd Annual Enivironmental Design Research Association Conference, 97–101.

Appleyard, D. (1981). Liveable Streets. London: University of California Press.

Aroztegui, C., Solovyova, I., & Nanda, U. (1997). Architectural Research and Representation : Expressing Sense of Place Through Storyboarding and Animatics University of Texas at San Antonio , TX Upali Nanda , American Art Resources , Houston , TX.

Asanowicz, A. (1994). Computer - Tool VS. Medium.

Atkinson, R., & Willis, P. (2009). Transparent Cities: Re-shaping the Urban Experience through Interactive Video Game Simulation, (July 2015).

Baglioni, M., Antônio, J., Macêdo, F. De, & Renso, C. (2009). Advances in GIScience. Notes, 25–42.

Bailey, R. (2000). The Intelligent Sketch: Developing a Conceptual Model for a Digital Design Assistant, 137–146.

Balfour, A. (2001). Architecture and Electronic Media. Journal of Architectural Education, 54(4), 268–271.

Batty, M., Dodge, M., Doyle, S., & Hudson-Smith, A. (1998). Modelling Virtual Urban Environments.

Biljecki, F., Ledoux, H., Stoter, J., & Zhao, J. (2014). Formalisation of the Level of Detail in 3D City Modelling. Computers, Environment and Urban Systems, 48, 1–15.

Bishop, I. D., & Leahy, P. A. (1989). Assessing the Visual Impact of Development Proposals: The Validity of Computer Simulations. Landscape Journal, 92-100.

Bjork, S., & Holopainen, J. (2005). Patterns in Game Design. Hingham, Massachusetts: Charles River Media.

Boas, Y. (2013). Overview of Virtual Reality Technologies. Interactive Multimedia Conference.

Boos, K., Chu, D., & Cuervo, E. (2016). FlashBack: Immersive Virtual Reality on Mobile Devices via Rendering Memoization. In International Conference on Mobile Systems, Applications, and Services (pp. 291–303).

Bowman, D. a, Mcmahan, R. P., & Tech, V. (2007). Virtual Reality: How Much Immersion Is Enough? (Cover story). Computer, 40(7), 36–43.

Boyen, S. (2009). A Virtual Failure: Evaluating the Success of Nintendo’ s Virtual Boy. Velvet Light Trap, 23.

Brooks, F. P. (1999). What’s Real About Virtual Reality? Proceedings IEEE Virtual Reality (Cat. No. 99CB36316), (December).

Ceconello, M., & Spallazzo, D. (2008). Virtual Reality for Enhanced Urban Design. 5th INTUITION, International Conference Virtual Reality in Industry and Society, From Research to Application. 6-8 Ottobre 2008, (October).

Chang, R., Butkiewicz, T., Ziemkiewicz, C., & Wartell, Z. (2008). Legible Simplification of Textured Urban Models. IEEE Computer Graphics and Applications, 27–36.

Chang, R., Butkiewicz, T., Ziemkiewicz, C., Wartell, Z., Pollard, N., & Ribarsky, W. (2006). Hierarchical Simplification of City Models to Maintain Urban Legibility. ACM SIGGRAPH 2006 Sketches on SIGGRAPH 06, 1000(c), 130.

Chen, I. R., & Schnabel, M. A. (2011). Multi-Touch: The Future of Design Interaction. Designing Together - Proceedings of the 14th International Conference on Computer Aided Architectural Design Futures, 557–571.

Coe, R. (2002). It’s the Effect Size, Stupid. What Effect Size is and Why it is Important. In British Educational Research Association Annual Conference (pp. 1–18).

Cohen, M. M. (1992). Full-scale Architectural Simulation Research for Space Station Freedom and Exploration. IDEEA One: The First International Design for Extreme Environments Assembly.

Creswell, J. W. (2003). Research Design Qualitative Quantitative and Mixed Methods Approaches. Research Design Qualitative Quantitative and Mixed Methods Approaches, 3–26.

