Usability of Online Virtual Geographic Environment for Urban Design

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Abstract

Collaborative Virtual Geographic Environment (CVGE), a technology derived from Virtual Reality (VR), is today becoming widely and freely available. This technology has potential for use in the field of 3D urban planning and design. An example is the online tool OpenSimulator. Rigorous assessment of the usability of such tools is needed to determine their impact on the field of urban design. A previous study consulted with a small group of urban design professionals and concluded from a user satisfaction and usability standpoint that online VR had potential value as a 3D collaboration, remote communication and marketing tool. However, visual quality and geographic accuracy of the technology are downsides that need to be overcome. This research takes the investigation a step further than the previous study to also examine the usability aspects of efficiency (how quickly tasks are completed) and effectiveness (how successfully tasks are completed), relating to CVGE used in the design process. The comparative study tests a CVGE (with increased graphic fidelity and geographic content to address the feedback of the previous study) of a subdivision design in a suburb of Dunedin, New Zealand, against 3D models built with a Geographic Information System (GIS – ArcGIS) and Computer Aided Design (CAD – BricsCAD) tools, two types of software that are already widely adopted and well established in urban design professional practice. This research collected and analysed the experiences and results from 16 urban design professionals and students who attempted to perform timed tasks correctly in each of the environments, before being asked questions about the technologies involved and the importance they perceive the technologies to have to their professional work. The results support and reinforce the feedback for VR from the previous study, with the graphical and geographic data issues being somewhat addressed and a number of new issues identified which also require further refinement of the technology to suit the application. Ease-of-use, and the associated fastest speed of completion of tasks, were significant outcomes to emerge from the comparison with GIS and CAD, and the results point to the likely level of integration of CVGE technology in an urban planning and design context in the future.

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List of Abbreviation

3D	Three dimensional
ANOVA	Analysis of Variance
CAD	Computer Aided Design
CSCW	Computer-support Cooperative Work
CVGE	Collaborative Virtual Geographic Environment
DCC	Dunedin City Council
DEM	Digital Elevation Model
DTM	Digital Terrain Model
GeoVE	Geovirtual Environment
GIS	Geographic Information System
GNS	Geological & Nuclear Science
GPS	Global Positioning System
GPU	Graphic Processing Unit
GUI	Graphical User Interface
HCI	Human-Computer Interaction
LIUDD	Low Impact Urban Design and Development
LIDAR	Light Detection and Ranging
LOD	Level of Detail
OpenSIM	Open Simulator
PC	Personal Computer
RS	Remote Sensing
SE	Software Engineering
SL	Second Life
TIN	Triangular Irregular Network
UCD	User-centred Design
UE	Usability Engineering
UI	User Interface
VE	Virtual Environment
VGE	Virtual Geographic Environment
VR	Virtual Reality

Chapter 1 Introduction

This chapter defines the motivation, background, and structure for this research.

1.1 Research Motivation

Significant growth of global information exchange and collaboration influences the working pattern of urban design. Generally, urban designers occupy a dominant position in the overall design process. However, more citizens and other stakeholders such as land developers, local authorities, and surveyors, want to be involved in making important decisions as part of the design process (Laurini, 2001). For centuries, technology such as hand drawings and models has been sufficient to communicate designs of urban spaces. Such technology is still used, and is still sufficient, for many urban design tasks. However, an urgent priority for designers and planners today is to explore innovative approaches that can respond to the requirements of growing global collaboration and increasing expectations of public participation. This is especially the case for tasks such as developing a vision of an urban design environment, testing and evaluating design solutions, and communicating design proposals to interested parties (including the wider public). The practices and tasks that make up urban design are described in greater detail in Section 3.1, and many of these practices and tasks rely on technology for visualisation and communication. However, little has been done previously to comparatively evaluate urban design technologies to discover the benefits and drawbacks of each.

The use of 3D technology to perform urban design "tasks" as listed in Section 3.1 will enable the public to understand and participate in urban design. Greater participation in the *process* of urban design ensures that designs are of a sufficient quality to satisfy the needs of *people*, not just the conveniences of the designer (see Section 3.1). More efficient communication and collaboration with other professionals from fields such as surveying, engineering, architecture, planning, and many others can also be facilitated.

Surveyors and urban designers have recognised the value and potential of utilising 3D representations in their day-to-day operations (Batty et al., 1998). However, they still

mainly use computer-based tools such as CAD, GIS (Campagna, 2006), and even hand drawing, which have constrained capabilities in the third vertical dimension (Batty et al., 1998). There are dimensional mismatch issues between the data collected from the real world and the software that they are working with: with this constrained capability, screen-based technologies such as CAD and GIS are well suited to 2D representations, but the real world is three-dimensional.

In this ubiquitous digital age, rapid developments of computer-based technologies (such as cheaper computer hardware, faster rendering and calculating capacity, etc.) significantly impact on methods of collecting and processing data. In particular, three-dimensional technology is one of the hottest topics in recent years, including 3D modelling, 3D printing and 3D computer graphics.

A possible reason for the current situation is that urban designers and planners require a tool that can keep the best balance between geographic and geometric truth and rendering speed. Also, due to economic, environmental and local financial issues these professionals have an expectation of cutting costs by choosing an inexpensive but efficient tool.

As the literature review (Section 4.5) shows, little has been done previously to implement a comprehensive usability assessment of 3D technology, and in particular Virtual Reality (VR), for urban design. Research must directly address this through a comprehensive comparative usability assessment of available technologies applied to urban design tasks and practices (discussed in Section 3.1) to determine their relative benefits and drawbacks.

1.2 Research Background

Virtual reality, or the generation of virtual environments, is defined as a 3D computer-based simulation of a real or imagined environment that users are able to navigate through and interact with (Slocum, 2009). It is an interactive approach to the presentation of 3D models that provides users with a more immersive, interactive and visualised experience than conventional delivery mechanisms.

Integrated with the internet, gaming technologies, and upgraded hardware, online (real-time) virtual environments have become free and accessible enough for widespread dissemination and use during the past decade (Germanchis et al., 2007). They enable the user to connect remotely, increasing the possibility of public engagement with processes that have previously remained difficult for the layperson to access due to the need for specialised knowledge and tools.

Online Virtual Geographic Environments (VGEs) are considered a promising approach in urban design (Zhang & Moore, 2014). A VGE is an extension of Virtual Reality (VR), which incorporates geographic information into the VR models used, enabling the VR to emulate the geography of the real world in virtual space. In comparison to the highly abstract coding of height information with 2D contour lines and shading, 3D products provide a more intuitive modelling of space (Jobst et al., 2007). VGE gives a user the ability to visualise and interact with geographic data. It is also an effective 3D interface that is capable of representing the "real world" in a computational environment.

One branch of online virtual geographic environment is the Collaborative Virtual Geographic Environment (CVGE). This is defined as a distributed geographic environment (i.e. it can be shared among multiple distributed users across the internet, providing collaboration functionality) containing geographic phenomena and models, to support collaborative research and planning (Gong et al., 2010). This is one of the theoretical foundations of this project, as it enables increased communication and collaboration between professionals from different fields, as well as the general public who may not be experts in any related field.

The technological progress of computing and the internet enables geographic information scientists, particularly those involved in cartography and geovisualisation, to find more innovative ways of representing geospatial data. Previously such data was little more than a map, i.e. a 2D picture of a geographic area, perhaps stored digitally with attribution of map features. Now, geographic information can often be visualised in three dimensions, interacted with in multiple

different ways, and communicated to many different people. It has also significantly changed people's expectations of viewing and analysing geospatial data, as many people want to access the information they require in an easier way, and increasingly expect technology to help them do so.

In this context, the continued developments of 3D visualisation and interaction technologies bring exciting possibilities for cartography. It is also a visualisation method which is more in line with the way people 'view' and 'perceive' the world. Common uses of this technology include natural disaster risk modelling, tourist information, and public communication of plans for developments such as roading and subdivision development.

Rooted in this topic area, professionals increasingly expect a fresh and comprehensive approach, integrating with other spatially related technologies, to deliver and present design works. Considering previous projects (Greater London, UCL Centre for Advanced Spatial Analysis, reported by Hudson-Smith (2008); virtual Queenscliff, Germanchis et al, 2007, etc.) which support the representation of city environments for the purpose of better information sharing, it is crucial that designers and developers explore a more realistic representative modelling method which is better at the three-dimensional level.

This research is built upon the previous project reported in Zhang (2011) and Zhang and Moore (2014). In the 2011 project, a 512m by 512m site, including proposed developments and existing surroundings, was built using OpenSimulator (OpenSim), an online virtual reality (VR) platform, as a sample for the invited professionals to evaluate. The purpose of the previous project was to investigate whether or not urban designers would benefit from a VR-based urban design environment.

However, the previous research only explored satisfaction and remote communication aspects. As further research, this project is aiming to explore in-depth, online CVGE as an innovative way to deliver a proposed urban or subdivision development plan, and provide a direct usability comparison with the incumbent CAD and GIS

technologies regularly used by urban designers and planners.

1.3 Thesis Structure

Chapter 2 includes a full description of the aims and objectives of this project, setting the context and defining what is in scope for this research. The major objectives and sub-objectives of this research are defined in this chapter.

Chapter 3 provides a definition of urban design, and the key tasks involved in the urban design process. This chapter reviews several urban design concepts and practical technologies (especially CAD and GIS) that are in current use.

Chapter 4 outlines advantages of using Collaborative Virtual Geographic Environments (CVGEs) for urban design, and particularly for the tasks identified in Chapter 3. Chapter 4 also refers to previous research that uses CVGE as a visualisation and collaboration tool, and includes a brief summary of the previous research project (Zhang & Moore, 2014) on which this research project is built.

Chapter 5 presents the usability criteria that are used for assessing CVGE as an urban design tool, a description of the evaluation method (usability testing), data collection method (questionnaire), and data analysis techniques (Statistical Analysis, Chi-Square test, and ANOVA). These relate to the main objective outlined in Chapter 2, which is to undertake a comparative usability assessment of proposed urban design scenarios realised by three different technologies: CAD, GIS, and online VR.

Chapter 6 covers the workflow of this project, including the 3D environment construction process, data preparation for the Virtual Geographic Environment, and the outcomes in VGE, GIS and CAD. A detailed usability assessment process using the methods described in Chapter 5 is then presented. This supports the purpose of this thesis, which is to determine the feasibility of using Virtual Reality (VR) technology, that is supported by geographic information and is geographically realistic, as a useful tool for urban design.

Chapter 7 contains the research results. This chapter first presents the content of a questionnaire which was used to obtain data from participants in the study, including feedback assembled from the surveyed professionals. The results obtained from this questionnaire are then analysed and presented. Tables and charts are used to present the quantitative data, and this chapter also includes a summary of the qualitative data obtained. This data is the result of the usability testing performed using the methodology presented in Chapter 6.

Chapter 8 focuses on the outcomes and research limitations based on the analysis results presented in Chapter 7, and on observations during the testing stage. A discussion of the results presented in chapter 7 is presented, against the background of the main objective and sub-objectives presented in Chapter 2.

Chapter 9 identifies improvements for this research, and also proposes functional improvements for an urban design tool on the basis of the findings reported in Chapters 7 and 8. Further research directions are also proposed.

Chapter 2 Aims and Objectives

This chapter includes a full description of the aims and objectives of this project, setting the context and defining what is in scope for this research. The major objectives and sub-objectives of this research are defined in this chapter.

2.1. Purpose

The field of urban design has been transformed by modern technology, enabling a degree of collaboration and communication between designers and the public which was previously unavailable. Virtual Geographic Environments have been recognised as a valuable method to visualise abstract urban design concepts. In previous research, urban designers showed their willingness to use this technology in future projects (Zhang, 2011; Zhang & Moore, 2014).

The ultimate purpose of this research is to **determine the feasibility of using Virtual Reality (VR) technology, that is supported by geographic information and is geographically realistic, as a useful tool for urban design.**

This thesis proposes the hypothesis that **urban design practice can benefit from the use of online VR software for tasks that involve visualisation and interaction,** particularly tasks such as developing a vision of an urban design environment, testing and evaluating design solutions, and communicating design proposals to interested parties (including the wider public) - See Section 1.1. This is in the context of comparison with more conventional technologies traditionally used in urban design, such as CAD and GIS. To research the validity of this hypothesis, the main objective is **to implement a comparative usability assessment of proposed urban design scenarios, realised by CAD, GIS (screen-based technologies including both 2D and 3D capability) and online VR software (screen-based but purely 3D technology orientated)**, for urban design tasks (as described in Section 3.1) to discover the benefits and drawbacks of each.

This research aims to compare the advantages and disadvantages of these three tools, particularly when visualising and communicating an urban design proposal. It also aims to investigate the possibility of using online VR software to determine if real time 3D rendering would help the design profession. The comparison will focus on the three fundamental aspects of usability testing (Haklay et al., 2010): **efficiency** (speed of use), **effectiveness** (correctness of use) and **satisfaction**.

Usability testing of different technologies is an acknowledged systematic way to assess whether they can succeed in supporting the specific urban design tasks listed in Section 3.1. A comprehensive comparative usability assessment will address the technology's ability to facilitate performing these core urban design tasks. This research uses usability testing to evaluate CAD, GIS, and VR for urban design and draw comparisons between them.

To reach the main objective and prove or disprove the hypothesis, several sub-objectives were identified. These each needed their own research in order to achieve the main objective, and were mostly technical in nature, comprising steps that were required along the way. However, the sub-objectives were also chosen with the usability criteria in mind, to highlight the suitability of the visualisation methods (CAD, GIS and VR) in application to urban design.

1. **To build and comparatively evaluate 3D environments, based on a proposed urban subdivision development, containing existing buildings and potential developments.**

   A test site called Grandvista, part of the Dunedin suburb of Fairfield, was built in CAD, GIS and online VR workspaces separately. Experienced specialists were invited to test these environments in the three aspects of usability testing (efficiency, effectiveness and satisfaction) to determine whether they would be useful to them in their work as urban designers. When the testing was complete, the participants were asked to answer a series of questions contained in a questionnaire,

about the quality of experimental models and their experience of using the software.

The experimental region contains pre-existing surroundings and a planning area populated by proposed buildings. The elements within 3D environments include terrain models, building models and vegetation models. Using these models, we explore the advantages and disadvantages of the VR-based design environment, as compared to conventional approaches used by urban professionals (static design platform in CAD and GIS).

To carry out the evaluation and comparison, a group of participants were invited from the surveying and urban design communities. The models and a set of tasks were sent to these professionals for evaluation. They were accompanied by task introductions and a questionnaire. The participants were asked to modify the virtual environment, evaluate the 3D-based site design models and finish a set of tasks.

The results gathered from the questionnaire, along with statistical metrics summarised from the participants' answers, were then subjected to analysis. The results of this analysis constitute the primary data for this project. They also demonstrate where 3D online VR may fit into designers existing working practice.

This sub-objective allows the evaluation of screen-based and VR-based methods of performing urban design tasks using all three of the chosen usability criteria, as the results obtained through the questionnaire posed to participants elicit responses regarding such things as the time taken to perform tasks, and the feelings of the participants themselves towards the methods used. This addresses the efficiency of the solution, i.e. how quickly urban design tasks can be carried out using the technology, as well as the satisfaction of the users towards its use, i.e. whether they felt that the solution was useful to them in their work. This enables the realisation of visions of urban design (See "Visioning", Section 3.1), and the 3D online VR technology facilitates rapid construction of alternative scenarios, which fits in with urban design concepts of testing competing visions (see "Synthesis and Prediction",

Section 3.1).

2. **To explore an effective method to improve the realism of interaction with the CVGE and its realistic texturing and rendering to make it more effective for urban designers.**

The rendering effect is one of the vital factors influencing the presentation of the design result. Added realism means more effective communication, including both visual communication and remote communication with collaborators - the latter a vitally important part of ensuring efficiency in the urban design process. It impacts people's judgement towards the entire outcome. Therefore, it is an important consideration in terms of choosing the design package and delivery method. On account of user feedback collected from the research project documented in Zhang and Moore (2014), this research references the Kolbe et al. (2005) suggested standard for CityGML virtual city models - Level of Detail (LOD) 1 to LOD 4 - to obtain a higher visual quality model.

In the previous research project, participants who had prior experience of using 3D software pointed out that a successful tool should provide accurate and quick rendering capacity to support better performance at three-dimensional level. The results also showed that it is important to improve the level of 'realism' before a VR-based urban design environment becomes truly feasible. The texture of models visualised in the 3D environment was often "blocky", with sharp edges and large areas of uniform shading in certain situations, which had a negative effect on the level of realism of the model because it was sometimes difficult for users to interpret and visualise the 3D modelled objects.

This sub-objective is mainly concerned with the satisfaction of the users towards the tools used (screen-based or VR) and to some extent their effectiveness. Giving the user more ways to control the environment and their interaction with it was tested, and the results analysed. This too relates to Visioning, as well as to

Decision-Making and Evaluation, allowing urban designers to be more effective in their work (see Section 3.1).

3. **To understand the effects on efficiency and effectiveness, of incorporating geographic data into the environment.**

Zhang & Moore (2014) describes improving the realism of a 3D environment by importing georeferenced orthophotos into the environment. While this is a common feature of screen-based tools, particularly GIS which has traditionally been strong on the enforcement of geographic topology, 3D tools have often left out this texture-rich data in order to improve 3D rendering and make user interaction easier - sacrificing realism for speed of rendering. With the advances in computer technology discussed in Section 1.1, this may largely be unnecessary today.

However, georeferenced information inside the environment can act as an aid to design, by enabling designers to see and work within the context of the existing environment. This is important for many reasons, such as navigation within the environment, the placement of objects such as buildings in the context of existing objects, and for assessing the effects of proposed changes such as tall buildings and sun angles at different times of day. It is therefore important that if screen-based methods of carrying out design tasks are able to utilise this detailed georeferenced information, that a rigorous test of 3D methods should include the same, in order to provide a valid comparison.

Georeferenced orthophotos were brought into a virtual environment as guidance for locating 3D building objects as well as being used for providing context for existing real-world objects. This sub-objective is concerned with all three of the usability criteria, though it is largely aimed at assessing the efficiency and effectiveness of the design tool, assessing speed and the amount of error in completing tasks as desirable attributes. This relates to the tasks of Analysis and Evaluation in urban design, and to a lesser extent the Visioning and Decision-Making tasks (see Section 3.1).

Chapter 3 Urban Design

This chapter provides a definition of urban design as used in this research to understand the key tasks involved in urban design practice. Later in the chapter (Section 3.3), the contribution of digital tools to the urban design process, particularly the use of 3D elements, are examined.

3.1 What is Urban Design?

Many definitions of urban design have been proposed, depending on the context e.g. historic, proprietary, or process oriented (Barnett, 1982; Mackay, 1990; Punter & Carmona, 1997; Schurch, 1999; Moughtin, 2003; Krieger, 2011). Madanipour (1997) analysed various aspects of urban design and summarised seven areas of ambiguity in its definition:

1.   Should urban design be focused at particular scales or levels?
2.   Should it focus only on the visual qualities of the urban environment or, more broadly, address the organisation and management of urban space?
3.   Should it simply be about transforming spatial arrangements, or about more deeply seated social and cultural relations between spaces and society?
4.   Should the focus of urban design be its product (the urban environment) or the process by which it is produced?
5.   Should urban design be the province of architects, planners or landscape architects?
6.   Should it be a public or private sector activity?
7.   Should it be seen as an objective-rational process (a science) or an expressive-subjective process (an art)?

Although Madanipour's ambiguities are deliberately presented as oppositional and mutually exclusive, in most cases, it is a case of 'and/both' rather than 'either/or' (Carmona et al., 2010). In particular, Madanipour (1997) refers to urban design as both a process and a product. Most definitions commonly agree that urban design is a *process* of shaping city structure and public networks (e.g. transportation and

infrastructure) to create a harmonious relationship between people and their environment, and to provide adequate connections and interactions between neighbourhoods. This process includes a variety of activities (e.g. zoning, transportation planning, housing programs, etc.) to achieve envisioned and desired goals within the natural and built environments (Laurini, 2001).

Some definitions also incorporate Madanipour's idea of urban design as a *product* (Madanipour, 1997). Carmona et al., (2010) refers to this definition. While, in practice, 'urban design' can be used to refer to all the products and processes of development, it is often useful to use the term in a more restricted sense to mean *adding of quality* to them (Carmona et al., 2010).

This is the definition of urban design selected for this research, in terms of the tasks that are performed (e.g. placing design elements into the model space), the tools that are used to perform them (e.g. Computer Aided Design (CAD), Geographic Information Systems (GIS), or Virtual Reality (VR)), and the product outcomes used to communicate with professionals and the public (e.g. a 3D environment representing an urban design scenario).

To reinforce this definition, the ultimate goal of urban design is to design environments that are of a *quality* to ensure people live, work, and play efficiently and comfortably, and to serve contemporary living (Rowley, 1994). Therefore, this research adopts the concept of *adding quality* to the design of urban spaces as being the goal of urban design practice.

Practices and Tasks in Urban Design

Carmona et al. (2010) defines ten types of urban design practice:

- The total designer, where a single person or team carries out the entire design.

- The 'all-of-a-piece' urban designer, where a single designer or firm prepares the master design and acts as a reviewer for design sub-elements.

- The vision maker or concept provider, where the designer provides the concept for the design as a set of guidelines for others.

- The infrastructure designer, where the designer is purely interested in the infrastructure such as streets, public spaces etc. and enables others to add other design elements around these.

- The policy maker, closely involved with the decision-making process for a positive future, providing guidance and advice to decision-makers.

- The guideline designer, who establishes detailed design principles in the form of policies for the use of urban spaces.

- The urban manager, who promotes, develops and undertakes day-to-day management of urban areas.

- The facilitator of urban events, who facilitates and initiates cultural programmes to encourage a diverse range of people to visit.

- The community motivator or catalyst, who is responsible for enabling community participation in the development process (a role facilitated by online VR and other freely-available tools such as open-source GIS).

- The urban conservationist, who influences the decision-making process with regard to the delicate balance between retention and change.

Each of the above practices of urban design performs a different role, and it is clear that urban design is not one single linear effort, but is a multi-faceted discipline. The set of tasks performed in each practice varies depending on the needs of the practice. However, each practice sets similar goals, and works to the same set of design principles.

Meanwhile, Sorkin (2004) defines eleven tasks that urban designers must perform to design quality urban spaces: Reinforce neighbourhoods; make it sustainable; add

green everywhere; secure the edge; make public places; be sure rooms have views; finesse the mix; elaborate movement; localise architecture; defend privacy; and make it beautiful.

Sorkin's list appears more concerned with the end results of urban design (the *product*) than with the *process* of creating quality designs for urban spaces. If these tasks apply to process at all, they are more akin to a set of rules by which urban designers should perform their work, rather than "steps" performed in urban design in a practical sense. Nevertheless they are useful to identify the important aspects of urban design that can be enhanced by the use of 3D digital technology, whereby design plans can be modelled and visualised in three dimensions to add quality to the design in any of the tasks listed.

Carmona et al. (2010) define four phases to urban design: brief setting; design; implementation; and post-implementation review. These four stages are further disaggregated into six "thought stages" which are useful to think of as tasks performed by the designer during the urban design *process*:

- **Setting goals:** in conjunction with other actors (particularly clients and stakeholders), and having regard to economic and political realities, proposed time scales, and client and stakeholder requirements. This can be facilitated by online communication with these actors to gain greater speed and efficiency in the goal setting task.

- **Analysis:** gathering and analysing information and ideas that might inform the design solution.

- **Visioning:** generating and developing various possible solutions through an iterative process of imaging and presenting, usually informed by personal experience and design philosophies.

- **Synthesis and prediction:** testing the generated solutions to identify workable alternatives. This can be facilitated by technology, such as online VR, allowing

designers to test scenarios and easily modify and re-test in a short space of time.

- **Decision-making:** determining the alternatives to be discarded, and those for further refinement or promoting as the preferred design solution.

- **Evaluation (appraisal):** reviewing both the finished product and its success, measured against the identified goals. This thesis has evaluated the fundamental aspects of usability as applied to screen-based and VR-based technologies; this could potentially parallel their use to evaluate urban design proposals also.

The use of 3D digital technology to perform urban design tasks largely applies only to some of these, in particular visioning, synthesis and prediction, and evaluation. These are the urban design tasks we refer to in this research.

Although new technology offers the opportunity to make information more accessible and comprehensible, designers need to appreciate the many roles that a computer can play in the design process, as well as its advantages and disadvantages for each task. The ability to communicate design more persuasively raises important issues regarding the ethics of communication. State-of-the-art visualisations of projects often mean that few people understand precisely how the data is manipulated or can access the information to verify a simulation's accuracy. It is important therefore that technological developments are harnessed to enable better understanding and involvement of the public in decisions affecting their environment. The use of technology could help to create an increased awareness of urban design, and facilitate the ability for everyone to react to, and interact with, proposals for the built environment (Carmona et al., 2010). This is also facilitated by the advent of freely available and readily accessible software such as OpenSim and open-source GIS technologies such as QGIS.

Therefore, the use of 3D technology to perform the urban design "tasks" listed above will enable a better understanding of, and participation in, urban design by the public, and better communication between designers across the urban design practices defined by Carmona et al. (2010) as well as other professionals from fields such as

surveying, engineering, architecture, planning, and many others. Greater participation in the *process* of urban design ensures that designs are of a sufficient quality to satisfy the needs of *people*, not just the conveniences of the designer - This is a part of the motivation for this research (see Section 1.1).

Geodesign - a New Way of Thinking Urban Design Process

In moving from hard-copy based design to digital design, the term 'Geodesign' is used to describe design activities. Geodesign means bringing geographic analysis into the design process (Gardner, 2012).

The developments in geodesign reinforce two factors:

- The importance of effective collaboration. This enables experts from different fields to work together to address matters such as health, safety, and welfare in the built environment, and ensures integration of many different professional fields to come up with high quality design scenarios.

- Existing urban environments are vital elements which have been given increasing consideration in the field of design. Consistent design decisions must be made between existing and new urban environments, in order to develop a sustainable, environment-friendly community.

3.2 The Need for an Urban Design Process

The above section presents two requirements for a quality urban design scenario: collaboration, and sustainable development. A third requirement, the need to increase public participation in the design process through effective communication, is suggested by Laurini (2001). This section provides more detail about these requirements.

Collaboration

From a broad perspective, urban design deals with arranging buildings and landscapes

at large and detailed scales, connecting neighbourhoods, and structuring streets and service networks, to make areas attractive and functional. Urban design tends to be a cooperative and multi-disciplinary process incorporating urban functioning, economic issues of cost and benefit, aesthetic issues of appearance, and social issues involving social allocation and provision (Batty et al., 1998). The entire process involves a large number of people from initial concept phase through to implementation and on-going management (Ministry for the Environment, 2006).

Within this context it is unavoidable that communication issues will arise between local authorities, designers, surveyors and engineers, who each have different motivations and vocabularies when talking about urban design. Additionally, a wider range of clients and increasing collaboration between professionals and clients requires support through information sharing and remote communication, which raises challenges but also opportunities for urban designers. When properly administered, collaboration can result in more meaningful participation and more creative outcomes (Innes & Booher, 2000).

This means designers are able to make better quality decisions in resolving community needs and increasing community values through effective collaboration; therefore it is advantageous to look for methods or tools that can support the practice of urban design, to aim to eliminate any limits of understanding within the discipline and provide higher quality design outcomes.

Carmona et al. (2010) describes frameworks and masterplans drawn up by a number of people with different skills working in collaboration. Urban designers typically work within a context of multiple clients, often with conflicting interests and objectives, developing as a consequence of multiple solutions to a problem, rather than a single solution. This process includes not just architects, landscape architects, planners, engineers and surveyors, but also developers, investors, occupiers, civil/ public servants, politicians, events organisers, crime and fire prevention officers,environmental health officials and many others.

Sustainable Development

The core concepts of urban design have evolved, along with a transformation in attitudes about the relationship between humans and their environment. It is now widely recognised that decisions relating to land use and infrastructure (e.g. new roads, airports, housing developments, industrial estates, etc.) will affect our environment for a long period of time (Stillwell et al., 1999). Consequently, a vital factor in increasing urban competitiveness is environmental sustainability.

Coupled with this, the core concepts and attitudes of urban design are more inclined to create a sustainable community. They enable professionals to design good housing and living environments in a sustainable way, through efficient use of natural resources, mitigating the level and effects of pollution, increasing areas set aside for reserves and utilising natural systems to manage storm water and drainage. This demands a system that is capable of managing a large volume of data over a long term.

Urban design projects or developments are more likely to take place within existing communities, or enveloped by other neighbourhoods (Axford et al, 2007). Urban designers are advocating more compact and efficient land use as well as fitting potential developments into the existing surroundings and contexts (Krieger, 2011). To fit in this situation, a mixed use community including commercial areas and mixed-density residential areas is a key urban design strategy, and factors such as connections with other neighbourhoods and potential land use need to be considered within the whole design process in order to integrate designed projects within the surrounding urban landscape.

Innovations within the urban design realm have impelled urban design professionals to introduce advanced computer technologies to improve their simulation methods. A visualised and understandable spatial model is a valuable tool for designers to analyse, evaluate and improve their outcomes. Such a tool will enable clients to gain a good sense of potential developments, have better communication with urban

designers, and increase participation in the design process.

Public Participation

Section 3.1 states that urban design outcomes should service people who live, work and play within an urban environment. Public participation, supporting the population's commitment and guidance to urban planning actions, is therefore of utmost importance in the development process and transformation of the cities for the future (Amado et al., 2009).

Nobre (1999) has established four main degrees of community participation (paraphrased from Laurini (2001)):

- **"Inform"** - minimal participation in the process; design decisions are often made from afar to work toward a successful outcome.

- **"Consult"** - to inform, plus to collect the opinions of the represented parties, and accept the results of these opinions as input to the decision-making process.

- **"Discuss"** - to share knowledge, and help the represented parties understand the process and the inputs to it.

- **"Share"** - to discuss, but also to share the power to make decisions. The highest form of community participation.

Therefore, through better communication, the level of public participation can be increased from a "inform" scenario toward a "share" scenario. This will in turn result in better design outcomes as suggested by Amado et al. (2009).

3.3 Computer-Based Tools for Urban Design

Although urban *planning* has used computer models and information systems since the 1950s, and architectural practice has more recently structured to the use of computer based design and drafting, urban *design* has been late to come to the digital

world (Batty et al., 1998). Bosselmann (2007) also mentioned that physical models are still used for detailed discussions and presentations to the public even though three-dimensional urban modelling can be done with Computer-Aid Design (CAD) and Geographic Information System (GIS) applications. The following image (Figure 3.1) shows hand-drawn rendering effects of Lismore park in NSW, Australia. This type of hand drawing work is still commonplace; both physical models and hand drawings are still used in urban design because they are still effective communication methods.

Figure 3.1 Hand drawing plan for Lismore park in NSW Australia (Veedesign website, 2017)

Computer-Aid Design systems (CAD)

Digital visualisation and editing techniques, such as those provided by CAD, enable different capabilities for designers in comparison to conventional hand drawing methods which were ubiquitous prior to the digital age. Digital models can be used to gain knowledge of current urban structure, implement precise graphic analysis, and show the eventual effects of a future built environment (Jacunski, 1993; Bosselmann, 2007). The following image (Figure 3.2) is a development plan for a rezoned residential area around Taupo, New Zealand (Cheal website, 2017). The Taupo

District Council's design has set out to develop the subject site based upon sustainable design principles.

Figure 3.2 A development plan for a rezoned residential area around Taupo (source from Cheal, a surveying company in Taupo (Cheal, 2017))

Geographic Information Systems (GIS)

Geographic Information Systems are another tool used by urban designers, designed to store, analyse, manipulate and transform geographic data, and link the stored geographic features with an underlying database of attributes. It also incorporates accurate geographic data processing and effective 3D representations (Longley et al., 2005). GIS can not only produce excellent 2D maps, it can also associate with other technologies such as Global Positioning Systems (GPS), laser scanning and Remote Sensing (RS) to represent elevation data in 3D.

The role of GIS in urban design is largely in providing long-term data management and decision support functions (Laurini, 2001), and enabling exploration and visualisation capabilities and improving communication among stakeholders such as Local Authorities (LAs). An example is in Figure 3.3 which portrays the Wellington City (New Zealand) district plan through the Wellington City Council's webGIS tool

(*eplan*) powered by ESRI (*Environmental Systems Research Institute*) GIS technology. The webGIS is a great public engagement tool which create an effective communication channel in between the Wellington City Council and the public who live in this area.
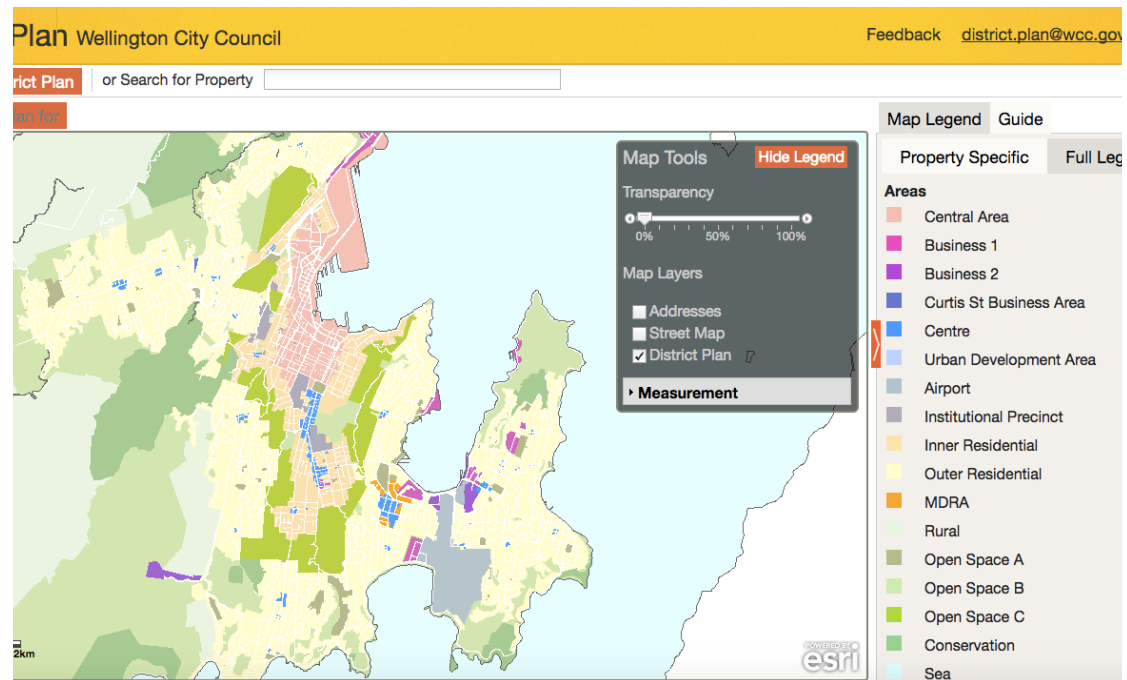
Figure 3.3 Wellington City district plan accessed from Wellington City Council webGIS tool (Wellington City Council webGIS , 2017)

Advancements in three-dimensional software

In recent years free or cheap software and data for 3D communication have provided designers an increasing opportunity to use three-dimensional geospatial visualisation and simulation. Mainstream design related software has followed this trend and equipped 3D functions into design products. For example, BricsCAD is a powerful CAD platform that provides a good user experience in three-dimensional design. Users can create 3D templates and transform easily between 2D and 3D (BricsCAD, 2015).

CAD packages are capable of supporting design curves, surfaces and solids in 3D. Designers are able to scale, generalise, analyse and colour 3D maps. They can also generate 3D models with CAD. However, the 3D productions of CAD are still very few back to the 2D world (Batty et al, 2002).

ArcGIS Desktop is another example which is used in this research project for data transformation and 3D modelling. It includes three viewers: ArcMap, ArcGlobe and ArcScene 3D. Among these viewers, ArcGlobe and ArcScene are 3D-oriented, and enable users to view and edit geographic data in three dimensions (ArcGIS 2015).

Compared with CAD, geographic information systems are more refined in their level of analysis, and more smoothly embody the 3D world in their various extensions (Batty et al, 2002) such as the above ArcGIS viewers. However the capabilities of CAD and GIS overlap to some extent, and both have made the technological jump into the 3D world. The following screenshot (Figure 3.4) shows Sedbergh in the United Kingdom in 'semi-3D' created by QGIS (termed '2.5D' due to its 3D look made up of 2D features extruded by using a height attribute), which is a realistic way for users to 'see' the features on the ground.

Figure 3.4 A screenshot of 2.5D land features in Sedbergh, UK (Dragons8mycat, 2017)

Both GIS and CAD have been used for some time in urban design practice, and are useful tools for urban design tasks (listed in Section 3.1). GIS is useful for information storage and management, and can be used for analysis, visioning, synthesis and prediction, decision-making, and appraisal. CAD is also used for

visioning, but less for analysis and information management. GIS and CAD have a different focus in the tasks they perform in urban design. The combination of these two technologies can be used to achieve an urban design result covering most of the urban design tasks listed in Section 3.1.

Geodesign tools and models

Typical geodesign tools combine different methods, such as simulation models, spatial multi-criteria analysis, and visualisation. With the acceptance of digital technologies, geodesign has now proceeded further toward interactive map interfaces, with direct interaction between participants and information (Janssen et al. 2014).

The digital models of geodesign are also increasingly matched with other information and communications technologies to increase the degree of collaboration across and among disciplines and professions. Designers can now collaborate with those who can create rigorous analytical models of processes that take place at and above the scale of a site (Steiner, 2016).

3.4 Urban Design Case Study of Wellington Central City

In 2015 Wellington City Council (A New Zealand Local Authority) funded an improvement project to provide high-quality public spaces and to enhance the liveability of the central city and suburban environments. The objectives of this project are related to the modern urban design requirements described in Section 3.2 (collaboration, sustainable development, and public participation), showing the importance of each.

- **Walkability** - making Wellington's streets and spaces as people-friendly as possible. In the theory of walkable communities, a 10 minute walking distance between each neighbourhood centre is deemed to be ideal.
- **Sense of identity and place** - identifying and enhancing the qualities and characteristics that make Wellington special (such as using landmarks to make the city unique).

- **Connectivity** - making sure there are good connections for people to easily move to and through the central city, town centres and suburbs.
- **Accessibility** - easily accessible places and spaces, whether via road, foot, access to car parking or bus routes, with connections made to other areas that enable short travel distances for access.
- **Sustainability** - recognising the natural environment and using sustainable design solutions where appropriate.
- **Safety** - making sure public places and spaces are as safe and pleasant for people as possible (e.g. as assessed through decreasing criminal rates).

The study addressed aspects of urban design that have always been part of its core concepts, but are specific examples of design considerations that apply in this context. Wellington city is not a large city, but it is one of the most urbanised areas of New Zealand, reflected in its high density population, compact urban form, and creative, cosmopolitan atmosphere. The council's planning strategy aims to protect and enhance the existing urban living environment, rather than to develop an entirely new city (Wellington City Council, 2015).

The first step to achieve the above objectives is to investigate the current strengths, possible future challenges and potential opportunities. A pathway for the future then comes with understanding these. The entire project delivery landscape is shown as the below image (Figure 3.5).
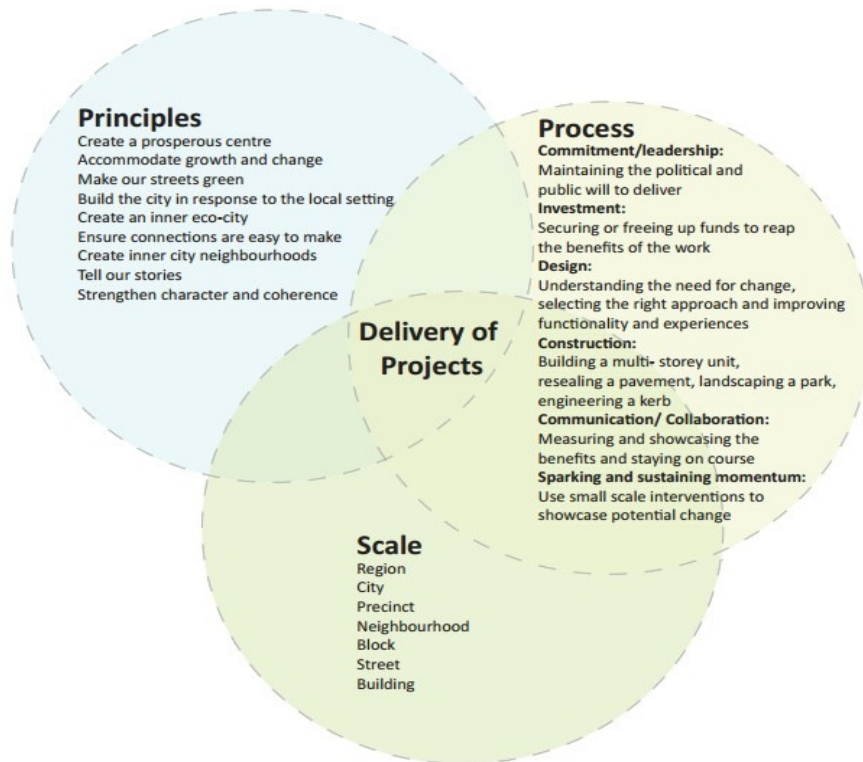
Figure 3.5 The design principle, the scale of project and the process, which is proposed in the council's report (Wellington City Council, 2015)

Wellington City Council's engagement of local experts and the public into the design process is clear. This engagement enables the council to deliver a long term strategy for city development. Firstly, a technical reference group (from the local development and design community) was set to draw the skills and experiences of experts into the project. Secondly, communication and collaboration with the public were encouraged through the use of interactive technology: four interactive story boxes (shipping containers, Figure 3.6) were used to engage with Wellingtonians about the direction of their city (Wellington City Council, 2015). In this way, the future direction of the city was shown to the public, and the council was able to communicate with its citizens more effectively. These activities reflect the new trends of urban design that we discussed in 3.2.

Figure 3.6 Four interactive shipping containers were located at Odlins Plaza and Te Aro Parkto during 23 June - 23 July 2011 for public visiting (Wellington City Council 2015)

Since the time of this study, further interactive technology has arrived on the scene. The use of Virtual Reality as a tool for urban design has evolved for the use of urban planning as well, thereby enabling greater interaction with the public.

A desirable platform should:

- Be capable of attractively simulating design and development plans and presenting them for the public to easily access and understand. This enables better communication with the public and greater public participation in the design process, and greater public satisfaction in the outcomes.

- Have an attractive way to distribute design plans, to generate greater public interest, and increase awareness of and participation in the design process.

- Have a way of collecting feedback to close the design loop, ensuring public ideas, concerns or expressions of interest in participation are taken into account

and acted on.

This project proposes that CVGEs could be used to perform urban design tasks. CVGEs in general meet these characteristics of a desirable platform, in addition to being technology which is relatively new as a method of communicating urban design ideas, and therefore one which generates interesting results for this research.

Chapter 4 Collaborative Virtual Geographic Environments (CVGE) in Urban Design

This chapter outlines the advantages of using Collaborative Virtual Geographic Environments (CVGEs) for urban design, and particularly for the tasks identified in Section 3.1. This chapter also refers to previous research that uses CVGE as a visualisation and collaboration tool, and includes a brief summary of the previous research project (Zhang & Moore, 2014) on which this research project is built.

4.1 3D Spatial Modelling

The recent popularity of 3D content not only engages users by offering aesthetically pleasing, real-world perspectives, but may also play an important role in providing communication support (Jobst & Germanchis, 2007) between urban design professionals and non-professionals.

Governments have also used 3D technology for applications such as disaster resilience. For example, Land Information New Zealand (LINZ), a New Zealand government agency, in dealing with the aftermath of the earthquake in Christchurch (New Zealand) in 2011, worked with local and central government agencies through the Spatial Data Infrastructure (SDI) programme in support of the province of Canterbury's earthquake recovery efforts. One key project within this programme was to develop a digital 3D city model (through the 3D Enabled Cities project), which enabled people to see what the rebuilt province of Canterbury, and the major city of Christchurch, would look like.

The Canterbury SDI programme has assisted professionals in communications, urban planning, and traffic management, amongst other things. It used GIS, CAD, 3D modelling, and visualisation and simulation technologies, through open standards based data sharing, to illustrate the past, present and future (in some ways, this could be described as a fourth dimension) of the built environment in greater Christchurch. This project has given people access to a wide range of information and engaged the public into the rebuild process.
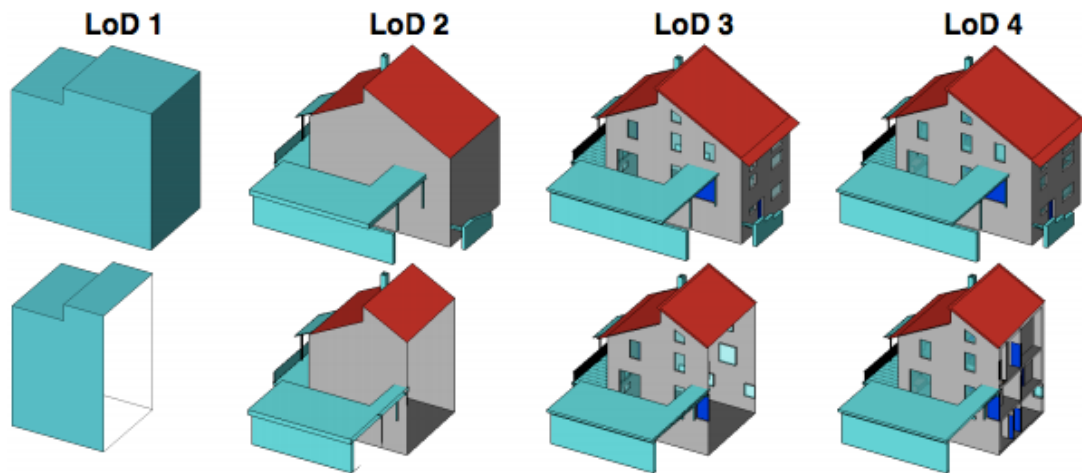
Figure 4.1 Four LoDs of CityGML. LOD0 is not shown here. Karlsruhe Institute of Technology. (Biljecki, 2013)

CityGML and Level of Detail (LoD)

CityGML is a proposed standard for virtual city models (Kolbe et al., 2005). One of the key terms used in CityGML is Level of Detail (LoD), which is borrowed from computer graphics (Luebke et al., 2003). LoD is used to describe the complexity of the representation of a geographic object. One of the main aims of LoD is to reduce the geometry complexity of an object for visualisation performance (Biljecki, 2013). Five general Levels of Detail are distinguished:

- **LoD 0** - Buildings are represented in LOD 0 by footprint and/or roof edge polygons (2D shape in 3D space).

- **LoD 1** – A box model developed according to its 2D polygon and height, which is suitable for creating a simple virtual model.

- **LoD 2** – Building models with facade and roof geometry particularly suited for far-away buildings. These can be used for providing context. Level 1 and 2 buildings can be generated mostly in an automated way, which makes them suitable for large-scale virtual landscapes.

- **LoD 3** – Building models which have detailed textures and architecture elements. These models may be built from data (e.g. architectural plans) that

is richer and more detailed than data which is commonly used in CAD or GIS, containing elements such as detail of external building features.

- **LoD 4** – Architectural models complete with interior design.

Professional 3D modelling packages and 3D computer graphic software provide solutions for modelling objects in three-dimensional level. For example, 3D Studio Max and Blender allow users to create and alter models via 3D mesh, and to view and edit details from different perspectives. However, these professional modelling software packages require users to have in-depth knowledge of spatial modelling, spatial awareness of 3D designs, and familiarity with the structure of the modelled objects in order to be able to visualise the objects on a three-dimensional level. Additionally, users of these packages require a long time to master the basic software operations. More information, such as landscape structures, are also required to satisfy the needs of urban design. These requirements constrain the development of a more general modelling and data sharing approach.

CityGML is an XML application schema for the Geography Markup Language version 3.1.1 (GML3). It has been adopted as an official international standard by the OGC (as an approved GML3 application schema), enabling easy and free access to all the international community (CityGML, 2017). CityGML mainly describes the geometry, attributes and semantics of different kinds of 3D city objects. These can be supplemented with textures and/or colours in order to give a better impression of their appearance. Specific relationships between different objects can also be stored using CityGML, e.g. that a building is decomposed into three parts, or that a building has a both a carport and a balcony (CityGML, 2017).

In adopting the concept of LoD, CityGML defines the classes and relations for the most relevant objects in cities (e.g. buildings) and regional models with respect to their geometrical, topological, semantical, and appearance properties. It is applicable for both large regions and small areas and can represent the terrain and 3D objects in different levels of detail simultaneously. It allows the user to employ virtual 3D city models for sophisticated analysis tasks such as simulations, urban data mining,

facility management, and thematic inquiries (CityGML, 2017).

Building Information Modelling (BIM)

Building Information Modelling (BIM) is a set of interacting policies, processes and technologies generating a "methodology to manage the essential building design and project data in digital format throughout the building's life-cycle" (Penttilä, 2006). It is an expansive knowledge domain within the Architecture, Engineering, Construction and Operations (AECO) industry (Succar, 2009).