Creswell, J. W. (2014). Research Design: Qualitative, Quantitative, and Mixed Methods Approaches (4th Editio). SAGE Publications, Inc.

Dai, F., & Lu, M. (2008). Photo-based 3D Modeling of Construction Resources for Visualization of Operations Simulation: Case of Modeling a Precast Facade. In Proceedings - Winter Simulation Conference (pp. 2439–2446).

Dalholm, E. H., & Mitchell, B. R. (1996). Spatial Navigation in Virtual Reality. In Proceedings 6th EFA-Conference (pp. 107–123).

Dannevig, T., & Thorvaldsen, J. A. (2007). Immersive Virtual Reality in Landscape Planning. Norweigian University of Life Sciences.

Darken, R. P., & Peterson, B. (2001). Spatial Orientation, Wayfinding and Representation. Handbook of Virtual Environment Technology, 4083(2001), 1–22.

Darsa, L., Costa, B., & Varshney, A. (1998). Walkthroughs of Complex Environments Using Image-based Simplification. Computers & Graphics, 22(1), 55–69.

Day, A., & Radford, A. (1998). An Overview of City Simulation. Proceedings of the Third Conference on Computer Aided Architectural Design Research in Asia (CAADRIA ’98), 183–192.

De Vaus, D. A. (2002). Surveys in Social Research (5th Edition). New South Wales: Allen & Unwin.

Dehghan, N., Moradi, A. M., & Memariyan, G. H. (2012). Comparing the Dimensions of Spatial Legibility with Wayfinding Strategies. International Research Journal of Applied and Basic Sciences, 3(S), 2637–2646.

Donmez, B., Boyle, L. N., & Lee, J. D. (2006). Driving Simulator Experiments: Power for Repeated Measures vs. Completely Randomized Design. Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 50(21), 2336–2339.

Drettakis, G., Roussou, R. M., Asselot, U. C. L. M., & Alex, R. (2005). Participatory Design and Evaluation of a Real-World Virtual Environment for Architecture and Urban Planning.

Edwards, B. (2005). The Use of Drawing in Architectural Design: Some Recent Experiences from UK Practice. Arq: Architectural Research Quarterly, 9(3–4), 273.

El Araby, M., & Okiel, A. Y. (2003). The Use of Virtual Reality in Urban Design: Enhancing the Image of Al-Ain City , UAE. In International Conference on Urban Planning and Regional Development (pp. 383–392).

Elias, B. (2003). Determination of Landmarks and Reliability Criteria for Landmarks. Fifth Workshop on Progress in Automated Map Generalization Paris, 1–12.

Evans, G. W., Smith, C., & Pezdek, K. (1982). Cognitive Maps and Urban Form. Journal of American Planning Association 48, 232–244.

Fox, J., Arena, D., & Bailenson, J. N. (2009). Virtual Reality: A Survival Guide for the Social Scientist. Journal of Media Psychology, 21(3), 95–113.

Freitas, M. R. De, & Ruschel, R. C. (2013). What is Happening to Virtual and Augmented Reality Applied to Architecture? In Proceedings of the 18th International Conference on Computer-Aided Architectural Design Research in Asia (CAADRIA 2013) (pp. 407–416).

Gao, S. (2013). 3D Model Simplification Method with Maintaining Local Features. In Proceedings of the International Conference on Information Engineering and Applications (IEA) 2012 (Vol. 217, pp. 269–276).

Ghani Abdul, N., Shimizu, T., & Mokhtar, S. (2015). Assessment of Pedestrian Facilities in Malacca World Heritage Site, Malaysia using P-Index Method. Journal of the Eastern Asia Society for Transportation Studies, 11, pp 1535-1554.

Goradia, I., Doshi, J., & Kurup, L. (2014). A Review Paper on Oculus Rift & Project Morpheus. International Journal of Current Engineering and Techonology, 4(5), 3196–3200.

Graham, E. (2016). What is a Mental Map? Area, 8(4), 259–262.