BIM can be described by a framework consisting of Fields (such as Technology; Process; and Policy); Stages (such as Modelling; Collaboration; and Integration); and Lenses (such as Disciplinary, representing BIM views through the application of fields of knowledge; Scoping, representing the BIM view at macroscopic, mesoscopic and microscopic levels; and Conceptual, generating BIM views by applying conceptual filters derived from a BIM ontology). These are described in detail by Succar (2009).

BIM is a highly detailed form of 3D spatial modelling which enables the representation in the 3D environment of even minute details of individual building elements such as door handles and light switches. A 3D environment which incorporates BIM data and spatial models could therefore be used to provide realism and interactivity to the urban design process.

4.2 Virtual Reality and Virtual Environments

Virtual reality (VR) is defined as "a real or simulated environment in which a perceiver experiences telepresence" (Steuer, 1992, p.76). Telepresence here is defined as the experience of presence in an environment by means of a communication medium (Steuer, 1992). VR is often used for visualising and interacting with geographic data. It is a simple and effective 3D interface that attempts to replicate reality in a computational environment.

The link between VR and urban design is strong: "...exposure to computer games is generating an expectation that similar techniques could be used to show what a future city will 'look' and 'feel' like" (Axford et al., 2007, p.284). The inner city redevelopment trend within the profession is such that demands like this will increase due to an increased need for consultation (Axford et al., 2007) with a wider range of client types and global reach (Innes and Booher, 2000).

Ernst Kruijff (1998) defined a type of VR application called VR Interactive Walkthrough. Users can walk or fly through the environment as well as perform real-time editing (e.g. rotate, rescale and move) the digital objects within the model. The book *Thematic Cartography and Geovisualization*, edited by Slocum et al. (2009), also describes Virtual Environments (VE) as 3D computer-based simulations of a real or imagined environment that users are able to navigate through and interact with.

Virtual Environments replicate a real or imagined world and instil a sense of presence in the user (Ben-Joseph, 2008). That is to say we can simulate our tangible world under a virtual working environment, and experience this virtual world from various view points and positions. The following image (Figure 4.2) is an example of virtual Auckland City (New Zealand).

Figure 4.2. One sample of the virtual/visual Auckland City (New Zealand) (Nextspace, 2015)

VE not only can construct a graphic environment like CAD and GIS, it can also provide a better understanding of a place and geographic relationships. Designers of 3D environments try to reproduce reality in order to follow concepts of VR (Jobst & Germanchis, 2007). There are many efforts in this area; the advantages of VE are apparent and have been shown in many projects, such as in virtual London (Linden Research Inc., 2014; Hudson-Smith, 2008) and Virtual Kyoto (Yano et al., 2012).

Maceachren et al. (1999) propose four important "I" factors to describe VEs: immersion, interactivity, information intensity, and intelligence of objects (Hudson-Smith, 2008). These four factors form the basic requirements for virtual environments.

- **Immersion** – closely tied to the sense of presence, which is defined as "the subjective experience of being in one place or environment when one is physically in another" (Witmer & Singer, 1998). In other words, users are enveloped by the environment and can not only "look" but also "feel" it (in terms of presence).

- **Interactivity** – users should have the ability to interact with and edit the VE through provided tools or control devices.

- **Information intensity** — the levels of detail (LoD) presented in the VE, including appropriate details at various scales and for specific purposes.

- **Intelligence of objects** — objects in the VE could act or behave to some degree as they would in the real world.

Virtual environments significantly increase users' feelings of engagement and enable users to process objects both in space and time. In addition, users can understand and interact with the phenomenon in a three-dimensional and dynamic process instead of a static 2D one.

4.3 Concepts of Collaborative Virtual Geographic Environments (CVGE)

Within the above context, Virtual Geographic Environments (VGE), which are also

known as Geovirtual Environments (GeoVE), are VEs that integrate true geographic content. Gong and Lin (2006) state that VGEs should be constituted based on physical geographical information - i.e. from geographical data about physical features, such as buildings, and their attribution (such as measured height, or number of floors; roof architecture, etc). In addition, VGE has the capacity to deal with comprehensive and complex geo-problems (Gong & Lin, 2006). Döllner (2007) also made a point that virtual geographic environments can be broken down to three parts: terrain models, building models, and vegetation models.

Further to the theory of VGE, Gong and Lin (2006) proposed a new concept which they named Collaborative Virtual Geographic Environments (CVGE). CVGE brings in distributed elements that enable remote communication and planning. Through the online distributed CVGE, users can share the same virtual space and are able to conduct collaborative work. CVGE also has the ability to handle both visualisation (of a representation of the "real" world), and spatial data analysis. The advantages of CVGE can be summarised as follows:

- CVGE is an entirely 3D-led technology;
- CVGE has the ability of real time 3D viewing;
- Online VR clients can support remote collaboration;
- CVGE is a human-oriented technology for urban design;
- The user interface is easy to use;
- Online VR client is relatively cheap or no-cost.

More specifically, CVGEs provide an all-around three-dimensional design platform, compared to CAD and GIS packages which are largely 2D-led with some 3D features. GIS is more concerned with geographic rigour, providing georeferencing, spatial analysis, modelling, storage, and visualisation tools geared towards the capture of a true geography. Conversely, CVGE concentrates on making the users somehow feel present in a realistic-looking visually modelled world whether real or imagined. CAD fits between these two extremes.

Through the online collaborative environment of CVGE, many designers and stakeholders can communicate and share their ideas at once. This communication facilitates rapid development of urban design proposals, by enabling stakeholders to work almost in real-time (if they desire) on a single project, making the process vastly more efficient than traditional, offline methods. Such rapid communication and collaboration is well suited to many of the urban design practices discussed by Carmona et al. (2010) and listed in Section 3.1, freeing professional designers across these practices to come together with other professionals on a single urban design project without being hindered by remote communication constraints.

CVGE also allows the rapid building of 3D environments to take place, shortening the time taken to set goals, analyse proposals, create and share 3D visions, synthesise and predict outcomes, make decisions, and evaluate the results of an urban design project - the tasks of urban design, as discussed in Section 3.1.

The conventional method of urban design, at least in the digital world, has been largely constrained by two-dimensional presentation and the majority of those urban design works have remained at 2D level. The use of 3-dimensional physical models somewhat compensates for this. Commonly designers depict their ideas via hand-drawing or digital design software (i.e. CAD and GIS) and sometimes text description. CVGE is undoubtedly a method that corresponds to the main trends in this field (as discussed in Section 3.2).

The availability of 3D viewing and 3D model navigation provided by online VR clients will greatly benefit urban designers. Users within this realistic-looking visually modelled world can engender the sense of presence (or "feel real"). Integrated with a real-time chatting function (both text and voice), CVGE possesses the ability to enable remote communication and global collaboration, which is one of the major potential benefits resulting from this technology.

Furthermore CVGE is a human oriented technology, which is more in line with the typical collaborative process of urban design (a people-led field). Users can interact

with the workspace via an avatar which corresponds to their natural way of exploring the real world (sometimes called "telepresence", refer to Section 4.5). CVGE can significantly increase users' sense of engagement and involvement in a design situation that requires remote communication.

Regarding ease of use, the VGE chosen for this study (OpenSim) was originally designed for online gaming purposes. The platforms driven by computer gaming techniques have the capability to present very large and complex 3D worlds (Germanchis et al., 2007). OpenSim's user-friendly interface and easy-to-learn operations could engage a wider range of clients not only limited to specialists but also involving non-specialists. This will contribute to the goal of increased public participation. It will raise the possibility of global collaboration because of its online attribution and data sharing. CVGE also provides a suitable method to interact with an abstract and conceptual design environment.

Finally, the online VR software provides a relatively cheap or no-cost option, which increases its attraction. Even though designers are conscious of the potential and value of VGE, reaction from governments and local authorities is slow. This situation can be partly explained by the fear of cost, and partly by the scarcity of opportunities to be exposed to this novel visualisation approach (Axford et al., 2007).

As more free and open source CAD and GIS software (e.g. FreeCAD, Quantum GIS, PostGIS) has appeared, potential budgets need to be considered for purchasing advanced extensions, such as spatial analysis toolbox or editing plug-ins. However, through integrating gaming and internet technology the platform for constructing VGE has become free and accessible enough for widespread dissemination and use in recent years (e.g. the online social VE Second Life - Hudson-Smith, 2008; Axford et al., 2007).

4.4 OpenSimulator (OpenSim)

VGEs can be distributed by the following five methods: desktop, wall-sized, head-mounted, room-format, and drafting table-format(s) (Hudson-Smith, 2008). Among

these methods, desktop display is the most common and low cost approach for delivering VGEs. They are facilitated by free downloadable clients such as Second Life viewer (Linden Research Inc., 2014), Hippo viewer, or Firestorm viewer (Firestorm viewer, 2017). The following image (Figure 4.3) shows Sweden's virtual embassy in Second Life including building and vegetation models. This is a good example of a VGE distributed via desktop PC, making it easily available as it requires no special hardware.

Figure 4.3 Sweden's virtual embassy in Second Life (Swedish Institute, 2017)

OpenSimulator (OpenSim) is an open source multi-platform, multi-user 3D application server. It can be used to create virtual environments which can be accessed through a variety of clients on multiple protocols (OpenSimulator official website, 2014).

The clients access a virtual world grid, which acts to organise the regions and their positions in the world, and handles things that need to exist across regions such as a user's inventory (OpenSim, 2014). In terms of using grid in CVGE, it can be treated as a robust, distributed computing platform, which enhances overall system performance. It enables CVGE to discover, acquire and manage data about 3D objects. At the same time, users can publish and exchange their resources and

geographic data effectively.

OpenSim provides a degree of freedom for users to customise their worlds, and the source code is available to the public for implementing specific tasks. Therefore, OpenSimulator can be considered a suitable choice for developing the Virtual Geographic Environment in this project.

In order to carry out the comprehensive assessment, we implemented usability testing to evaluate the representative design package (i.e. BrisCAD, ArcGIS and OpenSim). Section 4.7 introduces usability criteria used in the testing stage.

4.5 Previous Attempts at CVGE

There are many projects that have explored various aspects of CVGE in the past, for example Gong and Lin (2006) and Lin et al. (2010) integrated agent, grid, and other collaborative tools to create a shared 3D space for the planning of a silt dam system. CVGE was used to integrate their data and model resources, with the aim of supporting collaborative water soils loess research and planning of a silt dam construction. Note that grid is used in this project as a platform to enhance the overall preference. More explanation of grid will be provided in section 4.4.

At the same time, some potential drawbacks were also pointed out. To support the planning of silt dam systems, more capable applications and greater processing ability would need to be implemented (combined with specific purpose, the CVGE should be equipped with the corresponding applications). Java, the computer language used to develop their project, was not powerful enough to control the resources.

The virtual planning of a silt dam system is not the only one to use CVGE to visualise geographic information. One related work is by Manoharan et al. (2002), based on Geometrek's DeepMatrix 1.1. They established a collaborative urban planning prototype system to assist shared analysis of urban planning proposals by visualisation and interaction with spatial data (Manoharan et al., 2002).

Another example of using CVGE is a Personal Rapid Transit (PRT) system reported

by Lopes and Lindstrom (2012). It is an application of OpenSim to city planning in Uppsala, Sweden, in the context of a possible PRT system for the city. They characterise the existing network of stakeholders involved with urban design and the associated use of technology as fragmented (small disparate groups involved in specific and localised projects). Accordingly, they applied online VR as a tool that acts holistically, with communication capability to link stakeholders and a comprehensive digital modelling approach to model whole cities or substantial city parts.

In summary, to support urban design visualisation, the platform should be capable of constructing 3D environments, landscapes and architectures, and providing animation and sounds to improve realism for the viewer by enabling them to move/navigate around the model using physical actions and experience what it would be like to be inside the model; meanwhile, it should allow users real-time movement and interaction (Germanchis et al., 2007). The graphic engine also should have the ability to offer a powerful graphic quality as well as retain system performance at a satisfactory level. Facing the above challenges and evolutions in the urban design field, online Collaborative Virtual Geographic Environment (CVGE) which integrates 3D and gaming technology and enables its users to navigate through and interact with the environment should be considered a promising solution.

CVGE not only preserves artistry and fidelity of the environment, but also implements geovisualisation techniques, real-time edit, and geospatial analysis. Undoubtedly, Collaborative Virtual Geographic Environments are an effective and intuitive design platform that opens opportunities for urban designers to improve the way that they present and deliver design plans. The real-time communication function brings additional value for VGEs and enables a new approach for collaboration.

4.6 Summary of Previous Research Project (Zhang, 2011)

This research project is built upon Urban Design based on Online Virtual Reality (Zhang, 2011) reported in Zhang and Moore (2014).

The major aim of the previous project was to **investigate whether or not urban design professionals would gain advantage by using online virtual reality (VR) software due to the benefits of real time 3D visualisation and online communication.** A sub-objective within this was the design and construction of virtual house and landscape elements to fill a virtual site, ready for testing with subjects. Another sub-objective was to assess the suitability (in terms of satisfaction) of using the online VE and its communication facilities to engage experienced urban designers. The second major objective was in forming **a critique of the featured use of the tool as a low cost and easy to use tool for urban design**.

A 512m by 512m region (a part of Fairfield, Dunedin suburb) was built as a virtual geographic environment (VGE) in OpenSimulator, containing pre-existing surroundings and the design area populated by proposed buildings. The following image (Figure 4.4) is a screenshot taken from the VGE constructed in the 2011 project, showing the whole development in the research site.

Figure 4.4 The screenshot of the virtual environment in OpenSim from Zhang (2011)

In summary, the benefits from the online VR-based urban design environment were

significant to the participants, particularly in usability and remote communication. The results also supported the hypothesis that VE can be considered a low cost desktop delivery approach (Axford et al., 2007).

The previous research (Zhang, 2011) identified that visual quality and geographic truth were weaknesses of VGE, overshadowing the intended 'sandpit' approach of the model. Urban designers were concerned at the 3D models' level of detail and precision when incorporating rapid and accurate editing operations. In this new research, these issues were further investigated by devising programming scripts to put georeferenced spatial data into VE to address the need for more detail and accuracy.

Virtual Geographic Environments, integrating computer gaming technology, the Internet and virtual reality, are a promising combination. Virtual reality is a step outside the geospatial realm, but can provide its users with a more immersive and real experience of the environment than their usual tools. Users also can interact with the virtual environment through "walking" or "flying" as well as perform real-time editing (e.g. raise or lower terrain and move or rotate selected objects).

Although VR and urban design have been linked to each other for some time and researchers have implemented many diverse projects in this space, more effort needs to be devoted to further investigation of these methods. For example, designers require a high quality of real-time rendering and geographic accuracy, allowing them to perform accurate analysis and computation. However, the lack of effective and proper navigation tools can trigger users' confusion and disorientation. In this research project, efforts are also made to address these issues.

Based on the above background, this project employed CAD, GIS and VR packages (BricsCAD, ArcGIS and OpenSimulator) to build 3D environments for the purpose of comparing their strengths and weaknesses, particularly in the aspect of 3D modelling.

4.7. Previous Research Gap

Although these examples of previous research provide a literature discussion of VR used in urban design, and previous urban design projects such as Manrohan et al. (2002) and Lopes and Lindstrom (2012) have utilised VR as a tool, little has been done previously to implement a comprehensive usability assessment of VR for urban design, and in particular the use of online Collaborative Virtual Geographic Environments (CVGE).

Usability criteria (Gould & Lewis, 1985; Norman, 1990; Shneiderman, 2005) include efficiency (time taken to achieve a specific goal), effectiveness (how accurately and completely a task is realised), and Satisfaction (the level of acceptance by the users, or how happy they are to use the tool for their purpose). Zhang (2011) explored this area, but stopped short of going through the stage of making a comprehensive comparative usability assessment of technologies for urban design.

It is only through a comprehensive comparative usability assessment that researchers can directly address the technology's ability to support the core urban design tasks mentioned in Section 4.3 and discussed in greater detail in Section 3.1. Therefore this research uses usability testing to evaluate available technologies for urban design and perform a direct comparison to determine their relative benefits and drawbacks. This takes the research a step further by directly assessing the efficiency, effectiveness and satisfaction of three tools for urban design: CAD, GIS, and VR.

Chapter 5 Usability Testing Criteria and Evaluation Methods

This chapter presents the usability criteria that are used for assessing CVGE as an urban design tool, a description of the evaluation method (usability testing), data collection method (questionnaire), and data analysis techniques (Statistical Analysis, Chi-Square test, and ANOVA). These relate to the main objective outlined in Chapter 2, which is to undertake a comparative usability assessment of proposed urban design scenarios realised by three different technologies: CAD, GIS, and online VR.

5.1 Usability Criteria

The way in which humans interact with computers has received a better understanding and increasing awareness over the past few decades. Since the 1950s, a wide variety of people who are not experts and programmers have begun to utilise computers for numerous applications, particularly from the 1980s on (Haklay et al., 2010).

Support for the broadest range of users, while at the same time satisfying their diverse requirements and needs, has become one of the most important system design criteria; As a result, a set of theories and methodologies have been developed to minimise the gulf between computers and users as well as to enhance user experience. These theories and methodologies are described here.

The field of Human-Computer Interaction (HCI), which first appeared during the 1970s, aims to tackle all aspects of human interaction with computers and provide functionality appropriate to intended users (Haklay et al., 2010). It can be regarded as the intersection of multidisciplinary research realms such as Computer Science, Ergonomics and Human Factors, Linguistics, Cognitive Psychology, Philosophy and Anthropology (Preece et al., 1994). In this field, a number of methodologies are engaged to improve communication between users, designers and engineers.

It is important that User-Centred Design (UCD) should take account of who the users are and then engage them in the design process (Gould & Lewis, 1985; presented in Sharp et al., 2007). Within the design life cycle, a decision must take 'usability

criteria' into consideration. UCD is a framework for hardware and software development that emerged in the mid-1980s with the rise of HCI and became one of the guiding principles for designing usable computer technologies (Haklay et al., 2010). The following paragraphs will give a brief introduction to usability criteria used in this research.

It is necessary to define what "usability" is before using it as basis to develop other criteria. Several definitions exist, for example ISO standard 9241-11, cited in Haklay et al. (2010) p. 108, defines usability as "the extent to which a product can be used by a specified user to achieve specified goals with effectiveness, efficiency, and satisfaction, in a specified context of use". Nielsen (1994), also cited in Haklay et al. (2010), refers to usability as "a quality attribute to evaluate the ease of use of systems or interfaces". Norman (1990), Shneiderman & Plaisant (2005), and Gould & Lewis (1985) all define other usability principles which may be applied.

No matter what the definition of usability is, the ultimate aim of usability criteria is to meet users' requirements so that they can carry out their tasks safely, effectively, and enjoyably. The early stage of the design process is to fully understand user tasks and work context. This is an important consideration in this research because usability of the systems that perform these tasks in the users' work context governs the efficiency, effectiveness and satisfaction of the systems themselves.

In addition, a successful application should take users' cognitive process and conceptual model into account, and should also have the capability to tolerate errors or prevent them from occurring altogether. As stated by Gould and Lewis (1985), this is because the user-centred framework is not linear but an iterative design process, which needs to follow design, test, measure and redesign cycles (Haklay & Nivala, 2010).

Though the attitudes towards UCD are various, the ultimate purpose of these theories is to guarantee that the product can meet the usability criteria. The criteria can be summarised as: Effective, Efficient, Error-tolerant, Learnable and Satisfying (Haklay

et al., 2010).

- **Effective** – How correctly the specific users can accomplish a task.
- **Efficient** – Effort and time taken to complete a task.
- **Error-tolerant** – The system has the ability to adapt and vary, in that it can recognise users' mistakes and recover from these mistakes.
- **Learnable** – the system should be easy for users to master its basic operations.
- **Satisfying** – the system should ensure it is pleasant and/or satisfying for users to work with.

These criteria provide a set of principles that can be used for evaluation in the design process. This research will specifically highlight aspects of effectiveness, efficiency and satisfaction.

5.2 Evaluation Method

A vital part of the User-Centred Design process is evaluation. Evaluation in this case is a process to check whether the application or the product is responding to the requirements that were set for it.

The process can be divided into two categories: Formative (also known as process or progress evaluation) and Summative (also known as outcome or impact evaluation) (Scriven, 1967). The main difference between formative and summative evaluation is when the evaluation is conducted. Formative evaluation acquires feedback during the process of development and implementation for suggesting improvements. Summative is carried out after the process of development and implementation is finished for gathering information and feedback to assess the effects, effectiveness, impacts and outcomes (Chen et al., 2011). A summative evaluation was conducted to evaluate support the main objective of this project, which is a comparative usability assessment of proposed urban design scenarios realised by CAD, GIS and online VR software.

Evaluation methods that are suitable for geospatial technologies include usability

testing, field studies, predictive evaluation, heuristic or guideline-based expert evaluation, cognitive walkthrough, task analysis, and so on (Marsh and Haklay, 2010). The following paragraphs will explain the evaluation methods, data collection techniques and data analysis methods that are used in this research.

Usability Testing

Usability testing was used to evaluate the three design methods of CAD, GIS and VR in this project. Usability testing tests user performance in terms of errors and task completion times. This is a commonly used form of evaluation (Marsh & Haklay, 2010). This type of testing mainly aims to test the interaction of the user with the system. The advantage of this method is that everything the user does can be recorded and performance is quantified (Marsh & Haklay, 2010), allowing us to understand the efficiency, effectiveness and satisfaction of the methods under evaluation.

The testing includes a pre-test questionnaire to find out users' backgrounds, followed by a set of tasks that the user is asked to perform and finally a post-test questionnaire or interview (Marsh & Haklay, 2010). This leads to two requirements: One, the questionnaire should be constructed to fit the purpose of the project, and enough user background and feedback should be collected; and two, statements on the task sheet and questionnaire should be very explicit.

Usability testing can incorporate different data collection and data analysis techniques. In this project, we will use the questionnaire for data collection, Analysis of Variance (ANOVA), and chi-square testing. More details will be provided in the following sections.

Data Collection Technique — Questionnaire

Having decided upon the method of evaluating the performance of all of the software products, a more detailed data collection technique was selected. Commonly used data collection techniques include questionnaires, interviews/demonstrations, focus groups, scenario modelling etc. (Marsh & Haklay, 2010). Among these techniques,

questionnaires are good for collecting subjective data, and are often more convenient and more consistent than a personal interview (Bowman et al., 2002). Consistency between respondents is a major advantage, since all respondents are given the same questionnaire so any differences between them are easily highlighted.

The questionnaire is a written set of questions used to obtain the demographic information, views and interests of users before or after they have participated in a (typically formative) usability evaluation session. This method allows for qualitative and quantitative analysis. One specific example is Likert scale questions, where respondents are asked to rate the level at which they agree or disagree with a given statement on a five-point scale from Strongly Disagree to Strongly Agree. The exact phasing of the questions, and their order, enables evaluators to explore certain perceptions and views of the participants by using different statements (Marsh & Haklay, 2010).

Data Analysis Technique — Statistical Analysis, Chi-Square test, and ANOVA

Statistical techniques, such as average values and standard deviations, are used to understand collected feedback and data. Analysis of Variance (ANOVA) and chi-square tests are also used in this project, as these correspond to the data collection technique (i.e. the questionnaire). Together these techniques enable a thorough understanding of the users' response to the various methods tested and provide some measure of the three usability criteria of efficiency, effectiveness and satisfaction.

For example, ANOVA is a test of statistical significance of the difference among mean scores of two or more groups of one or more variables. ANOVA testing can be used to indicate whether one technology is performing significantly better or worse than others in usability dimensions. This can be used to evaluate the results of the questionnaire, and other quantitative outcomes (Marsh & Haklay, 2010). These include the time that it takes to complete a task (efficiency), and how correctly the users can accomplish a task (effectiveness).

A chi-square test is a test of significance for categorical variables. Significance tests

let the researcher know what the probability is that a given sample estimate actually mirrors the entire population (Trobia, 2008). It is used to examine the difference between what is actually observed (by collecting primary or secondary data) and what we expect to find (Barlow, 2010). This method can help understand the trends found in quantitative data, for example user preference for particular functions (such as 3D editing).

A Chi-square test tells us whether trends are significant or not. For example, if a significant number of questionnaire participants chose a particular value in response to a question, to lift it from the null hypothesis situation where an equal number of participants answer each value on a Likert scale, this indicates that the majority of participants had a particular view.

In short, ANOVA tells us whether the differences observed between user experiences of CAD, GIS and VR are statistically significant. The chi-square test tells us whether any differences observed in Likert responses are statistically significant. One thing to note is the number of participating users, since if evaluations use small numbers of users, results may not be statistically significant (Marsh & Haklay, 2010).

5.3 Usability and Evaluation Case Study

The above sections summarise criteria of the usability testing as well as the evaluation methods. This section will provide an insight into how these methods are structured in previous research.

Carroll and Moore (2008) implemented and tested a multi-scale dynamic map which used a cartogram algorithm in a nested structure to distort shape, enlarging any areas of user interest or focus. The purpose was to develop a dynamic map that was more usable than traditional methods at communicating multiple scales.

There were three parts to the experiment. The first part was to prepare a series of cartogram maps which were created for the testing stage. Another series of commonly known country and continents maps were also created to eliminate factors that may

affect the result such as lack of geographic knowledge. The second part was the participants' testing stage, where participants were asked to navigate themselves to a specified location. The time taken and the correctness of each task was recorded as a method of evaluating usability (efficiency and effectiveness) of each mapping method. The third part was to ask participants a set of general questions about their experience of digital maps, knowledge of geography and their satisfaction of their experience with the cartogram. Participants gave a range of responses from one to five (one means strongly agree and five means strongly disagree) to indicate their satisfaction. All results from the testing stage were collected and analysed by the chi-square and ANOVA tests.

In this case, ANOVA tests were used to identify whether there were any significant differences between different methods of multi scale representation. To analyse participants' perceptions, a chi-square test was used to test whether the results from the five point scale occurred because of the pooled preferences of the participants and were significantly different from a random sample of values.

Carroll and Moore (2008) conducted a comparative assessment of multiple cartogram maps, with a similar goal to this research. Their research includes the same usability testing criteria, and the same results analysis methods as this project, as presented in Section 6.5. Therefore, Carroll and Moore (2008) is a useful template to structure this research.

Chapter 6 Methodology

This chapter covers the workflow of this project, including the 3D environment construction process, data preparation for the Virtual Geographic Environment, and the outcomes in VGE, GIS and CAD. A detailed usability assessment process using the methods described in Chapter 5 is then presented. This supports the purpose of this thesis, which is to determine the feasibility of using Virtual Reality (VR) technology, that is supported by geographic information and is geographically realistic, as a useful tool for urban design.

This research extends from a previous project (Zhang and Moore, 2014) and has a similar overall method: to construct a sample 3D environment, invite specialists to evaluate the 3D product and collect their feedback via a questionnaire, and analyse this feedback. The one key difference in this project is that three experimental 3D environments were built in CAD, GIS and a Virtual Environment (VE). In all three cases, tasks were set to complement the questionnaire. Due to the timeframe, one more iteration loop can be incorporated into the research. The whole work flow is shown in the diagram below (Figure 6.1).
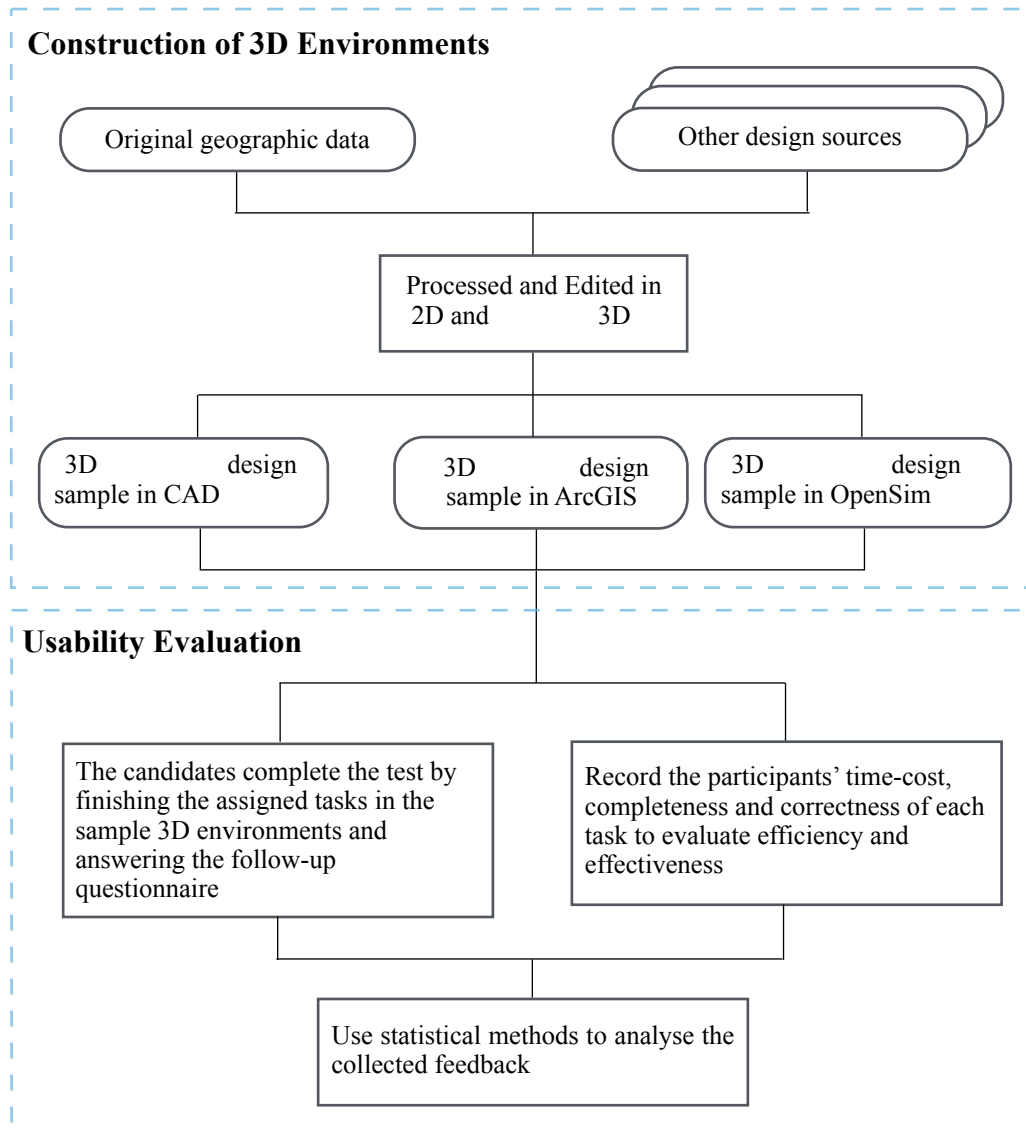
Figure 6.1 The whole project workflow.

A detailed description of the design area, required datasets, and the modelling process in the three different software packages is summarised in this chapter.

6.1 Dataset

6.1.1 Description of the Research Site

The research site is Grandvista (Figure 6.2), located in Abbotsford, in the Southwest region of Dunedin City. Originally, Grandvista was a rural area but Dunedin City Council approved rezoning it due to substantial residential demand.

Figure 6.2 A screenshot of Grandvista from LINZ Data Service (2017), data as at 2013. The yellow line highlights the whole Grand Vista re-planning zone. The red line indicates Stage 2 of the development. Arrows indicate access points.

The above figure is an aerial image that shows Grandvista and the block highlighted by the yellow line is the location of the entire area that has been rezoned. The red line shows the extent that will be developed as a 3D urban design environment in GIS, CAD and VR. The south-eastern end of the site is stage one of Grandvista which has been designed and is under construction. Stage one is also considered as the existing features/neighbourhood.

Overall, this block is orientated in a north-west to south-east direction, and enjoys views of the rural land to the north of Abbotsford. It is surrounded by the residential land to the north and east, and rural land to the south and west.

The original access points are indicated by red arrows. The primary access point of Grandvista is via the eastern corner, but it also has one entrance along the southern edge of the development site. The two orange arrows point to the entrances that

connect stage one and stage two (the undeveloped area, red line highlighted zone) of the development. These access points were used in this research.

6.1.2 Dataset for Construction of 3D Experimental Models

Supporting data for this research included a 3D terrain model and existing features (e.g. roads, boundaries). This data provided accurate topographic information and surrounding context of the design site. However, the data needed to be transformed into a compatible format for further processing.

The original terrain data was a Digital Elevation Model (DEM) exported from 12D, a professional engineering design package (12D, 2017), covering Grandvista (the thick yellow line highlighted area in Figure 6.2) and surrounds. To ensure the design outcome fits the existing features, a 2 metre contour dataset was obtained from Dunedin City Council (DCC) and used to supplement the process of creating the entire terrain. The output was a 768 x 768 metre Triangular Irregular Network (TIN) including the design region and surroundings, generated by ArcGIS 10.0.

In terms of the overall context and subdivision/parcel boundary plan, 2D digitised CAD data were used in the form of parcels, road edges and site boundaries. They were then given a constant z-value and converted to 3D by extruding their form in ArcGIS 10.0. These features were added to the level of the underlying terrain. These files are the groundwork for constructing the 3D urban design environments in CAD and ArcGIS, further details will be provided in section 6.3 and 6.4; however, there were more steps taken to prepare the terrain data for the OpenSim Virtual Environment (VE) (see Section 6.2.1).

In addition, an orthophoto downloaded from Dunedin City Council (DCC) was cropped to the extent of the 768 metres x 768 metres site. This image was used in ArcGIS and OpenSim to provide a more visual and realistic design context.

Lastly, a selection of floor and interior design plans of typical New Zealand dwellings was obtained from design company and real estate agent websites, and used as the

blueprints for 3D building construction.

6.2 3D Design Environment Construction Process in Open Simulator

Open Simulator (OpenSim, 2014) is a free, open VE that emulates Second Life, and runs off a dedicated online server. During the development of this CVGE, the data needed to be reformatted before it could be imported into the VE server of OpenSim. Essentially, the terrain is converted to a generic binary format which can be understood by OpenSim. ArcGIS (a GIS package) and Erdas Imagine (digital image processing software) were used to achieve this.

The CVGE could then be built upon the OpenSim platform. The following sections outline the steps taken to prepare the terrain data and to represent the proposed development in the VE.

6.2.1 Terrain Model for Open Simulator

The procedure for preparing the terrain data for OpenSim was more involved than with CAD and GIS. The following diagram (Figure 6.3) details the terrain development process.
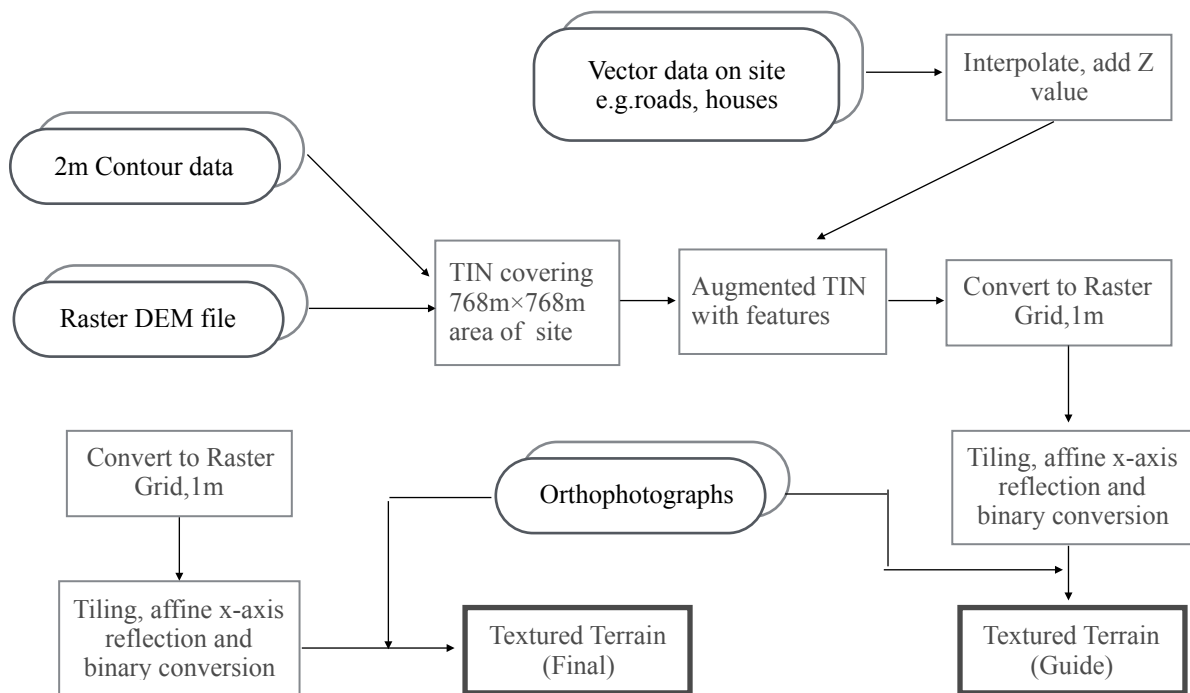
Figure 6.3 The workflow for creating the terrain model

The outcomes of this step were two generic binary files:

- A guide terrain model, essentially the real terrain model with land parcel boundaries imprinted as 3D spikes (extrusions of the boundary feature classes). These were used for placing roads, houses and vegetation objects in the correct context, in lieu of parcel boundaries being printed directly on the overlaid imagery.

- An unmodified, true terrain model which replaced the guide terrain model at the end of the process.

Before editing the VE details, the guide terrain was uploaded into Open Simulator and used to place the design elements. Once the construction was accomplished, the smooth and unbroken terrain replaced the guide terrain. The entire virtual geographic environment was then deemed to be completed.

The source data comprised the site terrain model (Digital Elevation Model, or DEM, of Grandvista), site extent polygon (768m x 768m) and contextual features (surrounding houses, road next to the central site) in CAD data exchange format

(.dwg), which was assembled from field data and processed in 12D and CAD. They were imported into ArcGIS 10.

The 768m x 768m study area involves a central region (the region subjected to subdivision design) which was extracted from the full extent of the Grandvista subdivision and existing surroundings. However, the exported elevation model (from 12D) only covers the research site, and had to be augmented with 2m contour data to fill the entire area.

In Erdas Imagine, the raster image of the terrain was split into nine 256m x 256m tiles (at 1 metre resolution) in a 3 x 3 configuration. The nine tiles were affined reflected across the x-axis and exported in generic binary format (bit interleaved, 32-bit floating point, Big Endian ordering). A tiling and affine transformation operation was also performed to gain 9 orthophoto tiles corresponding to the tiles of terrain. The integrated output from Imagine can be processed by Open Simulator.

These photographic textures for ground and existing contexts were overlaid onto terrain after being compiled to XML format. This was performed by a C# script adapted from a program written by Diva Canto (Christa Lopes). Each tile of the textured terrain contains 8 x 8 sub-tiles.

The following subsection outlines the method of representing the proposed development in a Virtual Geographic Environment with embossed features.

6.2.2 Realising the Proposed Development in the CVGE

The nine tiles were imported into the OpenSimulator server, which is powered by the virtual Survgrid hosted at the National School of Surveying, University of Otago. OpenSimulator, an open source multi-platform, multi-user 3D application server, hosts the Virtual Environment. It can be accessed from client viewers such as Imprudence/Hippo OpenSim Viewer, that runs on local devices (e.g. desktop and laptop). In this project, it was also a platform to carry the grid engine (Survgrid), an open access grid.
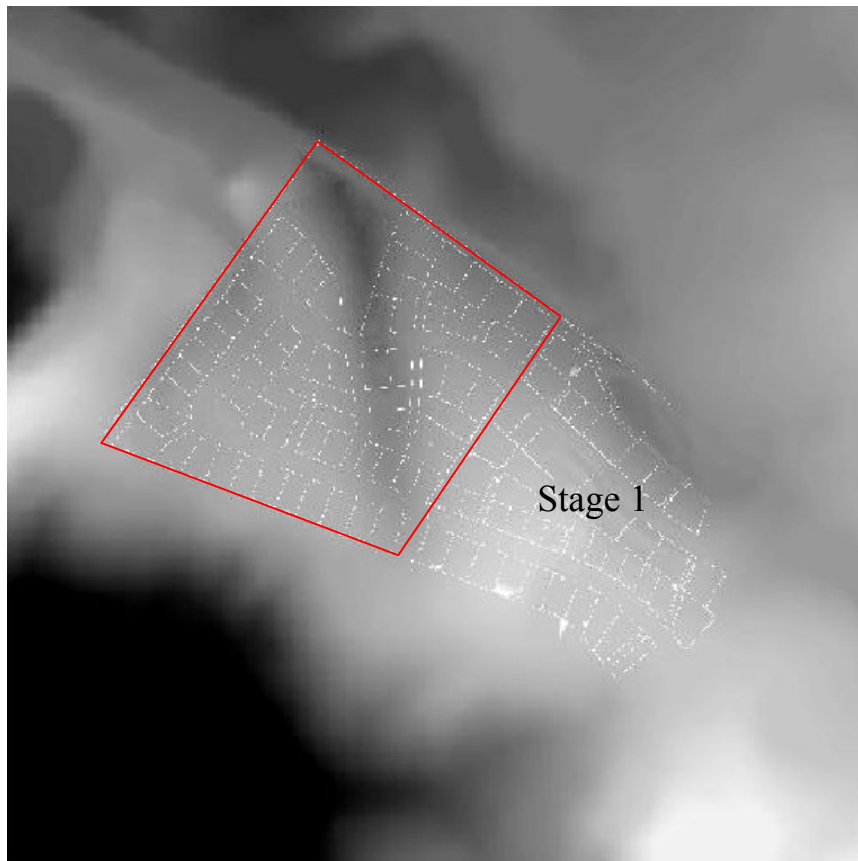
Figure 6.4 The 768m x 768m raster terrain. The zone highlighted by a red line is the area which has been built as a CVGE in this project.

Two XML format textured terrains were loaded into this OpenSim server, first with embedded guide features and finally without (just the terrain). The image below (Figure 6.5) is the guide terrain viewed in OpenSim via the client.

(a) The aerial view of the guide terrain of the design and surroundings in VR

(b)

Figure 6.5 The guide terrain viewed in OpenSim: (a) is the aerial view and (b) is an avatar in the CVGE

6.2.3 Construction of 3D Buildings

This stage developed details of the Virtual Environment, i.e. the 3D elements. Building models are fundamental objects from which virtual landscapes are composed (Döllner, 2007, p.246). This procedure can be defined as developing an entity based three-dimensional model consisting of buildings, public spaces and transport systems. These are the key elements for visualising and simulating designers' abstract design concepts. Accordingly, buildings, roads and vegetation needed to be built via the OpenSim client.

As summarised in the Section 4.1, this research referenced the criteria (defined by Kolbe et al., 2007) for virtual city models (from LoD 1 to LoD 4), involving box models based on 2D polygon ground planes with associated heights and detailed texture of building models etc. The interior decorations were not considered for this research since they are not a part of the virtual landscape which we are modelling for urban design purposes.

The dwelling models were referenced 2D floor plans gathered from online resources, such as real estate agencies' and house construction companies' websites. These 2D plans were used to re-create the scale of actual houses. For the external details, the texture of roads and buildings was adopted from photos taken of the actual site features.

The building models principally referenced three generic house plans, specifically one traditional 2-storey style, one modern 2-storey style and one traditional bungalow style (Figure 6.8, 6.9 and 6.10). These house plans include 3 or 4 bedrooms, kitchen, bathroom, garage and living room, similar to many New Zealand houses. These 2D floor plans were also used as references during the 3D design environment construction process in CAD and GIS.

Another two key features that needed to be taken into consideration were fences and vegetation. These formed the physical boundary as well as providing privacy for residents.

The guide terrain (prepared in the previous stage) was used in this stage for locating constructed 3D objects and placing the road features to represent a workable and attractive subdivision.

The OpenSim client (Hippo was used in this research project) provides a toolbox named 'Build' which enables users to construct their own 3D objects and edit their attributes. By adjusting parameters (position, size and angle) of primitive objects (e.g. cube and prism, etc.) the appearance of the building components (i.e. walls and roof) can be replicated. These primitive objects were then linked together to form a

completed 3D model. The image below (Figure 6.6) is the Build toolbox in OpenSim.
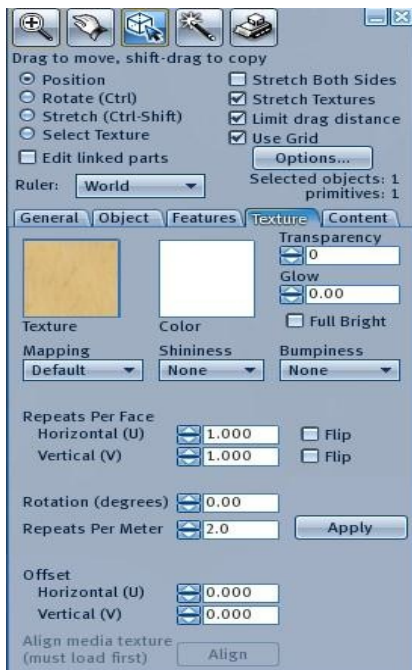
Figure 6.6 The Build toolbox for 3D modelling

Figure 6.7 Land tab of the Build toolbox for modifying terrain

It is also possible to simulate earthwork on the terrain within the virtual environment. The Land tab which is contained in the Build toolbox can mimic the progression of earthworks (shown in Figure 6.7). Users can modify the terrain, through flattening, raising and lowering, to gain a desired topographical surface.

The last stage was selecting textures for the surface of those complete 3D geometric models, increasing the fidelity of their appearance. For this stage, photographs of wood, bricks and concrete were uploaded into OpenSim's online library.

The following images show the 2D plans that were used to construct 3D houses and their final appearance in the CVGE. Figure 6.8 is the traditional 2 story house style.

Ground Floor

MASTER BATH
(9' CLG)

JACC.

SHWR TILE

W.I.C.

COVERED PORCH
22'-6"x8'-0"

STEPS

MASTER BDRM
14'-0"x18'-0"
(10' TRAY CLG)

GREAT ROOM
22'-6"x14'-0"
(9' CLG)

NOOK

KITCHEN
10'-9"x11'-8"
(9' CLG)

DW

FRIG

LNDRY

D

W

SHOP/STORAGE
11'-10"x15'-5"
(9'-6" CLG)

COATS

9' CLG

STEP

DESK

UP

PANTRY

FRENCH DOORS

PWDR

OPTIONAL DOORS

OFFICE/GUEST/
HOME SCHOOL
11'-8"x10'-1"
(9' CLG)

FOYER
(9' CLG)

DN

FORMAL DINING
11'-8"x11'-0"
(9' CLG)

COATS

GARAGE
21'-0"x21'-10"
(9'-6" CLG)

COVERED PORCH
41'-6"x8'-0"

STEPS

9' OVERHEAD DOOR   9' OVERHEAD DOOR   9' OVERHEAD DOOR

BEDROOM #4
11'-1"x11'-7"
(8' CLG)

LIN

LIN

BATH

LINEN

STORAGE

TUB/SHWR

LINEN

W.I.C.

REC ROOM
21'-3"x12'-6"
(VAULTED)

DN

BEDROOM #3
11'-8"x16'-2"
(VAULTED)

SITTING AREA
(VAULTED)

BOOKS

(a)

(b)

Figure 6.8 The traditional 2 storey style house: (a) is the 2D interior plan (including ground floor and first floor) (The Plan Collection, 2017) and (b) is the house viewed in CVGE

Figure 6.9 and Figure 6.10 show the floor design of another two houses, and their representation in OpenSim.