Groat, L., & Wang, D. (2013). Architectural Research Methods (2nd Edition). New Jersey: John Wiley & Sons, Inc.

Guba, E. C., & Lincoln, Y. S. (1994). Competing Paradigms in Qualitative Research. In Handbook of Qualitative Research (pp. 163–194).

Halley-Prinable, A. (2013). The Oculus Rift and Immersion through Fear. Bournemouth University.

Haq, S., Hill, G., & Pramanik, A. (2005). Comparison of Configurational, Wayfinding and Cognitive Correlates in Real and Virtual Settings, 387–406.

Helvacıoğlu, E. (2010). Colour and wayfinding. Colour and Light in Architecture: First International Conference 2010 Proceedings, 464–468.

Herzog, T. R., & Leverich, O. L. (2003). Searching for Legibility. Environment and Behavior, 35(4), 459–477.

Hill Jr, R. W., Han, C., & Van Lent, M. (2002). Applying Perceptually Driven Cognitive Mapping to Virtual Urban Environments. AI Magazine, 23(4), 69.

Horne, M., Podevyn, M., & Thompson, E. M. (2013). An Overview of Virtual City Modelling: Emerging Organisational Issues. Journal of Chemical Information and Modeling, 53(9), 1689–1699.

Hsieh, H.-F., & Shannon, S. E. (2005). Three Approaches to Qualitative Content Analysis. Qualitative Health Research, 15(9), 1277–1288.

Hudson-Smith, A. (2007). Digital Urban - The Visual City. Retrieved from

Hussain, K. A. M., & Ujang, N. (2014). Visitors’ Identification of Landmarks in the Historic District of Banda Hilir, Melaka, Malaysia. Procedia - Social and Behavioral Sciences, 153, 689–699.

Hussain, K. A. M., Norsidah, U., & Noor Azizi, A. (2013). The Effect Of Landmarks On Visitors’ Attachment Towards The Historic City Of Banda Hilir, Melaka. In Proceedings of International Conference on Tourism Development (pp. 9–19).

Ibrahim, N., & Noor, N. F. M. (2004). Information Legibility in 3D Information Visualisation: Navigation aids to assist information finding. In iiWAS (Vol. 183, pp. 735–744).

Ingram, R., & Benford, S. (1995). Legibility Enhancement for Information Visualisation. Proceedings Visualization ’95, 209–216.

Ishii, H., Underkoffler, J., Chak, D., Piper, B., Ben-Joseph, E., Yeung, L., & Kanji, Z. (2002). Augmented Urban Planning Workbench: Overlaying Drawings, Physical Models and Digital Simulation. Proceedings. International Symposium on Mixed and Augmented Reality.

Ismail, A. L. R. . (1995). Pragmatic Visualisation: A Detour from the Nth Dimension to Infinity. Transactions on Information and Communications Technologies, 12, 99–106.

Ismail, A. W., & Noh, Z. (2008). Augmented Reality Theory and Applications. In M. Shahrizal, & M. Najib, Advances in Computer Graphics and Virtual Environment (pp. 88-105). Skudai: Penerbit UTM.

Ismail, A. W., & Sunar, M. S. (2009). Survey on Collaborative AR for Multi-user in Urban Studies and Planning. Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics), 5670 LNCS, 444–455.

Ja'afar, N. H., Sulaiman, A. B., & Shamsuddin, S. (2012). The Contribution of Landscape Features on Traditional Streets in Malaysia. Procedia - Social and Behavioral Sciences, 50(July), 643–656.

Jiang, B. (2012). Computing the Image of the City. In Informatics and Urban and Regional Planning INPUT 2012 (pp. 111–121).

Jick, T. D. (1979). Mixing Qualitative and Quantitative Methods: Triangulation in Action. Administrative Science Quarterly, 24(4), 602–611.

Joroff, M. L., & Morse, S. J. (1984). A Proposed Framework Field of Architectural Research. In J. C. Snyder, Architectural Research (pp. 15-28). New York: Van Nostrand Reinhold Company.