Ground Floor
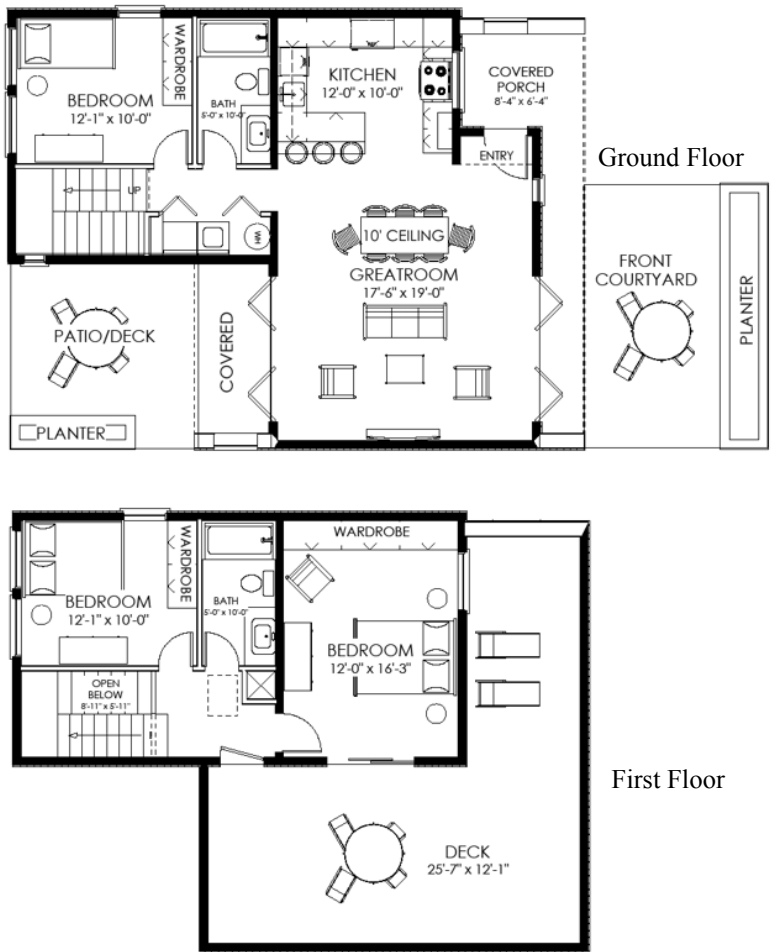
First Floor

Figure 6.9 The modern 2 storey style house: (a) is the 2D interior plan (including ground floor and first floor) (61 Custom, 2017) and (b) is the house viewed in CVGE
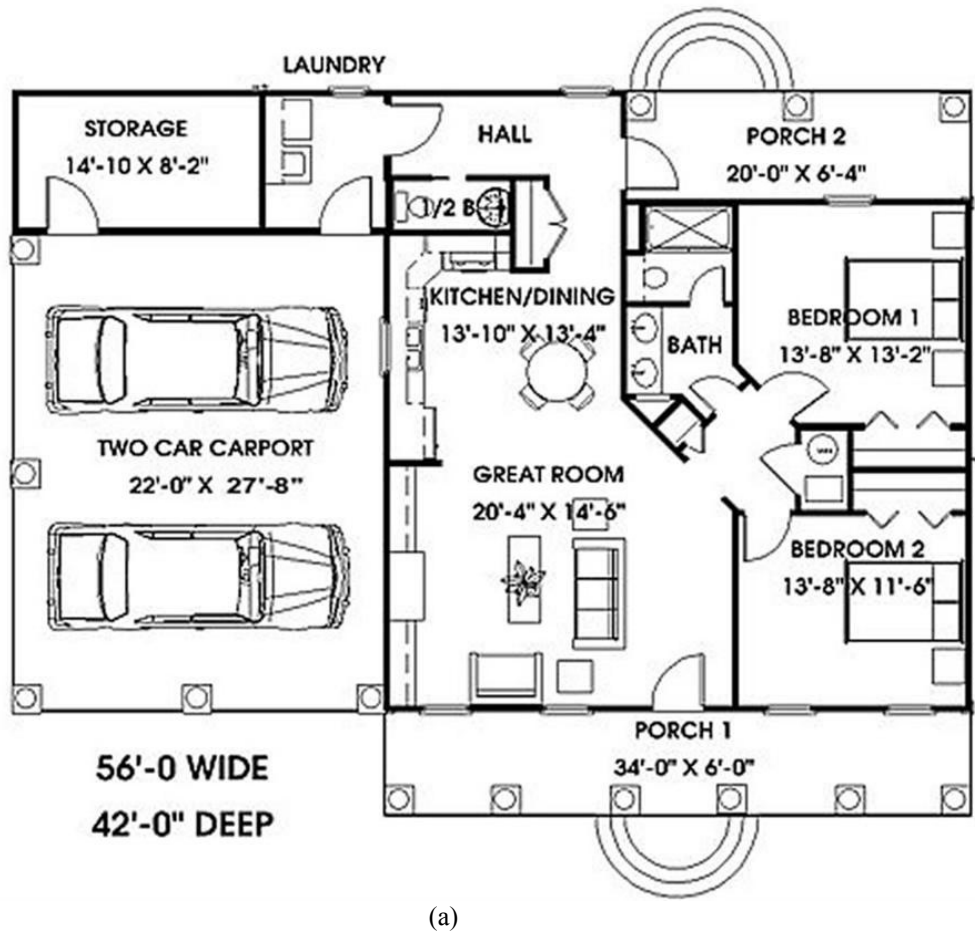
Figure 6.10 The bungalow house style: (a) is the 2D interior plan (Architectural Designs, 2017) and (b) is the house viewed in CVGE

The following figure (Figure 6.11) shows the completed CVGE containing all design elements (building, fence, vegetation and road) and contextual circumstance.

(a)

(b)

Figure 6.11 Screenshots of the completed CVGE. Image (a) is one lot with fences, vegetation, building and 'spiky' boundary. Image (b) shows the completed CVGE with the 'guidance' terrain removed and replaced by the normal one.

6.3 3D Design Environment Construction Process in CAD

Computer aided design (CAD) software is one of the most common design software types utilised in current urban design projects. It has the capability to work with other

professional engineering software packages (e.g. Trimble Business Centre, Topcon Magnet Office, and Leica Geooffice). Furthermore, it has acceptable 3D drawing and rendering capacity, which can satisfy various requirements from fields such as mechanical design and environmental engineering.

BricsCAD (BricsCAD, 2015) is the CAD platform used for testing in this project. It has a typical feature set of 2D, 3D and modelling tools. To realise the 3D urban design, the digital elevation model (DEM) of the design site extracted from 12D was imported into BricsCAD. The image below (Figure 6.12) displays the topography of Grandvista in Triangular Irregular Network (TIN) format.
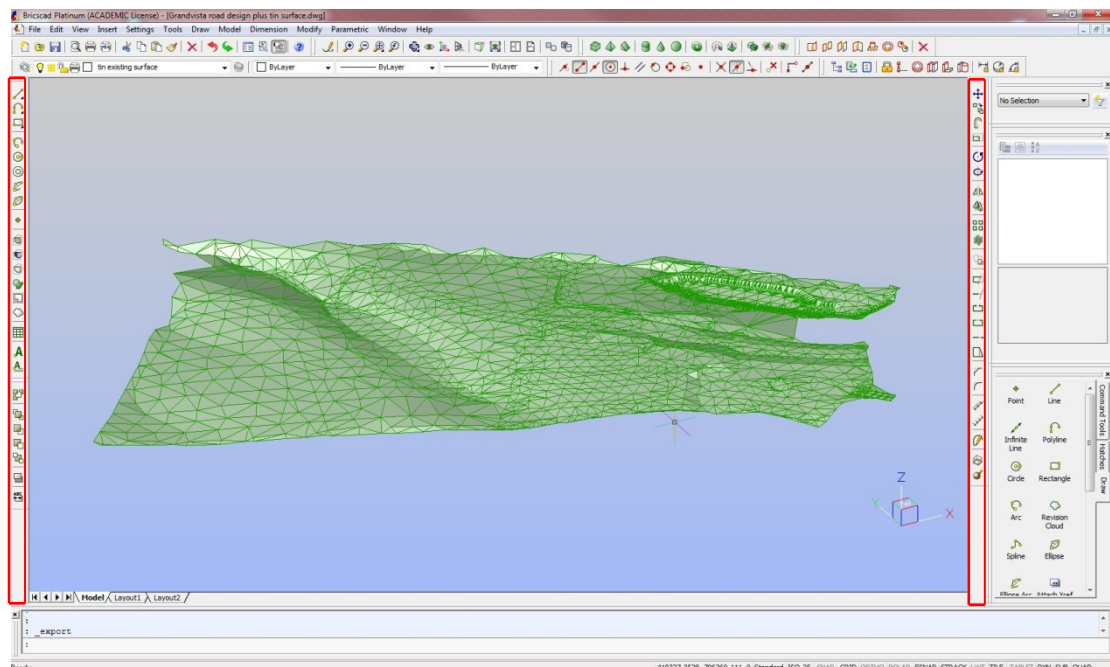
Figure 6.12 Grand Vista TIN terrain model opened in BricsCAD. The area highlighted by the red line shows drawing tools used to complete the initial 2D plans.

Urban design features were represented in CAD, using polylines to indicate roads and parcel boundaries. Similarly, a 2D plan was developed in this project (using drawing tools, in the area highlighted by the red lines in Figure 6.12). This 2D plan was used as a base layer to locate 3D buildings.

As discussed in the previous section, building models are one of the key elements in a three-dimensional CVGE. The same 2D floor plans that were used for the VR building models were used in the CAD and GIS environments. This was to ensure that

we can do a horizontal comparison between them in the usability testing stage.

Most CAD software provides both 2D and 3D views, which enable users to easily exchange viewpoints and develop their project in different dimensions. BricsCAD also provides a set of 3D editing toolbars for creating objects as well as modification and editing toolbars similar to the 2D tools. Similar to the modelling process within VR, primitive objects were also used to create 3D houses in the environment (Figure 6.13).
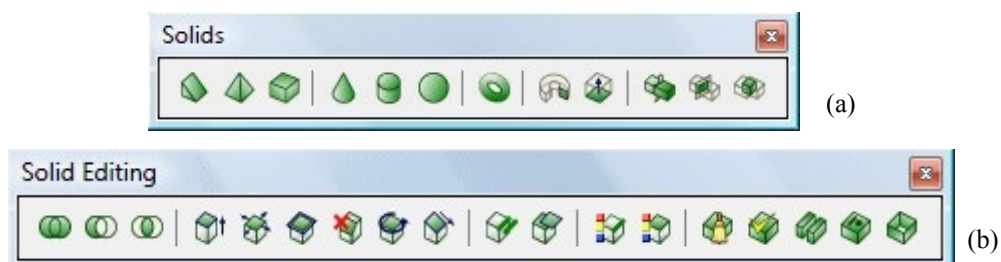
Figure 6.13 Three-dimensional modelling toolbars embedded in BricsCAD: (a) Solids including primitive objects; (b) Solid Editing can modify and edit 3D objects.

Two methods can be used for editing the object's size and dimensions: by inputting the length of each side when creating the object; and, by using the solid editing toolbar (Figure 6.13, b) to modify the object's shape, such as angle and height. In addition, the 3D rotation tool can be used for carrying out minor adjustments, to ensure buildings are located at their correct orientation within each parcel. Users are able to achieve precise editing by entering exact dimensions in the command window (red line highlighted area 1, Figure 6.14).

At the same time, texture rendering functions shown in the object's attribute window (right hand side of the main window, red line highlighted area 2 in Figure 6.14) were also used to improve the overall effect of the experimental design environment. Various colours were used to distinguish land use, such as residential area (pink line) and reserve (green line). These can also be used to indicate the density of a block.
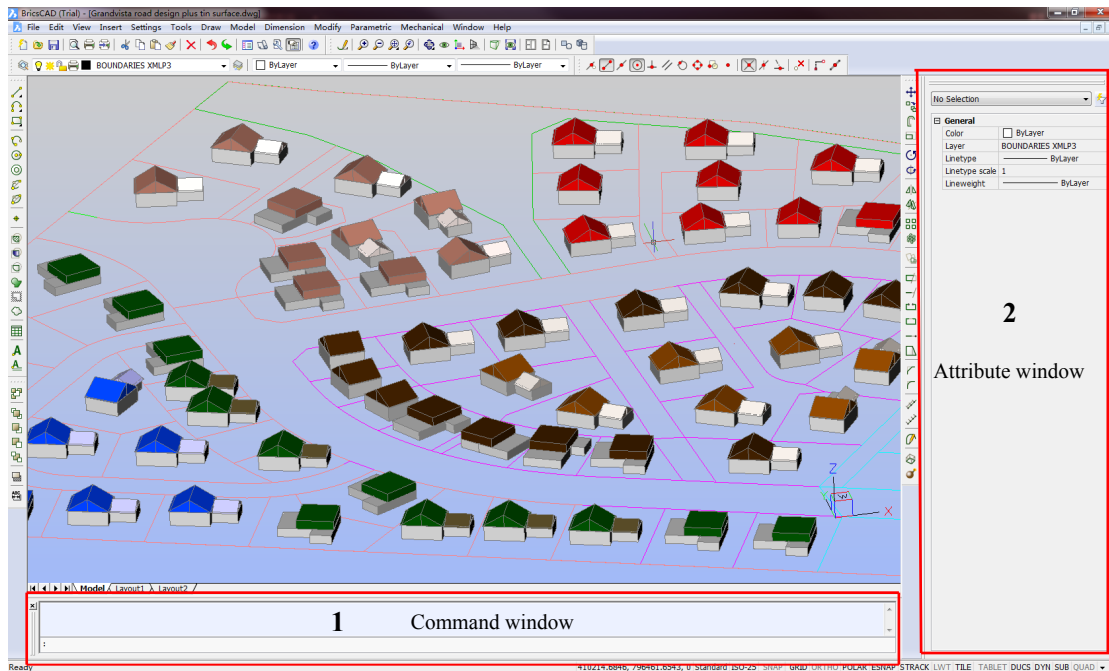
Figure 6.14 The screenshot of the sample 3D design environment constructed in this research. Users can enter commands and dimensions in command window to create or edit objects. In the attribute window, users can change the details of an object.

For instance, the above image, Figure 6.14 shows a screenshot of the Grandvista design plan visualised in BricsCAD at 3D level. The colourful roofs demonstrate their developing stage in the progress of subdivision development. For example, the red roof buildings in Figure 6.14 indicate those that will be constructed first in the construction stage of the development (stage 1).

The view toolkit (Figure 6.15) is another useful tool for looking into the position of each object and its spatial location within the entire environment. 'Real-time motion' was used to pan and rotate the view point. It helps to ensure each part of the object is linked correctly and to confirm that the objects were in their correct positions.
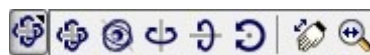
Figure 6.15 Expansion toolbar of the real-time motion button, which is used to pan and rotate objects

The following section outlines the data processing procedure for realising the 3D construction in ArcGIS 10.0.

6.4 3D Design Environment Construction Process in GIS

In comparison to the BricsCAD workflow, the construction of the 3D environment in GIS was more complicated. As another important tool used by urban designers, GIS functionality crucially includes 3D capabilities. To achieve the aim of this research, an external 3D modelling software package (Trimble SketchUp 8) was introduced into the 3D environment construction process, and was used to create 3D building models. Details are provided in the following sections.

6.4.1 3D Houses Creation in an External 3D Modelling Package (Trimble SketchUp 8)

Trimble SketchUp 8 (SketchUp, 2017) is a 3D modelling program for a broad range of applications including architecture and civil engineering. Compared with other professional 3D design and modelling packages (e.g. 3D Studio Max and Vectorworks), it has a more intuitive interface. Therefore, SketchUp was selected to build 3D house models for the purpose of this research.

Similar to CAD, SketchUp contains a variety of 3D modelling and editing extensions. In addition, its online repository of model assemblies (e.g. windows, doors, vehicles, etc.) provided a more flexible, fast and user-friendly workspace. The texture rendering library (Materials) significantly improved the realism of 3D objects.

In this project, we used Trimble SketchUp to build individual 3D building models and render them with textures provided in a local library. The process started with drawing individual building parts in a 2D plane (edit on x and y-axis surface) and then pull or push the planar exterior of the object (to define a height, or z, value). A building model will be comprised by a set of these primitive objects, like the VR and CAD modelling process. The following image (Figure 6.16) is a screenshot of SketchUp's workspace.
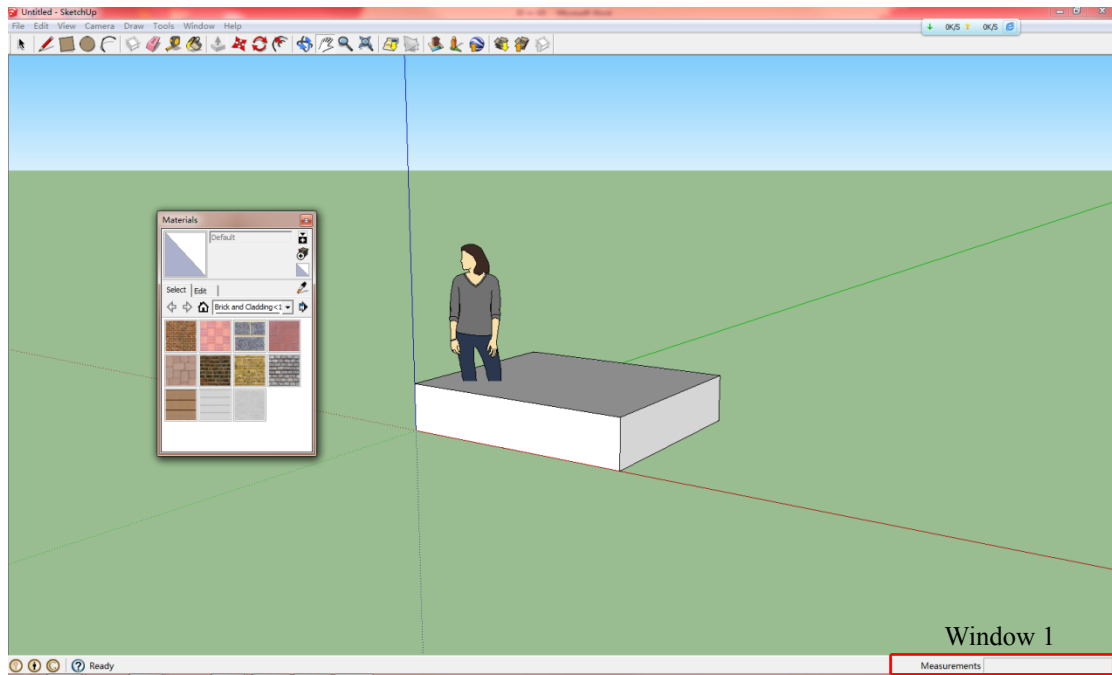
Figure 6.16 The User Interface of Trimble Sketch up showing a primitive object for modelling. Red line highlighted window shows the length, width or height.

Window 1 which is highlighted by red lines in Figure 6.16 will update size (length or height) of the object when users are doing edits. In this way, users can achieve precision modification of SketchUp objects. For example, users can monitor the height of a wall and adjust it to a required 3.5 meters. Lastly, the texture of the models was altered to improve their realism using the Materials box. It provides a set of textures including bricks, fencing and roofs (Figure 6.17).

(a)

(b)
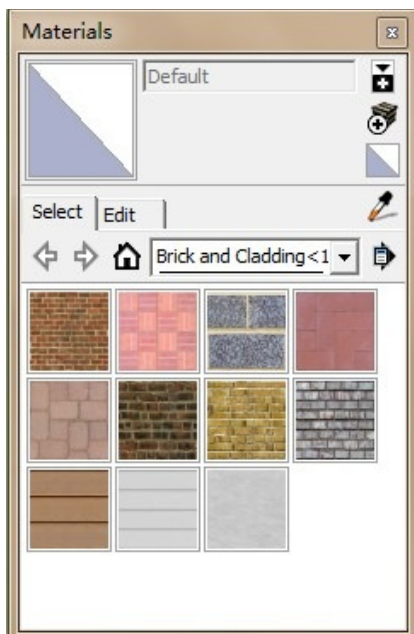
Figure 6.17 Modelling and editing tools provided in Trimble SketchUp used for constructing individual 3D buildings in this project: (a) is general toolbar and (b) materials box

The following two images (Figure 6.18) are screenshots of the resultant 3D houses.
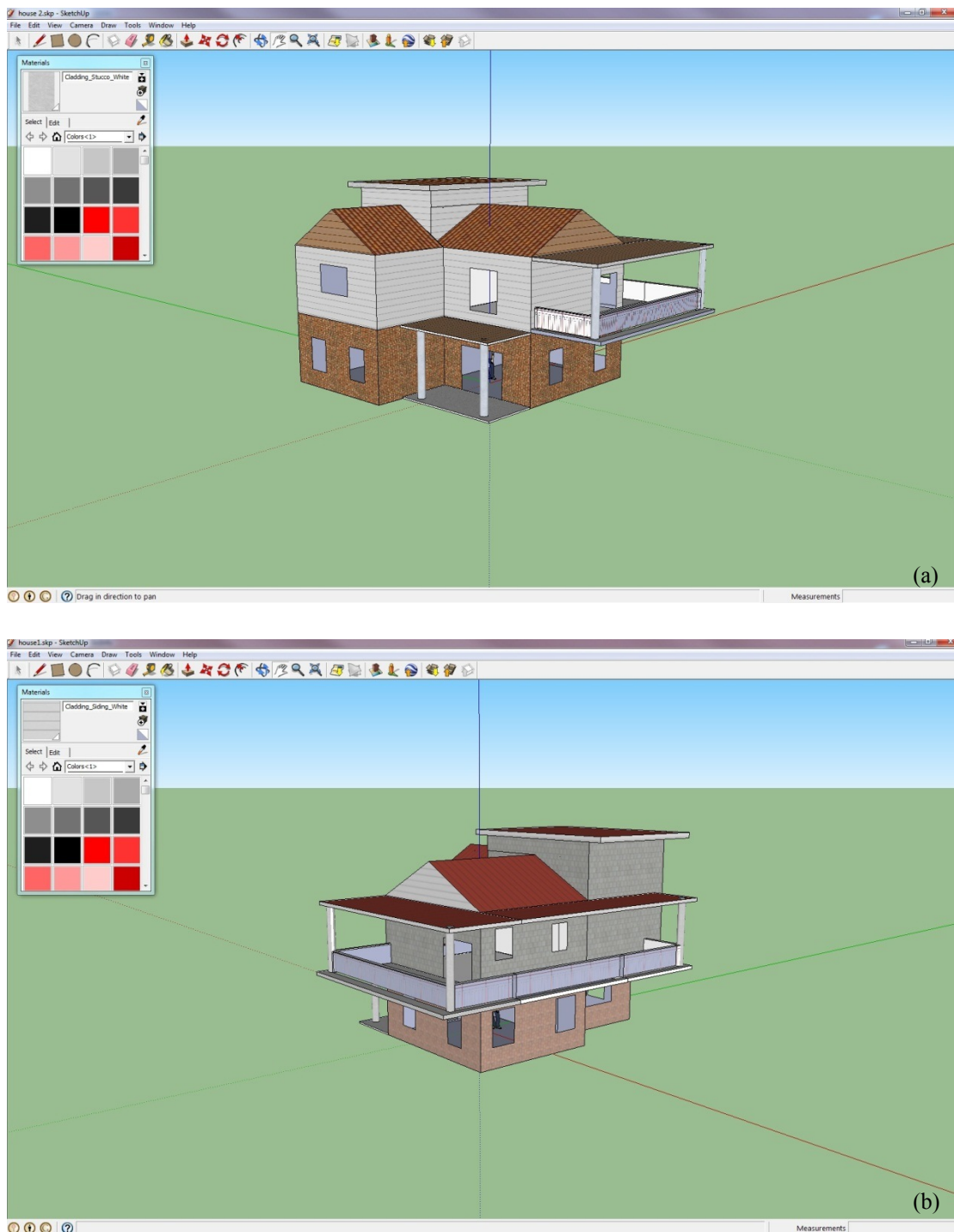
Figure 6.18 The 3D house model generated from Trimble SketchUp 8

6.4.2 Data Processing in ArcGIS

In contrast with CAD, GIS is more specialised in analysis, structuring and maintenance geographic information. ArcGIS 10.0 was used in this project (ArcMap for 2D and ArcGlobe for 3D), which not only provided analysis and mapping on a 2D level, but also enabled standard functions for 3D visualisation and analysis (e.g. create TIN, query a surface, etc).

In this research, the construction of a 3D urban design environment can be summarised in two stages. Firstly, the creation of 2D building footprints was performed in ArcMap, as up to this point these building footprints only exist in the design plans. These 2D footprint files were converted to 3D multipatch format in ArcGlobe, and used to locate 3D buildings in the next stage. Secondly, the new SketchUp model's geometry was used to replace the ArcGIS multipatches. The entire workflow is shown as the diagram below (Figure 6.19).
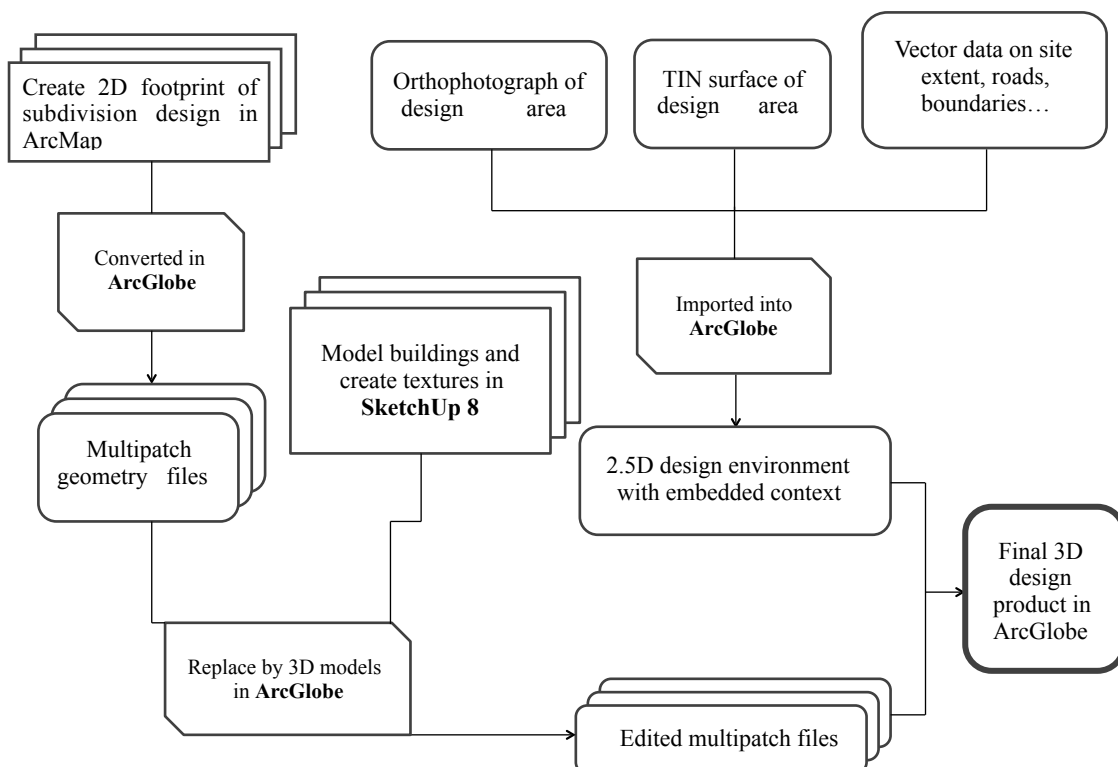
Figure 6.19 The whole 3D environment construction workflow in ArcMap and ArcGlobe

The first stage was completed in ArcMap. Initially, the 2D digital design features (including the future roads, lots and reserves) were exported from BricsCAD and imported into ArcMap as separate layers. ArcGIS has good compatibility with other engineering software; therefore, a CAD exchange file was used in this step. Then, a new layer was created for locating the position of each building. This layer was subsequently converted to a 2D footprint for next stage processing. Lastly, the files processed in ArcMap, as well as those building models created in Trimble SketchUp, were brought into the final integration and construction stage, which was implemented in ArcGlobe.

In the integration stage, more contextual data can be added into the 3D environment. A TIN surface (exported from 12D) and an orthophoto of Grandvista (downloaded from Dunedin City Council) were imported to ArcGlobe for simulating the actual terrain of the design site and displaying the surroundings. The 2D design plan that was created in BricsCAD was uploaded as separate feature classes (line and polygon) and used as an indication of land use. Figure 6.20 is a screenshot of the Grandvista terrain model represented in ArcGlobe.

Figure 6.20 The screenshot of the Grand Vista terrain model that displayed in ArcGlobe

For replacing the building multipatch layer with a SketchUp 3D model, the building

layer (digitised in ArcMap) needed to be converted into a multipatch file which represented the location of a 3D object as a single row in a database.

A multipatch feature is a GIS object that stores all related patches, such as texture, colour and geometry information. It is usually three-dimensional and can enhance the 3D realistic symbology of a feature. Additionally, ArcGlobe is a 3D environment which provides a favourable editing environment for multipatch features (ArcGIS Resource Centre, 2015).

The last stage was to edit the multipatch layer with the 3D Editor Toolbar. The 3D models in ArcGlobe were ready to be replaced by those built in SketchUp. In order to achieve the best presentation, minor rotations and adjustments were applied to these building models. The final environment is shown in the following image (Figure 6.21). Colours are used to indicate different land use and to distinguish the different development stages.
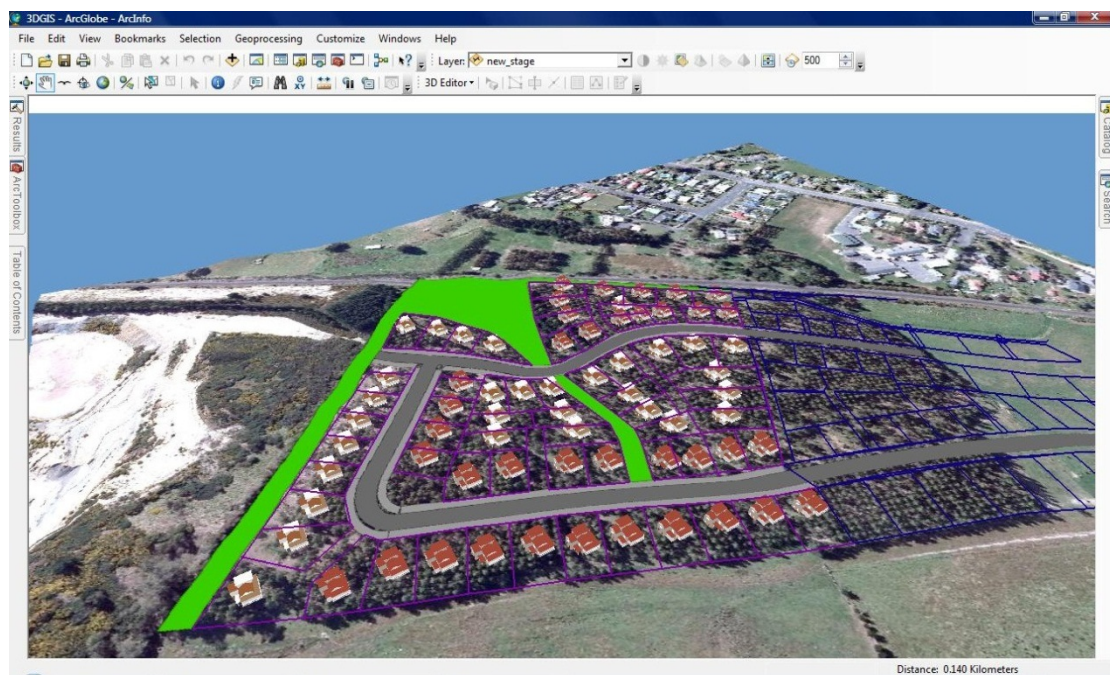
Figure 6.21 The screenshot the final 3D environment in ArcGlobe: the green polygon represents reserve area, the grey polygon indicates main road, the purple line means new stage developments, the blue line demonstrates the existing developments and the orthophotos shows the surroundings.

6.5 Usability Evaluation

The major aim of this project was a comparative assessment of urban design scenarios realised by CAD, GIS and online VR software. The last part of the project was to implement usability testing on the completed environments. Experienced urban designers, surveyors and senior students, in total 16, were invited to participate in the usability testing (details of participants refer to Chapter 7). Relative comparative factors of the three experimental environments and participants' feedback on them, were collected in this stage.

Participants received an information sheet about the project, which briefed them of the tasks to be performed in the three environments and the themes of the questions contained in the accompanying questionnaire. The questionnaire used in the testing stage was designed according to the usability criteria (refers to Section 5.1). The full questionnaire is attached in Appendix C. After reading through this, the participant could either undertake the study or withdraw from it at any time.

To fully explore and evaluate the experimental models, participants were asked to carry out a set of tasks. They performed the evaluation through the completion of tasks in three different design workspace. When the testing had been completed, they were asked to answer a series of questions in the questionnaire about the model and their impression of interacting with the models.

A key point in the questionnaire structure is the exact phrasing of questions and their order as these can have effects on the answers. The questionnaire was designed according to the usability criteria discussed in Section 5.1. It was aimed to evaluate user requirements, as well as collect their feedback about the sample three-dimensional design environments.

The questionnaire includes both qualitative and quantitative questions. According to Agee (2009), questions in qualitative research need to move the researcher toward discovering what is happening in a particular situation with a particular person or group. Therefore, a set of free text questions were used to understand participants

background, and their experiences with the three software packages that are used in this research.

The assessment was divided into five parts. The first part was to understand the participants' previous experience with the technologies (CAD software, GIS, 3D modelling software and virtual reality) and the users' requirements for applying 3D technology to urban design (Part A of the questionnaire). For instance, they were asked what sort of design tools (digital and non-digital) they had used in their work, and whether they were interested in using 3D techniques in urban design projects. The aim of this part of the assessment was to gain a basic understanding of the participants' backgrounds and to estimate the potential of utilising three-dimensional visualising/simulating/analysing techniques in their professional fields.

The following three parts (Part B, C, D of the questionnaire) were designed to assess the 3D environments built in BricsCAD (CAD), ArcGIS (GIS) and OpenSim (VR) respectively. Each part included a set of tasks to be completed with the software. Participants accessed the packages through a laptop. The tasks they performed were followed by ten questions that gathered their feedback on the software and the sample 3D environment. The three parts were randomly sorted in each questionnaire to eliminate any possible effects of having them in the same order. More details are provided in the following sections.

Task Setting

The tasks were designed for testing the usability of the software (BricsCAD, ArcGIS and online VR software). For the purposes of controlling variables and cross comparison between the three technologies, each part required identical tasks.

Detailed instructions were provided to participants to help familiarise them with the basic operations of the software, such as how to open the software and how to set up a new project. This enabled participants to get an initial impression of the software usability and to explore the software, particularly its 3D functionalities.

The main tasks were tested in four major sub-tasks:

- Create 3D objects - build 3D objects as provided in the instructions. The following example shows the 3D object the participants were required to build, consisting of two 3D shapes which approximately correlate with LoD 1 in CityGML terms.

- Alter the viewing parameter of an object (e.g. pan, rotate view). This views the objects from a different point of view - i.e. moving the viewpoint of the observer, while the objects themselves remain in a fixed location within the model.

- Edit geometric attributes of an object (e.g. scaling, rotation). This changes the objects themselves to ensure they fit within the correct spaces within the model - spatially rotating the object and changing its size to suit the surrounding environment.

- Change the texture of an object. This adds realism to the 3D objects, enabling the user to see them as objects instead of featureless boxes. Textures allow the user to see walls and details of building edges, and in CityGML terms, a higher Level of Detail would allow the user to see other features also.

Refer to the questionnaire in Appendix C for the instructions given to participants, and the questions they were asked.

Each sub-task shared an equal weight of 25%, therefore the potential score of a single participant can be 0%, 25%, 50%, 75% and 100%, depending on the success of completion of the task (effectiveness).

Efficiency and Effectiveness

In this project, time-costs of finishing tasks was the main measurement of efficiency, and effectiveness was reflected in correctness of completing these tasks. During the process of testing, the time-cost of completing each sub-tasks (refers to the four main tasks) was recorded and then they were summed up as total test time. The time-costs of each task will be shown in Section 7.3.

The correctness of the output that participants produced after each task was also recorded. In terms of the criteria of judging correctness, if a participant needed advice or help in the use of the software (such as asking where to find specific functions or how to use them) to complete the task, or if the outcome was not exactly the same as the sample provided in the task sheet, the task was marked as having failed. For example, participants were asked to create a 2m (width) $\times$ 5m (height) $\times$ 8m (length) object (sub-task: 3D object creation); however, if they created this object the wrong size, the points (25%) of this task were then deducted.

Lastly, the Analysis of Variance (ANOVA) technique was applied to the analysis where there was any significant difference between three groups (CAD, GIS and online VR). ANOVA is a collection of statistical models and is useful in comparing the groups for statistical significance (P-value less than 0.05) (Refer to Section 5.2).

Satisfaction

The major aim of this set of questions was to collect the overall user experience feedback of the three testing software packages. For example, how simple was it to master the basic operations of the software; was it easy to modify details in it; and how pleasing/fulfilling was the example environment? Identical questions were designed for each of CAD, GIS, and CVGE, to ensure a horizontal comparison.

The last part (Part E) of the questionnaire comprised nine additional statements used to investigate participants' satisfaction of CVGE's unique capabilities (i.e. online real-time editing, and navigating themselves in the entire 3D environment).

The statements for each question were followed by a balanced and symmetric Likert scale that is used to describe how users agree with the statement. The scale is from completely disagree (1) to strongly agree (5), with neutral in between (3). Participants could specify their level of agreement or disagreement by ticking corresponding points.

These Likert type statements (a quantitative assessment of satisfaction) were

complemented by open-ended (qualitative) questions on advantages, drawbacks, suggestions for future development and any other comments on the three environments, which were collected and used as feedback to enhance understanding of users' reactions to the software and methods.

Associated with the navigation issue mentioned in the previous project (Zhang, 2011), an initial attempt to resolve this was implemented in the testing stage. Participants were guided to use OpenSimulator's Map and Mini Map toolbars. This method was tested to discover whether it increased users' sense of overall spatial awareness and reduced disorientating situations.

A Chi-squared test was used to analyse whether there was any significant difference in the degree of satisfaction. The feedback and analysis results and interpolations of the analysis result are reported in Chapter 7.

The last portion of the questionnaire contained general questions that collect ed suggestions and comments about the research, as well as further specific questions about Virtual Geographic Environments.

Chapter 7 Results

This chapter first presents the content of a questionnaire which was used to obtain data from participants in the study, including feedback assembled from the surveyed professionals. The results obtained from this questionnaire are then analysed and presented. Tables and charts are used to present the quantitative data, and this chapter also includes a summary of the qualitative data obtained. This data is the result of the usability testing performed using the methodology presented in Section 6.5.

7.1. Participants' Details

The sixteen participants came from private organisations, local and central government, and tertiary students:

- Two were from private sector organisations, and had experience with surveying projects and client consulting.

- One was from local government, with experience in 3D modelling at the city scale.

- Six participants were from central government. Four of them had experience in both private and public sector, and had previously been involved in urban design practice. In their incumbent roles, they had a good view of stakeholder engagement. The other two participants from central government had good technical experience, and were able to use this experience to provide useful feedback from a software user perspective.

- Seven senior students were from the School of Surveying at the University of Otago, New Zealand, and were undertaking degree courses in Land Surveying with internship experience at local surveying companies.

7.2 Participants' Feedback for the Design Packages (Participant Experience)

This section summarises the participants' background in regard to urban design, including their comments on the design software that is used in their daily work. The

participants stated their experience in practical design projects and listed general design tools that they used every day. All but two of the participants have experience of working with at least one of the testing packages. They also expressed willingness to use 3D techniques in the future.

Participants who had experience of taking part in an urban design project were already commonly working with computer design tools. The packages are mainly conventional tools such as 12D, CAD and GIS. Most had used CAD software for their urban design tasks, and a couple had used GIS. Some of the participants had attempted to use 3D functionality in their work. However, two participants also pointed out that they prefer using pencils and paper because they feel they are more flexible, particularly when they draft their design.

In terms of utilising 3D functionalities in their daily work, most of the participants also showed a positive attitude to learning and using this new technology. The participants recognised that some current 3D applications such as terrain modelling and space modelling are helpful and useful. At the same time they also stated an expectation that the software should be easy to use and straightforward to master the basic operations.

The next part of the questionnaire included a set of general questions about the users' experiences in testing the software, and participants' feedback about it, such as what kind of software they used and what aspects they liked or disliked about it. (Refer to Appendix C: questionnaire, Part BI, Part CI and Part DI).

CAD

Fifteen out of sixteen participants had experience with CAD before, but only five of them had used CAD 3D functions in their job. The major purpose they used CAD for was concentrated on specific professional aspects, such as road design, earthwork design and calculation.

Among the participants, 12D and AutoCAD were the most used software packages

and were both widely used already both in professional design work and by student designers. CAD interfaces are capable of precise drawing and structuring of model features. Additionally, for urban design purposes, CAD files are the 'standard format' to a large degree due to their wide adoption by designers.

Most of the participants however, argued that the CAD software is very difficult to learn and is not user-friendly enough. The complex menu system is a weakness of this sort of design software. The functions within the packages are difficult to find and the commands are sometimes hard to understand. An example provided by participants is print-setting in 12D, in which users need to specify the scale and frame. To do this, they first need to understand what it means, and the importance of printing at the correct scale for their design.

GIS

All the participants had used GIS software in their job and nine of them had experience of 3D editing in GIS. ArcGIS by ESRI was the most common GIS package used by participants, but MapInfo also played an important role in some participants' work. According to participants' experiences, they mainly used GIS for geovisualisation and data management (e.g. of address points, water/waste water systems, etc), as well as data analysis and calculation (for example, transport network optimisation and test resource applications). They commented that GIS could display and produce professional quality themed maps, and was the go-to tool for analysing large amounts of both spatial and non-spatial data. GIS also has considerable interoperability which enables users to carry out their tasks while switching between different software packages.

However, the high knowledge requirements for GIS are a barrier for the novice. One participant argued that users require a long time to learn basic geospatial operations. High level programming skills are also required for some tasks. Some of the applications and tools needed a high level of spatial understanding, such as projection system transformation and geo-data visualisation.

Virtual Reality (VR)

All the participants indicated that they had heard of Virtual Reality techniques; however, only a couple of them had experience using virtual reality software. One participant used the software for professional purposes and another used it as a game. Participants pointed out several useful applications, for instance the calculation of the sunshine effect (sun angles), aiding explanation of policy using visual tools, and briefing the public.

The two users' feedback illustrates that VR software is easier to use than 'professional' design tools such as CAD and GIS, and can provide an effective communication medium between designers and clients. Compared to 2D modelling, the environment in virtual reality software can have greater realism - though there are also disadvantages to this, such as users' expectations of the capabilities of a 3D system.

Converting data files to a VR-understandable format is also a potential roadblock to uptake of the format. For example, one participant said that local projection systems can be a problem in translation. Files using a local projection took a long time to process and were difficult to integrate into VR.

7.3 Results for Assessment of Sample 3D Environments

In this sub-section, five tables summarise the participants' performance and comments. They include their efficiency in the use of three 3D modelling environments, the effectiveness of the environments, and participants' satisfaction with them.

Comparison of the Time Taken to Complete the Four Specific Tasks (Efficiency)

The set of tasks for testing the software tools were divided into four main parts: create 3D objects, edit the size of the objects, rotate the objects, and change the texture of the objects. Table 7.1 and the plot in Figure 7.1 show the comparative results for

efficiency. The results show the average times taken for the four specific tasks.

Object	CAD	GIS	VR
(1) Create 3D object	4.37min	9.49min	3.49min
(2) Edit size of the objects	2.63min	3.35min	1.93min
(3) Pan/rotate the object	8.14min	2.57min	2.69min
(4) Change texture of the object	1.01min	2.29min	1.86min
Sum	16.15min	17.69min	9.97min

Table 7.1 Summary statistics for time-taken (in minutes) for each method

Participants took the least time (9.97 minutes in total) to complete the tasks when they were working in the CVGE. The average time taken using CAD and GIS showed little difference, being 16.15 and 17.69 minutes respectively. To some extent, this shows that a VR-based urban design environment was the most efficient design tool for the participants. This is graphically shown by the Figure 7.1 box plot.

Distribution of time taken
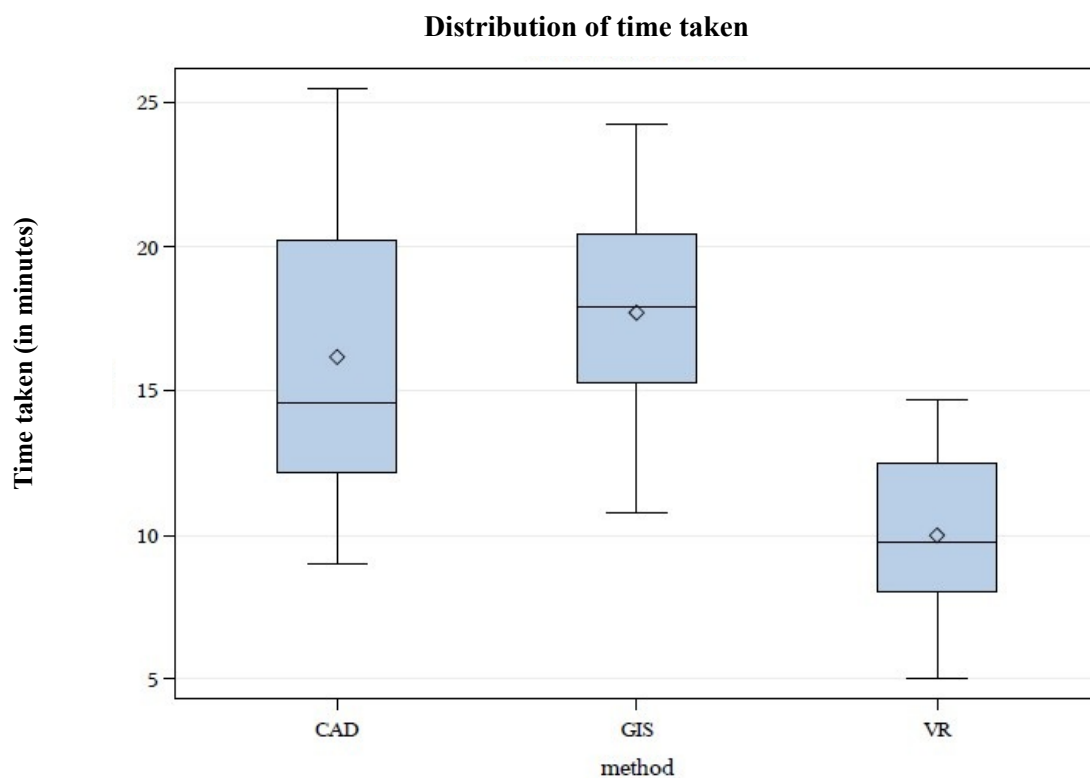
Figure 7.1 Plot of time taken (in minutes) in the three environments

For the ANOVA test results, the associated p-value is less than 0.05. This indicates there is a significant difference between the testing groups. Therefore, VR was judged to have a statistically significant difference when compared with the other two methods (CAD and GIS). There was no significant difference in performance between CAD and GIS.

Comparison of Effectiveness

The following box plot (Figure 7.2) shows the analysis result for correctness of the task output (effectiveness). This measured in terms of percentage of tasks completed without error or verbal instruction.

Distribution of correctness
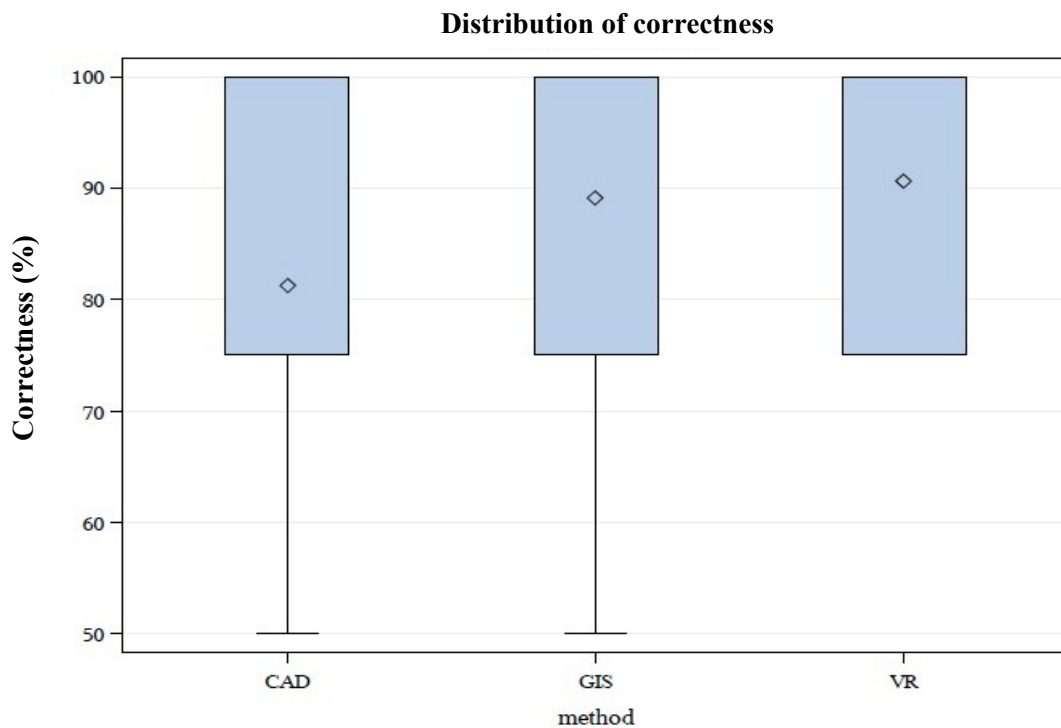
Figure 7.2 Box plot of correctness (effectiveness) for each type

There is no significant difference between the three methods even though VR got a marginally higher score. The correctness (in percentage) of VR-based operations is

approximately 91% (in average), while the results of CAD and GIS are approximately 81% and 89% respectively.

Participants' Perceptions (Satisfaction)

This part comprised ten questions, each identical for the three environments. These questions mainly cover three aspects: user interface (UI) design, 3D editing capability, and usability for a specific purpose (for urban design purposes in this project). This sub-section reports the results for Satisfaction. Table 7.2 shows the average Likert and standard deviation results for the three environments, with 1 meaning strongly disagree, and 5 meaning strongly agree. The result of a Chi-square test working on the null hypothesis is also reported.