Jul, S., & Furnas, G. W. (1997). Navigation in Electronic Worlds: A CHI 97 Workshop. SIGCHI Bulleting, 29(4).

Kahaner, D. (1994). Japanese Activities in Virtual Reality. IEEE Computer Graphics and Applications, 14(1), 75–78.

Kao, C. J. (2014). Landmarks Selection in Street Map Design. IOP Conference Series: Earth and Environmental Science, 18, 12075.

Kim, M. J., Wang, X., Li, H., Estate, R., Kong, H., & Kang, S. (2013). Virtual Reality for the Built Environment: A Critical Review of Recent Advances. Journal of Information Technology in Construction, 18(August), 279–305.

Klippel, A., Barkowsky, T., Freksa, C., Knauff, M., & Krieg-brückner, B. (2003). Wayfinding Choremes Conceptualizing Wayfinding and Route Direction Elements (Vol. 1).

Kobayashi, Y. (2006). Photogrammetry and 3D City Modeling. In First International Conference on Digital Architecture and Construction (Vol. 90). WIT Press.

Koseoglu, E., & Onder, D. E. (2011). Subjective and Objective Dimensions of Spatial Legibility. Procedia - Social and Behavioral Sciences, 30, 1191–1195.

Krippendorff, K. (2004). Content Analysis: An Introduction to Its Methodology. Education (2nd Editio). California: SAGE Publications, Inc.

Lavalle, S. M., Yershova, A., Katsev, M., & Antonov, M. (2014). Head Tracking for the Oculus Rift. Proceedings - IEEE International Conference on Robotics and Automation, 187–194.

Lawless, J. W. (2015). Melaka as a Cultural Landscape. Journal of Space and Communication, 1(1), 37–45.

Lawson, B. (1998). Towards a Computer-aided Architectural Design Process: A Journey of Several Mirages. Computers in Industry, 35(1), 47–57.

Leavitt, N. (1999). Online 3D: Still Waiting After All These Years. Computer, 21(7), 4–7.

Lee, K. M. (2004). Presence, Explicated. Communication Theory, 14(1), 27–50.

Legakis, J., Dorsey, J., & Gortler, S. (2001). Feature-based Cellular Texturing for Architectural Models. Proceedings of the 28th Annual Conference on Computer Graphics and Interactive Techniques - SIGGRAPH ’01, (August), 309–316.

Li, B., Zhang, R., & Kuhl, S. (2014). Minication Affects Action-based Distance Judgments in Oculus Rift HMDs. Proceedings of the ACM Symposium on Applied Perception - SAP ’14, 91–94.

Lombard, M., Reich, R. D., Grabe, M. E., Bracken, C. C., & Ditton, T. B. (2000). Presence and Television: The Role of Screen Size. Human Communication Research, 26(1), 75–98.

Losciale, L. V., Lombardo, J., & De Luca, L. (2012). New Semantic Media and 3D Architectural Models Representation. Proceedings of the 2012 18th International Conference on Virtual Systems and Multimedia, VSMM 2012: Virtual Systems in the Information Society, 533–536.

Lovelace, K. L., Hegarty, M., & Montello, D. R. (1999). Elements of Good Route Directions in Familiar and Unfamiliar Environments. Lecture Notes in Computer Science, 1661, 65–82.

Luebke, D., Reddy, M., Cohen, J. D., Varshney, A., Watson, B., & Huebner, R. (2003). Level of Detail for 3D Graphics. Morgan Kaufmann Publishers.

Luebke, D., Watson, B., Cohen, J. D., Reddy, M., & Varshney, A. (2002). Level of Details for 3D Graphics (1st Edition). New York: Elsevier Science Inc.

Lynch, K. (1960). The Image of the City. The M.I.T Press, 1–103.

Mahalingam, G. (1998). Representing Architectural Design Using Virtual Computers. Automation in Construction, 8(1), 25–36.

Marr, D. (1982). Vision. In Minds, Brains, and Computers: The Foundations of Cognitive Science (pp. 69–83).