Questions	AVG			Stdev			Chi
	CAD	GIS	VR	CAD	GIS	VR	
(1) interface is user-friendly	2.813	2.375	3.750	0.981	0.957	0.775	**6.33**
(2) simple to master the basic operations	3.094	2.375	4.063	1.068	1.147	0.929	**7.75**
(3) straightforward to master 3D operations	2.844	2.375	3.813	1.151	0.957	0.655	**7.88**
(4) easy to edit details	2.813	2.500	3.969	1.223	1.155	0.591	**9.10**
(5) visualise the attempts accurately	3.063	2.875	3.625	1.289	1.310	0.806	1.75
(6) produce 3D products rapidly and efficiently	2.906	2.563	3.844	1.241	1.365	0.995	2.33
(7) 3D models have high fidelity	3.469	3.250	4.188	1.087	1.111	0.834	2.39
(8) can estimate the possible need for earth works and land use	3.400	3.625	3.688	1.039	1.088	1.014	0.08
(9) can be used for professional work	3.688	3.400	4.000	1.352	1.183	0.779	1.36
(10) can save time in design progress	3.031	2.600	3.433	1.190	1.595	1.208	0.47

Table 7.2 Average Likert scale and standard deviation results for the three environments, indicating comparative satisfaction

According to the above table (Table 7.2), there was a trend of a more positive assessment (AVG score > 3) for VR. Participants' attitudes towards CAD and GIS were less positive to similar degrees. Meanwhile, the distribution of opinion was also narrower and better defined with VR than the other two technologies.

In terms of UI design perspective (Q1 and Q2), participants showed strong responses to the online VR software. VR's interactive interface derived from gaming technology was more intuitive and approachable, while the interface of GIS was considered too complicated for general users. The chi-square test results also reinforced the advantage of VR.

Specifically, VR had the most user-friendly interface with the highest average score 3.75, above the average of 3. Meanwhile the interfaces of CAD and GIS were only marked by scores below the average, 2.815 and 2.375 respectively. Benefitting from its user-friendly interface, VR was also the simplest tool to master basic operations, with average Likert score of 4.063, followed by CAD scoring 3.094 and GIS scoring 2.375.

When it comes to 3D model construction and editing capability, feedback about VR was more positive compared to the other two. Overall, the fidelity of 3D objects generated in CAD, GIS and VR were satisfactory, obtaining average scores 3.469, 3.250 and 4.188 respectively.

In summary, it was difficult to use 3D functionality in CAD and GIS as well as hard to modify details of 3D objects (Question 3 and 4), as evidenced by their below average scores. In contrast, VR had apparent strength in its operability, which was demonstrated by the significant chi-square test results. Compared to working with CAD and GIS, participants showed more confidence in using VR, including their ability to modify details of 3D models and visualise their attempts.

The last aspect of this section was the time-costs of constructing 3D models. Again, VR occupied the first place as the most time-saving tool by average score 3.844. Participants were not very satisfied with the efficiency of the two conventional

professional design tools (CAD and GIS). They were rated negative scores of 2.906 and 2.563.

In regard to the suitability for urban design, particularly communication of design plans and information, all of the three tested software packages have good performance and have demonstrated their capability. VR has its advantages in ease of use and realism, compared to CAD and GIS.

To support design work, particularly the engineering and spatial design, it is important that the tool is capable of estimating possible earthwork and classifying potential land use. In this regard, CAD, GIS and VR have reasonably good ability as recognised by participants, getting average scores of 3.400, 3.625 and 3.688 respectively. In terms of the ability to use these software packages for professional purposes (Question 9), participants gave relatively positive feedback overall. The evaluation of VR in this aspect was not inferior to CAD and GIS.

However, if taking the whole model construction and editing process into consideration, time-cost is still an issue. Participants were not entirely optimistic. The results are more inclined to the intermediate value 3.00. But VR was still evaluated to have a positive effect on time saving. CAD got a relatively neutral score 3.031 and GIS was considered the most time-consuming tool (average score 2.600).

Questions	Avg	Stdev
(1) employing VR in the future project	4.125	0.957
(2) can get comprehensive understanding of design context	4.094	0.584
(3) have an awareness of overall position	4.094	0.821
(4) simple to navigate from one place to another	4.375	0.719
(5) can modify details precisely via the tools in OpenSim	3.844	0.926
(6) 3D model better than 2D level	4.063	0.854
(7) The graphic quality is good enough for urban design purpose	4.000	0.816
(8) feel more engaged than using digital data	3.844	1.060
(9) real-time enough for urban design purpose	4.000	1.095

Table 7.3 The analysis result for the additional VR questions

The above tables report the participants' responses to each question, summarised their

comments on the performance of three design packages and the analysed scores of three sample geographic environments. The next section will provide an outcome table for further VR-related questions, which was used to investigate the functional specialities of the online virtual reality software.

7.4 Additional Participant Feedback for the CVGE

This section contains nine additional questions about the CVGE. These questions further investigated other aspects of the software, such as in-environment awareness, navigation, graphics, real-time aspects, and sense of engagement/presence within the environment. Table 7.3 reports the average Likert and standard deviation results of this VE-specific part of the research.

The above table shows that the participants expressed positive opinions (AVG score > 3) on all aspects. This is similar to the previous VE part, where the spread of opinion (standard deviation) was narrow and well defined. Participants' comments about this part reinforced that the additional attributes of the VR software (e.g. real-time, sense of immersion) is attractive for urban design. It also evidenced the potential of using virtual geographic environments in future urban design projects.

The feedback was convincing that objects presented in a three-dimensional environment are more realistic than conventional two-dimensional environments (4.063 average). Presented with this entirely 3D-led virtual reality technology, participants also voiced their enthusiasm for using it for professional working purposes, evidenced by an average Likert score of 4.125. Additionally, the conversation between designers, clients and the virtual design environment can also benefit from the VR's ability to present real-time updating of geo-information (statement 9, average score 4.000).

More specifically, regarding whether the online CVGE is suitable to perform urban design scenarios, the geovisualisation quality of the VCGE received the average score of 4.000. Additionally, the new approach using orthophotos to rebuild geographic data and provide the context for the design area, was also affirmed (average 4.094) by the

participants.

In terms of navigation perspective, the built-in tools in the online CVGE (mini map and world map) were useful in helping users to gain an awareness of overall position. In addition, users felt it was straightforward to shift their location by using map and teleport functions, which received an impressively high score of 4.375.

However, evaluators pointed out that the capacity for achieving precise and accurate modifications for design details is a vital factor that needs consideration. It was a vulnerability of the online VR software even though it also received a positive response. At the same time, the score of sense of presence was not as prominent as expected (3.844 on average), but it improved compared to pure static digital data.

In this chapter, participants' feedback was analysed and reported from efficiency, effectiveness and satisfaction perspectives. The CVGE-specific results have also been included. Overall the results have revealed some advantages of Virtual Environments as an urban design workspace. The discussion chapter will concentrate on the comparative assessment of CAD, GIS, and VR as urban design tools, particularly the advantages and disadvantages of the online VR-based urban design environment.

Chapter 8 Discussion

This chapter focuses on the significant outcomes and research limitations based on the analysis results presented in Chapter 7, and on observations during the testing stage. A discussion of the results presented in chapter 7 is presented, against the background of the main objective and sub-objectives presented in Chapter 2.

8.1 Review of Purpose and Hypothesis

The ultimate purpose of this research was **to determine the feasibility of using Virtual Reality (VR) technology, that is supported by geographic information and is geographically realistic, as a useful tool for urban design.**

This thesis proposed the hypothesis that **urban design practice can benefit from the use of online VR software for tasks that involve visualisation and interaction,** particularly for the tasks listed in Section 3.1. This is in the context of comparison with more conventional technologies traditionally used in urban design, such as CAD and GIS.

8.2 Review and Discussion of the Main Objective

The main objective of this research was **to implement a comparative usability assessment of proposed urban design scenarios, realised by CAD, GIS (screen-based technologies including both 2D and 3D capability) and online VR software (screen-based but purely 3D technology orientated)**, for urban design tasks (as described in Section 3.1) to discover the benefits and drawbacks of each.

This objective was achieved. Feedback collected from the surveys was generally positive about using online CVGE software for urban design. The research participants also indicated that there is potential for using CVGE in the urban design field, for designing new developments, understanding the integration of new developments with old ones and communicating the design plans with stakeholders and the public. The strengths and weaknesses (in terms of the three usability criteria of efficiency, effectiveness, and satisfaction) of online CVGE-based urban design

methods have been understood through the usability assessment of the three technologies: CAD, GIS and CVGE.

The three sub-objectives were chosen with the usability criteria in mind, to highlight the suitability of the tools (CAD, GIS and VR) in application to urban design.

The following diagram (Figure 8.1) shows the links made in this research between the three sub-objectives, the usability criteria used for assessment of the urban design tools (CAD, GIS and CVGE), and the tasks performed in urban design:
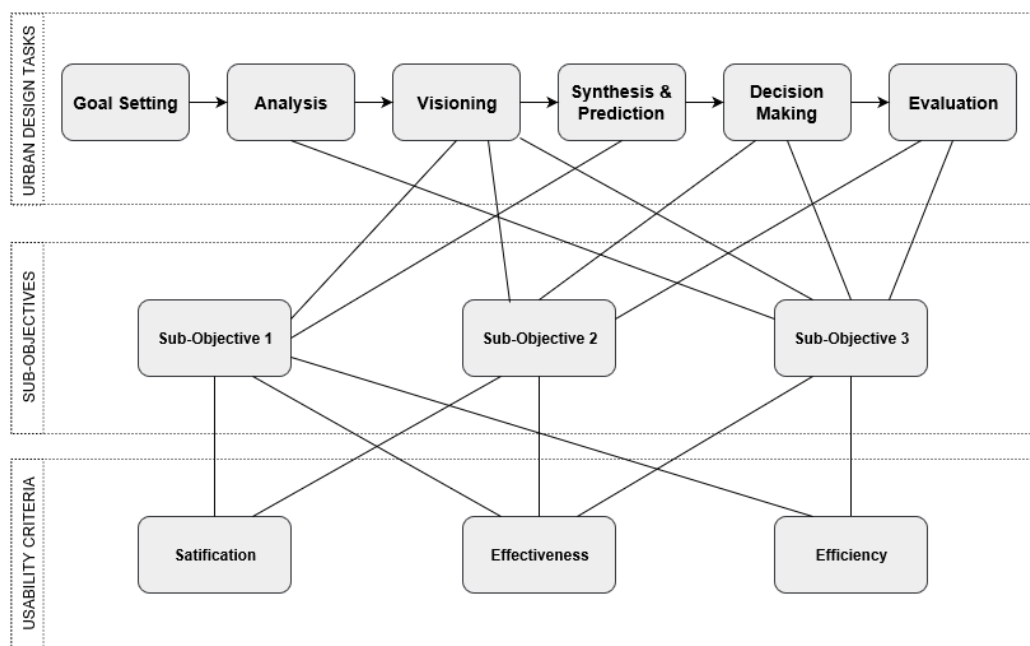
Figure 8.1: Links between thesis sub-objectives, usability criteria, and urban design tasks

8.3 Usability Testing

This research aimed to compare the advantages and disadvantages of screen-based and VR-based tools for urban design. The comparison focused on the three fundamental aspects of usability testing (Haklay et al., 2010): **efficiency** (speed of use), **effectiveness** (correctness of use) and **satisfaction**.

In terms of the three usability criteria, the online CVGE outperformed CAD and GIS (see Sections 7.3-7.4), according to the feedback received from participants. It was the most efficient tool for completing tasks and provided participants with a more

satisfying user experience. However, of the three there was no obvious winner in terms of effectiveness. The following discussions are based on an analysis of participants' responses which are summarised in Sections 7.3-7.4.

8.4 Prior Use of VR in Urban Design

Contemporary urban design tools for designing, visualising and communicating urban design scenarios are mainly professional engineering software packages (e.g. AutoCAD, 12D and MicroStation), physical models, and traditional paper and colouring pens. Geographic Information Systems are also playing an increasingly important role in the design process. The use of these tools was reinforced by the participants' feedback.

VR technology has become more accessible for specialised use due to the fast developments of graphic hardware and due to its integration with online gaming technology (Axford et al., 2007), a field already well established. More OpenSim based clients such as Firestorm (2017) are now available to use, enabling greater uptake of the technology in professional fields such as urban design.

Software companies such as ESRI and BricsCAD have also noted this trend of increased requirements for 3D visualisation and simulation in the professional arena (ESRI, 2017; BricsCAD, 2015). In response to this demand, these companies have devoted efforts to developing new functions or plugins to support 3D modelling and editing (ArcGIS, 2015; ArcPro, 2017; BricsCAD, 2015) - for example ArcScene and ArcGlobe. Designers have already used these plugins for assisting certain types of analysis. In addition, 3D software such as SketchUp and 3D Studio Max have been used to create detailed building/city models for use by designers (e.g. Trimble SketchUp, 2017).

Process vs. Product

While urban design *processes* have historically been dominated by the use of relatively few tools, today many different tools are used. As Janssen et al. described (refer to Section 3.4), geodesign combines many different methods. These tools and methods are integrated together to achieve the best results. The most desirable

outcome is the use of the correct tool for a particular situation. For example, CAD software can be utilised to perform engineering design (such as designing roads or detailed construction plans) and to visualise technical details such as road slope and angles. GIS is better for analysing the possible effects of future developments within the design site. CVGE, too, has its advantages: in providing a realistic and easily accessible design environment for the communication of urban design ideas and proposals between collaborating participants.

These tools and methods for the *process* of urban design depend entirely on the desired outcome, or *product*, that the designer is trying to achieve. It is important to remember that the urban design process will result in outcomes that must be sustainable into the long-term, and fulfill the needs of a diverse community. The practices of urban design (see Section 3.1) each have a different focus, and often need to work together to achieve desirable results. It is for this reason that communication, especially with the community, becomes paramount in the production of design plans, and the outcomes shared with all the stakeholders and the general public to encourage participation. 3D CVGE can facilitate this with its focus on communication and collaboration between designers, other professionals, and the public in a way that more traditional tools cannot.

Urban design *products* have often received community criticism (for example, the community's response to the plans for the city of Christchurch, New Zealand, after the 2011 earthquake was mixed, with criticisms from both the wider community who have to live with these products, and competing business interests who understand the economic realities of the city's situation). Once they are built in physical form, changing the city's form and function becomes vastly more difficult and expensive due to the time taken to move through the cycle of urban renewal. It is therefore imperative to get the design *process* right first time, including public participation in it, to create the right *product* for a community's needs.

8.5 Participants' Previous VR Experiences

Participants were asked to describe their previous attempts to utilise 3D techniques to represent development plans. In contrast with the traditional tools, Virtual Reality

(VR) has struggled to be adopted by professionals in this field, and is only recently becoming recognised as a useful tool. One possible reason is non-familiarity with the technology: Only 2 out of 16 participants in the study had tried VR before, confirming Axford et al.'s (2007) observed reluctance to adopt VR in this field (see also Lopes and Lindstrom (2012).

This might also be indicative of the relative newness of VR and its early stage of development for this purpose; most participants indicated that they had heard of this technology but it had not been widely experienced or used in their professional work. An opinion was also expressed by one participant that urban design could suffice with just its "traditional tools".

8.6 Sub-Objective 1: To build and comparatively evaluate 3D environments, based on a proposed urban subdivision development, containing existing buildings and potential developments.

To carry out the evaluation and comparison, a group of participants were invited from the surveying and urban design communities, to complete a set of tasks in each of the three urban design tools (CAD, GIS and CVGE), after which they completed a questionnaire. Results were then subjected to analysis by Chi-square and ANOVA testing, and the results analysed in Sections 7.3-7.4.

This sub-objective allows the evaluation of screen-based and VR-based methods of performing urban design tasks using all three of the chosen usability criteria, but especially efficiency and satisfaction. This also enables the realisation of the visioning and the synthesis and prediction urban design tasks as listed in Section 3.1. All the design elements used to complete the tasks (e.g. fences, houses, vegetation and roads) were constructed by primitive objects (e.g. cube, cone, etc).

8.6.1 Efficiency of 3D Environments Presented in CVGE versus CAD and GIS

As discussed in Section 5.1, efficiency refers to the time-costs of completing the set tasks, particularly the modelling of objects such as buildings and roads (Haklay et al., 2010).

According to the ANOVA result (as discussed in Section 7.3), OpenSim was the most productive tool (with a p-value less than 0.05), while there was no obvious difference between BricsCAD and ArcGIS in this study.

The participants' responses about efficiency were slightly different, the main focus being on CAD and GIS. It can be concluded from the observations during the usability testing and from feedback from the participants, that the user interface was the major reason for this result.

As shown in Section 7.3, CVGE cost the least time, of 9.97 minutes on average, compared with 16.15 minutes for CAD and 17.69 minutes for GIS. In addition, OpenSim is an open source platform, so users have enough flexibility to customise the software as they feel works best for them (OpenSim, 2014).

The study participants took the longest time to complete the assigned tasks in ArcGIS, and they showed obvious confusion over how to complete these tasks in this software. 3D editing in CAD and GIS required users to work with complicated functions which needed a certain understanding of the three-dimensional environment. This led many participants to request help during the testing stage, even though the description of the required commands was provided (both in the software command window and in the provided task instructions).

This may have been because the task descriptions were too complicated or difficult to absorb for some users. Another factor may be that the 3D modelling process was separated into three parts, and users needed to work with three different software packages (ArcMap, SketchUp and ArcGlobe). On the other hand, users could perform all required 3D modelling tasks in both CAD and OpenSim, which maintained the consistency of the modelling process and helped to reduce users' confusion.

The new version of ArcGIS (named ArcPro) has resolved this issue as it integrates three desktop products (ArcMap, ArcScene and ArcGlobe) and realises real-time 3D GIS (ArcGIS Pro, 2017). The study was unable to test this software.

8.6.2 Effectiveness of 3D Environments Presented in CVGE versus CAD and GIS

Although one advantage of online CVGE software is its representation of geographic information, it is not designed for accurate 3D editing. However, the results show that this resulted in no obvious weakness in terms of effectiveness. This may be because OpenSim does have some basic 3D editing capability, including modifying a 3D object's size and location (though not placing an emphasis on accuracy). Additionally, users edit the 3D models while immersed in the interactive environment, and while interacting with it via their avatar.

However, precision editing is still a weakness of OpenSim even though it has shown acceptable performance (evidenced by a positive result for effectiveness). Feedback comments highlighted this as a critical focus if VR is to become a useful tool in professional practice. For instance, in CAD and GIS the function to modify terrain (e.g. raise, lower or flatten) for calculating potential earthwork can be performed by spatial calculations (i.e. by directly specifying terrain height and slope degree). However, the users of OpenSim can only estimate the potential work by a visual check, which gives only a rough result. One of the potential solutions is to utilise scripts to modify the terrain model from the backend. However this requires knowledge of programming and scripting (e.g. C++ or Python).

It is not surprising that CAD and GIS have consistently high results for effectiveness. Effectiveness for their designed role is the purpose of these systems. CAD is the most commonly used digital design software in the design field because of its sophisticated drawing capacity and variety of editing options (as mentioned by Jacunski, 1993; Bosselmann, 2007). CAD's strengths are concentrated on precise graphic processing and multilayer functionality.

GIS meanwhile, specialises in spatial calculation and geovisualisation (Longley et al., 2005). It is a suitable tool for supporting site analysis and for sophisticated spatial calculation and processing, such as potential earth works and estimated area effects (Laurini (2001), Longley et al. (2005) and Ministry of Environment (2006)). The use of GIS in analysis and visualisation of future effects of developments was explored in this research.

8.6.3 User Satisfaction of 3D Environments Presented in CVGE versus CAD and GIS

The user-friendliness of the OpenSim CVGE was confirmed by the participants' performance when using it. From a functional perspective, participants ranked OpenSim as the easiest to use. One reason may be that the CVGE interface was derived from an interactive gaming background where user-friendliness was a high priority (Germanchis et al., 2007). This software should, therefore, be easy to learn for novices since its original design purpose aimed to service a wide user group.

Participants showed strong interest in using 3D visualisation and simulation techniques, and indicated an aspiration to use it in their own work. In contrast, the conventional CAD and GIS design tools were originally built with professionals and specialists in mind, and with relatively little attention paid to the user experience. As a result, only relatively recently has GIS in particular mass-entered the public realm. This was reinforced by the study feedback and scores for ease of use.

No doubt geographic information represented in 3D is desired over 2D when performing 3-dimensional design, such as urban design tasks. This, too, is reinforced by the test results. 3D environments provide technical benefits as well as providing users a realistic feel, at least at a level of detail that is high enough for users to believe they are immersed in the model. For example, 3D models have an advantage in showing multi-story buildings, and factors that impact on the site such as sunlight, shadow and wind flow can also be included into the model. Urban designers have introduced 3D technology into some aspects of their work as they have seen these benefits. 3D is also a more intuitive way for users to understand design concepts.

8.7 Sub-Objective 2: To explore an effective method to improve the realism of interaction with the CVGE and its realistic texturing and rendering to make it more effective for urban designers.

A successful tool should provide accurate and quick rendering capacity to support better performance. However, the results of the previous project showed that it is important to improve the level of 'realism' before a VR-based urban design environment becomes truly feasible.

This sub-objective is mainly concerned with satisfaction of the participants towards use of urban design tools, and to some extent effectiveness. This relates to visioning,

as well as decision-making, and evaluation, of urban design proposals.

8.7.1 User Satisfaction of Realism in CVGE versus CAD and GIS

The participants agreed that CVGE provides desirable geographic and visual quality for urban design. They gave positive comments on this aspect of the CVGE. The scores for all three urban design tools (CAD, GIS and CVGE) were marked higher than the average 3.00, however CVGE scored the highest fidelity of the three samples. Features in the virtual world were built according to not only the size and shape but also the texture of the features in the real world, to make the model a realistic representation. The 'look' of the environment affects users' feel of presence (immersion); therefore, texture is one of the key elements of realism.

One participant in the study proposed that designers do not really require this real-time and realistic approach to interaction with the online CVGE in their professional work. Another pointed out that designers are professionally trained and are able to present their ideas and concepts by using abstract symbols; therefore it is not necessary for them to use other tools for improving the realism of their design plans. However, CVGE can still improve the communication aspect between these professionals and those with no professional training, i.e. clients and the public.

8.7.2 Effectiveness of Realism in CVGE versus CAD and GIS

Contemporary technologies provide various options to designers. CAD, GIS and CVGE all received positive responses from the participants, who were generally in agreement that they could all be used in their professional work. When choosing which software package to use it is important to determine who the user group will be and what would be a suitable method of communicating the design plan.

Participants stated their expectation that 3D-related functions should be much easier to master and less time-consuming. They pointed out that they expect to work with a useful, yet at the same time a user-friendly, tool. Therefore, the 3D platform requires an effective yet simple method to create 3D models and should be easy to master the basic working operations. A simple and intuitive tool would also engage more people into the design process.

The ANOVA analysis results do not show any statistically significant difference in effectiveness between CAD, GIS and CVGE. In other words, the CVGE software was on a par with the mainstream design packages, scoring most similarly to CAD in this study.

Nevertheless, the professional participants commented that complicated interfaces and multiple toolbars dramatically increased the difficulty of using the CAD and GIS (largely screen-based) tools. Users required good knowledge and training to master these functions; they also need to devote time to modifying sophisticated 3D model details to ensure quality. This is a barrier for potential user take-up, limiting the use of these packages to only the professional community who have this knowledge and training. It also reduces the possibility of public participation.

An example of this is the observations made during the usability testing stage. One issue occurred when the participants were asked to complete the sub-task of creating a 3D model. One issue that led to participants' failure to finish the task is that some required help to understand low-level functions (rotate the object, edit the size of the object, etc.) in terms of their parameters and terminology.

CAD and GIS have have excellent performance, especially in sophisticated visualisation and advanced spatial analysis. They also have advanced capacities for processing and visualising spatial data.

8.8 Sub-Objective 3: To understand the effects on efficiency and effectiveness, of incorporating geographic data into the environment.

Georeferenced information inside the environment can act as an aid to design, by enabling designers to see and work within the context of the existing environment. This is important for navigation and for the placement of objects such as buildings in the context of existing objects, and for assessing the effects of proposed changes such as tall buildings and sun angles.

This sub-objective is largely aimed at assessing the efficiency (measured by the time-cost to complete tasks) and effectiveness (measured by correctness of task results) of

the design tool. This relates to the tasks of Analysis and Evaluation in urban design, and to a lesser extent the Visioning and Decision-Making tasks (see Section 3.1).

8.8.1 Effectiveness of Incorporating Geographic Data in CVGE versus CAD and GIS

Aerial photos were used to transfer geographic data into the CVGE by an adapted C# script written by Christa Lopes (also known by the GitHub handle Diva Canto). This rendering of data from the real world provided position, orientation, navigation and design context in which to set the design (Carmona et al., 2010).