McCleary, P. (1984). History of Technology. In J. C. Snyder, Architectural Research (pp. 81-94). New York: Van Nostrand Reinhold Company.

McIntyre, L. (2011). Let Me Show You What Happens as I get from A to B: Way-finding Design, Visual Ability & "Way-finding Hot-spots." In First European Conference on Design 4 Health (pp. 241–254).

Mihnevitš, A. (2015). Towards Oculus Rift based Augmented and Virtual Reality.

Milgram, P. H. T. A. U. F. K. (1994). Augmented reality: A Class of Displays on the Reality-Virtuality Continuum. Telemanipulator and Telepresence Technologies, 2351, 282–292.

Mohammed, A. (2012). Evaluating Way-finding Ability within Urban Environment. Eighth International Space Syntax Symposium.

Morello, E., & Ratti, C. (2009). A Digital Image of the City: 3D Issovists in Lynch's Urban Analysis. Environment and Planning B: Planning and Design, 36(5), 837–853.

Myers, B. A. (1998). A Brief History of Human-computer Interaction Technology. Interactions, 5, 44–54.

Natapov, A., & Fisher-Gewirtzman, D. (2016). Visibility of Urban Activities and Pedestrian Routes : An Experiment in a Virtual Environment. Computers, Environment and Urban Systems, 58, 60–70.

Nikolic, D. (2007). Evaluating Relative Impact of Virtual Reality Components Detail and Realism on Spatial Comprehension and Presence.

Nishimoto, S. (2012). Evaluating Mental Maps. University of Oregon.

Oculus. (2014). Oculus Developer Guide.

Omer, I., Goldblatt, R., & Or, U. (2005). Virtual City Design Based on Urban Image Theory. The Cartographic Journal, 42(1), 1–12.

Orellana, N., & Al Sayed, K. (2013). On Spatial Wayfinding: Agent and Human Navigation Patterns in Virtual and Real Worlds. In Ninth International Space Syntax Symposium (p. 77).

Oxman, R. (2008). Digital Architecture as a Challenge for Design Pedagogy: Theory, Knowledge, Models and Medium. Design Studies, 29(2), 99–120.

Patel, K. K., & Vij, S. K. (2010). Spatial Navigation in Virtual World, 1(1948), 101–125.

Peters, D., & Richter, K. (2008). Taking off to the Third Dimension - Schematization of Virtual Environments. International Journal of Spatial Data Infrastructures Research, 3(July), 20–37.

Peters, D., & Richter, K. F. (2007). Enhancing Wayfinding Abilities in a Large-Scale Virtual City by Schematization. GI-Days, 257–260.

Pohl, D., Johnson, G., & Bolkart, T. (2013). Improved Pre-Warping for Wide Angle , Head Mounted Displays. In Proceedings of the 19th ACM symposium on Virtual reality software and technology (pp. 259–262).

Portman, M. E., & Natapov, A. (2015). To Go Where No Man Has Gone Before: Virtual reality in Architecture, Landscape Architecture and Environmental Planning. Computers, Environment and Urban Systems, 54, 376–384.

Purwantiasning, A. W. (2015). Kajian Revitalisasi pada Bantaran Sungai Sebagai Upaya Pelestarian Bangunan Tua Bersejarah. In Simposium Nasional Teknologi Terapan (SNTT).

Ramadier, T. (2004). Transdisciplinarity and Its Challenges: The Case of Urban Studies. Futures, 36(4), 423–439.

Ramadier, T., & Moser, G. (1998). Social Legibility, the Cognitive Map and Urban Behaviour. Journal of Environmental Psychology, 18, 307–319.

Ramezani, S., Azri, Z., Abd, B., & Idid, S. Z. a. (2009). Public Space and Its Implication for Conservation of the Historic Living City of Melaka. Apsa Congress, 1–10.

Reinhardt, D. (2008). Representation as research: Design Model and Media Rotation. The Journal of Architecture, 13(2), 185–201.

Richardson, A. E., Montello, D. R., & Hegarty, M. (1999). Spatial Knowledge Acquisition from Maps and from Navigation in Real and Virtual Environments, 27(4), 741–750.

Said, S. Y., Zubir, S. S. S., & Rahmat, M. N. (2014). Measuring Physical Changes in an Urban Regeneration Scheme. WIT Transactions on Ecology and The Environment, 191, 1165–1174.

Samadi, Z., Omar, D., & Yunus, R. M. (2012). On-Street Visual Analysis on Outdoor Space of Jalan Hang Jebat, Melaka. Procedia - Social and Behavioral Sciences, 68, 353–362.

Schnabel, M. A., & Kvan, T. (2001). Immersive 3D Architectural Worlds : How to Get In and Out Again, 592–596.

Schnabel, M. A., & Kvan, T. (2003). Spatial Understanding in Immersive Virtual Environments. International Journal of Architectural Computing, (December).

Seichter, H. (2004). Augmented Reality Urban Design, 1–10.

Seichter, H., & Schnabel, M. A. (2005). Digital and Tangible Sensation: An Augmented Reality Urban Design Studio. The Tenth Conference on Computer-Aided Architectural Design Research in Asia (CAADRIA 2005), (pp. 193-202). New Dehli.

Shamsuddin, S. (2007). Konsep Baru Model Bandaraya/ Bandar Berasaskan kepada Rupabentuk Bandar Traditional.

Shiode, N. (2001). 3D Urban Models: Recent Developments in the Digital Modeling of Urban Environments in Three-Dimensions. GeoJournal, 52(3), 263–269.

Shokouhi, M. (2003). Legible cities: The Role of Visual Clues and Pathway Configuration in Legibility of Cities. In Proceedings. 4th International Space Syntax Symposium London 2003.

Shushan, Y., Portugali, J., & Blumenfeld-Lieberthal, E. (2016). Using Virtual Reality Environments to Unveil the Imageability of the City in Homogenous and Heterogeneous Environments. Computers, Environment and Urban Systems, 58, 29–38.

Simpson, D. M. (2001). Virtual Reality and Urban Simulation in Planning: A Literature Review and Topical Bibliography. Journal of Planning Literature, 15(3), 359–376.

Skagerlund, K., Kirsh, D., & Dahlbäck, N. (1994). Maps in the Head and Maps in the Hand, 2339–2344.

Snyder, J. C. (1984). Introduction to Architectural Research. In J. C. Snyder, Architectural Research. New York: Van Nostrand Reinhold Company Ltd.

Statistics, L. (2015). Kruskal-Wallis H test using SPSS Statistics. Statistical tutorials and software guides. Retrieved from Laerd Statistics: https://statistics.laerd.com/

Stavrić, M. (2013). The Use of Scale Models in Architecture. In Architectural Scale Models in the Digital Age (pp. 41–83). Springer-Verlag/Wien.

Stein, J. (2015, August 6). Inside the Box: The Surprising Joy of Virtual Reality. Time Magazine (pp. 30-39). New York: Time Inc.

Steinicke, F., Bruder, G., & Kuhl, S. (2011). Realistic Perspective Projections for Virtual Objects and Environments. ACM Transactions on Graphics, 30(5), 1–10.

Steuer, J. (1992). Defining Virtual Reality: Dimensions Determining Telepresence. Journal of Communication, 42(4), 73–93.

Tepavcevic, B., & Stojakovic, V. (2012). Shape Grammar in Contemporary Architectural Theory and Design. Facta Universitatis - Series: Architecture and Civil Engineering, 10(2), 169–178.

Thompson, E. M., Horne, M., & Fleming, D. (2006). Virtual Reality Urban Modelling - An Overview. In CONVR2006 6th Conference of Construction Applications of Virtual Reality. Orlando, Florida.

Tolman, E. C. (1948). Cognitive Maps in Rats and Men. Psychological Review, 55(4), 189–208.

Town and Country Planning Department Melaka. (2007). The Core and Buffer Zones of the Historic City of Melaka. Nomination Dossier: Historic Cities of the Straits of Malacca. Kuala Lumpur: National Heritage Department, Ministry of Culture, Arts and Heritage.

Travel 3Sixty. (2016, December). Hyper Tech: Gaming - The Next Generation. Travel 3Sixty.

Vanegas, C. a., Aliaga, D. G., Wonka, P., Müller, P., Waddell, P., & Watson, B. (2010). Modelling the Appearance and Behaviour of Urban Spaces. Computer Graphics Forum, 29(1), 25–42.

Vanian, J. (2017, January 1). Tech: Virtual Reality's Money Quest. Fortune Magazine, p. 18.

Vinson, N. G. (2003). Design Guidelines for Landmarks to Support Navigation in Virtual Environments, (May), 9.

Viswanathan, V. K., & Linsey, J. S. (2009). Enhancing Student Innovation: Physical Models in the Idea Generation Process. 2009 39th IEEE Frontiers in Education Conference.

Wan Ismail, W. H. (2010). Users ' Perceptions of Shopping Activities in the Historic City of Malacca. Asian Journal of Environment-Behaviour Studies, 1(3), 73–82.

Wan Ismail, W. H. (2012). Sustainability of Buildings in Historic City of Malacca. Asian Journal of Enviroment-Behaviour Studies, 3(10), 57–69.

Wann, J., & Mon-Williams, M. (1996). What Does Virtual Reality Need?: Human Factors Issues in the Design of Three-dimensional Computer Environments, 829–847.

Weebers, R. C. M. (2015a). Architecture and Typology of Dutch shophouses in Melaka, (August), 0–18.

Weebers, R. C. M. (2015b). The Dutch Settlements and Its Development in the Historic City of Melaka, (August), 0–11.

Weebers, R. C. M., Ahmad, Y., & Ali, Z. M. (2013). Dutch Public Buildings Facade Typology Analysis.

Whyte, J. (2002). Virtual Reality and the Built Environment. Oxford: Architectural Press.

Winter, S., Raubal, M., & Nothegger, C. (2004). 9 Focalizing Measures of Salience for Wayfinding, (2002), 129–139.

Wu, A., Zhang, W., & Zhang, X. (2009). Evaluation of Wayfinding Aids in Virtual Environment. International Journal of Human-Computer Interaction, 25(1), 1–21.

Xi, D., Fan, Q., Yao, X. A., Jiang, W., & Duan, D. (2016). A Visual Salience Model for Way Finding in 3D Virtual Urban Environments. Applied Geography, 75, 176–187.

Yeung, H. W., & Savage, V. R. (1996). Urban Imagery and the Main Street of the Nation: The Legibility of Orchard Road in the Eyes of Singaporeans. Urban Studies, 33(3), 473–494.

Yin, X., Wonka, P., & Razdan, A. (2009). Generating 3D Building Models from Architectural Drawings: A Survey. IEEE Computer Graphics and Applications, 29(1), 20–30.

Yuan, S., Song, S., & Zhang, Y. (2014). Experimental Research in Urban Spatial Cognition by Using Virtual Reality Technology. Athens Journal of Technology Engineering, 19-32.

Zachara, M., & Zagal, J. P. (2009). Challenges for Success in Stereo Gaming: A Virtual Boy Case Study. Ace, 99–106.

Zadeh, F. A., & Sulaiman, a. B. (2010). Dynamic Street Environment. Local Environment, 15(5), 433–452.

Zubir, S. S., & Sulaiman, W. A. (2004). Initiatives and Intervention in Promoting Pedestrianization in the Historic City of Melaka, Malaysia. Walk21-V Cities for People, The Fifth International Conference on Walking in the 21st Century, 1–21.

Zybaczynski, V. M. (2014). Colour - Important Factor in Preserving the Local Identity. Urbanism. Arhitectură. Construcţii, 5(4), 87–92.