From the participants' comments, the addition of this draped orthophoto was a key feature of the CVGE. This overcame one of the key criticisms of the previous study (Zhang, 2011), that the use of the CVGE led to geographic confusion. Participants in the previous research occasionally experienced disorientation when they explored the virtual environment; the results reinforce the feedback on the satisfaction aspect of the CVGE used in this study, as well as addressing a major concern of the 2011 study.

Participant feedback also reinforced that users gain a more comprehensive understanding of the context in which the design fits into existing neighbourhoods by using this method. Current design projects are more likely to happen within existing communities as discussed in Section3.2. This is, therefore, a key aspect in users' understanding of the wider context.

8.8.1 Efficiency of Incorporating Geographic Data in CVGE versus CAD and GIS

Navigation is one way to help the users to locate themselves, which contributes to efficiency through reducing the time-cost of completing tasks. A positive rating was given to the solutions for navigation in CVGE (i.e. the use of map tools and landmarks as described in Section 6.5). Since high resolution orthophotos enable designers to 'see' what is on the ground, known landmarks in the orthophotos are inbuilt into the CVGE and users can therefore gain a better spatial awareness within the model. Users associate places with representative features (e.g. a famous building or memorial), to help to locate themselves. This navigation method was also tested by Parush and Berman (2004) and shown to have a positive impact on the user experience.

This study also used 'mini map' and 'world map' as navigation tools to assist participants to locate themselves. 'Mini Map' is a toolbar pre-installed in OpenSim which acts as a compass within the model. 'World Map' allows users to find their location within a map of the entire virtual 'world' (indicated by a point), and they can use it to 'teleport' to a specific location or address. Combined, these tools acted as a 'directional compass' which is a well-known navigation tool used in both real-world and virtual environments (Ruddle et al, 1998). These tools provided participants with good spatial cognition, and enabled them to relocate themselves easily.

8.9 General Discussion

8.9.1 Textures and Online Libraries

The OpenSim software allows users to control their own textures by uploading high resolution photos or aerial images into the CVGE server to add to their own texture library. ArcGIS also provides an ability to load georeferenced photos/aerial images to be used as textures, and BricsCAD has its own material resources (texture library) but it is less flexible (e.g. limit texture options, and difficult to make the texture from scratch) for users to customise to their needs.

OpenSim has an online library which is free for users to publish and share their 3D models for objects such as infrastructure, furniture and vegetation. SketchUp was used in this study to construct the detailed building models for replacing the rough 3D models in ArcGlobe, and these models can be shared online with others to use also. In addition, SketchUp also provides a texture library both locally installed and online, and allows users to share the textures they use and add to the library. So it seems that an accessible platform for sharing 3D components and textures is an important and effective way to improve the quality of 3D models.

8.9.2 Factors Affecting Realism of the Environment

OpenSim is an open source platform and users have flexibility to modify their environment and share their code and 3D models (including buildings, roads and

vegetation, etc.) through the user community instead of starting their own modelling from scratch. These existing resources reduce the time-cost of developing a new virtual environment.

To maximise the usefulness of 3D models, the contextual data such as elevation and imagery require high quality standards, the data should be regularly updated and maintained (i.e. have good data currency). For example, LiDAR data could be used to show more information on the ground and higher quality elevation models could be generated based on this data.

Another factor affecting users' feel of realism is the way the user interacts with the environment. If users are able to explore the environment in a natural way, such as by "flying" or "walking" through it, their sense of immersion is improved (refer to Section 4.2). Users can experience the CVGE in a dynamic way, which has a positive impact on the user experience. Interactions within CVGE are more human-like than in CAD or GIS, in that users are able to walk or fly through the entire virtual world by using an avatar. Users of CVGE also have more control over the way to explore the virtual world. This means that users can change their viewpoint to 'look' at the environment as if they were in the real world, thereby dramatically increasing their sense of engagement.

In contrast, users interact with 3D environments in a relatively static way in both CAD and GIS. Users can largely only rotate or pan objects to change the view of the built model. Some engineering packages such as 12D offer a function for the user to pre-set a route for moving through the site (12D, 2017). However, users are still restricted by a pre-defined route or single position, and cannot control their position, orientation and movement within the model in real-time through direct interaction.

8.9.3 Data Sharing and Collaboration

To enable wider use of CVGE, wider data sharing should be taken into consideration. Greater use of 3D technology in professional fields could also be promoted by a relative standard file format (consider, for example, the developments of CityGML, 2017). Meanwhile, already matured software such as GIS and CAD already provide format compatibility between each other, ensuring ease of data exchange. Sketchup

Pro can also use GIS and CAD file formats.

Local authorities and communities also need to respond to the new techniques, by collecting related information for developing CVGE or upgrading their existing systems to ensure they have the ability to maintain authoritative 3D datasets. They also have a responsibility to provide guidance for designers on their data standards, data quality etc.

Chapter 9 Conclusion

This chapter summarises this project and its results in terms of the research objective and sub-objectives, identifies improvements for this research, and proposes functional improvements for an urban design tool on the basis of the findings reported in Chapters 7 and 8. Further research directions for CVGE are also presented.

9.1 Summary of this Project

This project was built upon a project run in 2011 by Zhang and Moore, (2014). Following the suggestions proposed in that project, a more in-depth testing of usability was implemented in this research. This research attempted to fully understand the advantages and disadvantages of online VR-based urban design visualisation software, by comparing online CVGE with other contemporary mainstream static design packages (CAD and GIS). This study undertook a horizontal comparison of 3D modelling in CAD and GIS, concentrating on efficiency (how fast tasks are done), effectiveness (how correctly the tasks are completed), and users' satisfaction.

The major research objective, which was **to implement a comparative usability assessment of proposed urban design scenarios, realised by CAD, GIS (screen-based technologies including both 2D and 3D capability) and online VR software (screen-based but purely 3D technology orientated)**, was achieved. The results of the full usability evaluation of the CVGE-based urban design workspace were presented in Sections 7.3-7.4.

The collected feedback shows that participants held generally responsive attitudes towards CVGE-based design environments. By analysing the feedback from participants, our knowledge of the benefits and the weaknesses of using online CVGE as a potential professional urban design tool have taken a step further.

Participants realised the value of 3D visualisation techniques and showed interest in the 3D-based urban design scenario. Most agreed that 3D products have the potential

to have a positive impact on the process of urban design, particularly in design communication. The participants also saw great potential for using 3D methods in future projects and that the benefits of the online CVGE-based urban design environment are significant.

For comparative assessment purposes, the first sub-objective, **to build and evaluate 3D environments, based on a proposed urban subdivision development, containing existing buildings and potential developments**, was also realised. The proposed subdivision (Grandvista) was built in CAD, GIS and OpenSimulator (a CVGE modelling engine) respectively. Participants assessed the performance of these sample three-dimensional environments by completing a set of tasks with provided instructions. They also evaluated the possibility of applying virtual reality technology as an urban design tool based on their experiences.

The online Virtual Geographic Environment, OpenSimulator, received the most positive performance result in comparative testing, particularly in efficiency of task completion and ease of use. The competitive features of online CVGE software included handy pre-installed plugins, an easy-to-learn interface, and 3D construction and editing functions.

One of the most attractive features of CVGE to participants was its interactive capability, i.e. the user can 'immerse' themselves (virtually fly through/walk around) 'in' the model. Online CVGE can also be equipped with real-time communication abilities which allow the user to perform remote and instant text/voice communication. In addition, online CVGE software can be used as an effective tool to communicate design plans and proposals with other professionals and between professionals and the public/clients. CVGE can also be more accessible as users can view the environment via an online platform, making public communication simple. However, accurate and precise editing of VR objects and compatibility of VR file formats are factors that need to be improved.

The second sub-objective was **to explore an effective method to improve the**

realism of interaction with the CVGE and its realistic texturing and rendering to make it more effective for urban designers. Participants' feedback showed that current digital design tools (e.g. CAD or GIS) have the capacity to carry out three-dimensional modelling with acceptable rendering effects, yet the workspaces are relatively isolated and outcomes are generally non-interactive. In contrast, CVGE is more flexible. Also, the model is dynamic, in that users are able to 'move around' inside the model, so that they are able to experience the environment from multiple points.

The last sub-objective, **to understand the effects on efficiency and effectiveness, of incorporating geographic data into the environment** (via georeferenced orthophotos)*, was also achieved. This research has satisfactorily addressed the previous concerns (from the first stage of the study - Zhang, 2011) with the graphical and geographical fidelity of CVGE. The geographic model was built based on the digital elevation model, which is a good representation of the real world terrain. A C# script was used for uploading aerial photos into the CVGE, which resolved the problem of importing large volumes of graphic data into the CVGE server. This dramatically enhances the realism of the CVGE.

To conclude, most of the participating professionals and students demonstrated an interest in employing 3D techniques in future projects. Their feedback also supports the idea that three-dimensional subdivision design outcomes can provide high geovisualisation quality, even for professional purposes where the quality requirements are already high. The real-time online virtual reality software is also better suited to interactivity, 3D performance and communication capability when compared with CAD and GIS packages.

9.2 Possible Future Improvements

This project has presented a comprehensive assessment of a CVGE-based urban design environment, and assessed comparisons between three design package types. It has also shown that CVGE has potential in the field of urban design. Several

improvements are possible however, to be covered by future research.

Further Research Directions of CVGE

This project identified five areas for further investigation of CVGE: The communication ability of CVGE; issues of navigating within CVGE; the method of delivery of CVGE; integration of data collection and modelling technologies with the CVGE, and CVGE used to perform real-life urban design tasks as listed in Section 3.1.

1. Further research could concentrate on the real-time communication ability of CVGE. An effective communication channel could increase opportunities for both professionals (planners to designers, designers to surveyors) and non-professionals (designers/planners/surveyors to clients/the public) to have a more informed, detailed and influential conversation.

   A real-time communication tool could be an effective way of collecting these ideas and feedback, which would have an impact on several of the urban design tasks identified by Carmona et al. (2010) and discussed in Section 3.1: Analysis, visioning, synthesis, decision-making and evaluation are all tasks that can potentially benefit from this approach. Designers can also absorb clients' feedback efficiently via this more interactive approach.

   The other comparison design packages (BricsCAD and ArcGIS) do not have similar communication abilities to OpenSim. Considering the discussion of the benefits of online communication outlined in Section 4.3, voice and video systems within CVGE should be tested in future research. The communication aspect of CVGE software also can be tested based on the same usability criteria (efficiency, effectiveness and satisfaction) as the CVGE itself.

   Communication ability not only refers to online real-time communication, but also to the capacity for explaining or demonstrating the impacts of existing or future urban design outcomes/environments. CVGE is a more natural approach to

engage the public and clients into professional design activities, compared to conventional abstract design plans. It is a more intuitive and user-friendly way to explain and distribute abstract design concepts. The public can 'look at' and 'feel' future developments and possible impacts on the existing environment, enabling a greater understanding of these impacts and better design decisions to be made.

Public interaction with the CVGE can be through the public platform (website) via desktop or mobile devices. This opens the opportunity for a detailed investigation of public participation in the planning and design process, a part of the goal-setting, visioning, and evaluation (appraisal) tasks of urban design (see Section 3.1). This is also clearly aligned with the usability criterion of efficiency, as it allows the CVGE to have a much greater impact on urban design than other more contemporary technologies. For instance, CVGE integrated with a district council website could be used to introduce scenic locations such as tramping tracks, camping grounds or nature reserves. This would help to increase the appeal of the place, by providing a sense of 'being there' and attracting potential visitors.

Another potential approach might be an augmented reality, combining the real world and the Virtual Environment. Such an application would be well suited for mobile devices which are commonly used outside of the office environment. Take the Christchurch (New Zealand) earthquake recovery as an example: CVGE can play an important role in which users can use their device to view the city as it was before the earthquake, the ruined buildings after the earthquake, and potential rebuild developments.

2. Navigation is an important factor affecting the user experience. Further research could focus on exploring potential navigation methods within the virtual environment. Navigation is a key factor for user acceptance of real-time virtual landscapes (Döllner 2007). However, this research has not touched this aspect in detail, and further research should explore this area, which is especially applicable to the visioning, synthesis and prediction, and decision-making tasks

of urban design, and to the efficiency usability criterion.

In the previous research project (Zhang and Moore, 2014), participants indicated that they experienced confusing or disorientating situations, due to the lack of appropriate landmarks and navigation tools.

This project has made a preliminary attempt to address this by using an embedded 'map' tool for basic navigation. This was supported by the imported aerial photos which brought geographic information from the real world into the virtual environment, thereby helping users to identify locations and directions within the model. This improved the situation by reducing disorientation. However other methods such as the use of landmarks, which has been briefly tested in this research, could be investigated further in future research.

3. With the fast developing technology of wearable VR devices, we could consider using these to make CVGE more accessible to a wider range of users and with better user experiences. A new, relatively cheap and readily available generation of VR devices such as Samsung Gear VR (Samsung Gear VR, 2017) and Oculus Rift (Oculus Rift, 2015) now enable VR users to use a more immersive approach to interact with CVGEs and to gain a better feel of the actual landscape (e.g. slope, flat).

    In this research, participants involved in the testing stage were impressed by the graphic quality and realism of the CVGE. On this basis, CVGEs can be considered a promising approach for supporting a high standard of quality of three-dimensional geographic visualisation. CVGEs can greatly improve realism and sense of immersion by combining high quality CVGE models with wearable VR devices such as those mentioned above. This is clearly aligned with the visioning task of urban design, and to the usability criterion of users' satisfaction with the technology.

4. Can we use other technologies to obtain more accurate 3D models or faster methods to generate 3D models for CVGE? For instance, 3D laser scanning and

mapping (e.g. LiDAR – Light Detection And Ranging) is a data collection method which is used to create a cloud of geometric sample points on the surface of a subject. The collected data can then be uploaded into the CVGE and used to automatically construct a surveyed object to a 3D model. More accurate 3D models and faster generation of 3D models aligns with both the efficiency and effectiveness criterion as well as enhancing the user experience with the technology (satisfaction) so all three usability criteria used in this research are covered. This is also aligned with the visioning task of urban design, as well as the synthesis and prediction task.

5. Further research could potentially address a more detailed investigation of CVGE's communication and collaboration capabilities in urban design, covering all of the usability criteria, as well as its potential role in public participation – for example, in urban recovery from the recent Christchurch earthquake in New Zealand. This could involve a more detailed study of CVGE used in real and specific urban design scenarios, with greater emphasis placed on users using the technology for all of the real urban design tasks listed in Section 3.1, instead of a selection of tasks set them by the researcher. The public may also be invited to participate in the study, interacting with the CVGE and providing feedback on the design solutions provided by the designers.

Other potential future research

6. The findings from this research suggest that CVGEs have potential as a tool in the field of urban design. However, online CVGE technology is still at a stage of infancy. For example, the online CVGE (OpenSimulator) used in this research was designed for online gaming. Much remains to be done to make it a professional design and planning tool. Future research could aim to optimise similar tools, so that they can be used widely in a professional field.

7. More participants could be invited to test CVGEs to give a greater statistical sample. Potential CVGE users can also contribute their ideas to the research. The

CVGE is also capable of serving professional user groups outside of the urban design field, such as surveyors and planners. It would be useful to collect feedback and suggestions from these groups also. These user groups can also bring a different perspective to the usability assessment of CVGE, such as for its use in sales and marketing or strategic planning.

8. The tasks set for users could be more complex than was performed in this research and could guide participants to explore the 3D modelling process in greater depth. Users unfamiliar with the software and construction process may experience confusion with the environment due to lack of input or knowledge of how it is created. If these users were more engaged in the modelling process they might gain a better understanding of the environment and their operations within it.

9. Future research could be held in a controlled environment with a stable computer network and large Graphic Processing Unit (GPU) to remove factors of processing power and network capacity from the equation, leaving the users free to engage with the environment and perform tasks without these hindrances.

Since there are correlative effects between the graphic quality of the online CVGE and internet speed, the user must choose a balance between their interaction speed with the environment and the CVGE's fidelity (such as graphic quality, graphic rendering speed etc.). The use of orthophotos as textures resulted in slower rendering speed and also caused delay of real-time response to user's operations. The effect of these issues on users' overall impressions of the CVGE and on the study result cannot be determined but we can assume that if the situation were improved then the results would only be more positive than shown in this study.

Possible Functional Improvements for OpenSimulator as an Urban Design Tool

OpenSimulator is a useful and easy-to-learn tool. Participants in this study agreed that the CVGE-based urban design environment was potentially a competitive method of

visualising design concepts.

Feedback collected from the participants not only assessed the 3D design environments, but also allowed us to identify six functional improvements which would improve OpenSimulator's usability as an urban design tool.

1. The realisation of accurate and precise editing operations in OpenSimulator needs to be resolved in the future. For professional purposes, urban designers and planners need to perform operations such as the calculation of earthwork volumes and to design appropriate road layouts (e.g. taking into account slope and angle, etc). For these types of operations, online CVGE software needs to have the ability to perform more precise data measurement, calculation and editing.

   One example is the Modify Terrain tool provided in OpenSimulator, which allows users to raise, lower and flatten the terrain. OpenSimulator was originally designed for online gaming purposes, in which users only need to modify terrain manually in the user interface instead of specifying an accurate value (height, width or depth). Therefore, the adjusted outcome is only a rough result which does not meet all of the requirements of the urban design application. Such an outcome could be useful for instance in the creation of a concept design using approximate measurements for model features, but cannot be used for accurate measurement of correctly proportioned features which is required for a design plan.

   Both CAD and GIS provide enquiry and measurement tools for measuring distance (e.g. an object's size and the distance between objects) and area, as well as snapping functions to ensure the correct points are selected to perform these measurements. These functions assist urban designers to perform precise spatial calculations and to estimate possible effects such as shadow and water flow.

   To perform the role of a professional design package, online CVGE software needs to add more specialised toolsets that can deal with various design activities. For this reason it would be valuable to develop and customise scripts to facilitate

higher level utilities such as these functions.

2. OpenSimulator should have the capacity to store and manage other information (large datasets management) for more reliable decision making. This could be achieved by improving the ability to integrate OpenSimulator with other systems or platforms such as databases. For example, CVGEs can be built with building information models (BIMs) as discussed in Section 4.1. Physical infrastructure data such as water, electricity, gas, refuse, and communication utilities can be stored in CVGE. This data can provide extra contextual information, allowing designers and planners to ensure that new developments will fit into wider district plans.

3. In addition to holding extra information in OpenSimulator, there is also a need to develop the tool to show the design of underground utilities, such as sewer pipelines, power and water networks. CVGE was developed to display a visible world but could also be used to visualise these 'invisible' elements. These infrastructure elements are important components in an urban design project. The development of an add-in/application to present these design components would be a useful extension (e.g. to have an option to add transparency to ground features).

4. Other dimensional information such as time could also be brought into the environment. In the sample CVGE, users can experience the time changing (i.e. from dawn to dusk) in a compressed time frame, which is a useful function to estimate sunlight and shadow effects. Future CVGE could show longer term changes e.g. how new developments happen in the site during each stage.

It could also be useful to develop a plug-in for the online CVGE software which can switch the view between 2D and 3D. CAD and GIS users can switch working vision between 2D and 3D by clicking a button, allowing designers to check their design outcomes from a more comprehensive perspective. However, users can only explore the environment at a three dimensional level in OpenSimulator. The

3D virtual world provides stereoscopic sensation and realism, while a 2D view can offer a simple and intuitive plan layout. Participants pointed out they need to view 2D plans as well as 3D plans during their work, which would enable them to confirm and perfect all the design details.

6. Lastly, conversion of projection systems (local or national) needs to be addressed during data preparation for CVGE construction. This requires more steps to process and transform projection system information files to a format readable by CVGE software such as OpenSim. CVGE systems cannot currently perform this functionality.

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Appendix A

Information Sheet for Participants

<div align="center">**INFORMATION SHEET FOR PARTICIPANTS**</div>

Thank you for showing an interest in this project. Please read this information sheet carefully before deciding whether or not to participate. If you decide to participate we thank you. If you decide not to take part there will be no disadvantage to you of any kind and we thank you for considering our request.

What is the aim of the project?

This project is a masters' thesis project, a paper taken as the requirement of the Master of Applied Science in Geographical Information Systems at Otago. The main purpose of this project is to fully compare the advantages and disadvantages of three design tools (CAD, GIS and VR software), particularly, in processing 3D projects for urban design and planning. In so doing, we intend to evaluate the potential of applying VR technique to urban design realm.

What type of participants is being sought?

Any person over the 18 years of age is eligible to be part of this study.

What will participants are asked to do?

Should you agree to take part in this project, you will be asked to evaluate three examples of 3D-based site planning for a subdivision development constructed in three different software packages: CAD, GIS and VR. As you carry out the testing you will be asked to perform a series of set tasks and answer a set of questions about these models. At the end of the tasks your results will be collated and analysed to assess efficiency, effectiveness and satisfaction of using VR and comparatively, CAD and GIS for urban design. It is estimated this will take less than **one** hour. No personal data will be collected as part of this study.

The tasks you will be asked to carry out will be very simple and full instructions will be given during the experiment. The model will be of a Dunedin suburb and will contain existing surroundings and possible planned housing developments; you will be asked simple questions about the software itself and the model illustrated to you.

Please be aware that you may decide not to take part in the project at any stage without disadvantage to yourself of any kind.

Can participants change their mind and withdraw from the project?

You may withdraw from participation in the project at any time and without any disadvantage to yourself of any kind.

What Data or Information will be collected and what use will be made of it?

An instruction sheet and questionnaire will be handed out to you and you will be asked to complete simple tasks and answer certain questions. Your answers to these questions will then be collected and used to compare how you felt and reacted to the 3D environment generated in CAD, GIS and VR software. Once the data has been collected it will be treated as anonymous and will only be used by the researchers named below. Therefore there will be no way of distinguishing what data set belongs to what subject, apart from being labelled subject 1, subject 2 and so forth. This is so that the data sets can be compared (no personal data will be collected as part of the study).

The results from the questionnaire along with the metrics associated with the tasks will be the main form of data in the experiment and will be used for the sole purpose of evaluating the feasibility of urban design based on virtual reality. The data collected will be securely stored in such a way that only those mentioned below will be able to gain access to it. Raw data on which the results of the project depend will be retained in secure storage for five years in the Surveying Department at the University of Otago after which time it will be destroyed.

You are most welcome to request a copy of the results of the project should you wish.

What if Participants have any Questions?

If you have any questions about our project, either now or in the future, please feel free to contact either:

Sisi Zhang

Cell phone Number: 021 0288 7450

Email address: zhasi717@student. otago.ac.nz

Or

Dr Tony Moore

School of Surveying

University Telephone Number: 479 7589

Email address: tony.moore@otago.ac.nz

CONSENT FORM FOR PARTICIPANTS

I have read the Information Sheet concerning this project and understand what it is about. All my questions have been answered to my satisfaction. I understand that I am free to request further information at any stage. I know that:

1. My participation in the project is entirely voluntary;

2. I am free to withdraw from the project at any time without any disadvantage;

3. The data will be destroyed at the conclusion of the project but any raw data on which the results of the project depend will be retained in secure storage for five years, after which time it will be destroyed;

4. The results of the project may be published and available in the library but every attempt will be made to preserve my anonymity. Any information I may want to be omitted from being published will be removed;

I agree to take part in this project.

....
            (Signature of participant)   (Date)

Appendix B

Instruction for Participants to Install online VR Viewer and Access to the Test Environment

Dear <name>,

Thanks for your participation in this experiment. Please let me know when you are ready to evaluate the Virtual Environment, and then I can create an avatar for you to interact with the environment.

To explore the virtual environment, you will need to install the viewer first. You can do that by following steps.

1. **Download the viewer**

   You could download the following viewers.

   Hippo Viewer **http://forge.opensimulator.org/gf/project/opensim-viewer/frs/**

   IMPRUDENCE **http://wiki.kokuaviewer.org/wiki/Imprudence:Downloads**

2. **Run the program and set up your viewer**

   Click on **Grids**. Click **Add** and specify the following as the Login URI: **http://survgrid.otago.ac.nz:8002/** .

   Click **Get Grid Info** and most of the other fields should be filled in. Click **OK**.

Then you can start to explore the virtual environment.

The attachment is the questionnaire for this research.

If you have any further questions please do not hesitate to contact me, either by email or the phone number below.

Kind Regards,
Sisi Zhang

Appendix C

Questionnaire Used in the Usability Testing

CONSENT FORM FOR PARTICIPANTS

I have read the Information Sheet concerning this project and understand what it is about. All my questions have been answered to my satisfaction. I understand that I am free to request further information at any stage. I know that:

1. My participation in the project is entirely voluntary;

2. I am free to withdraw from the project at any time without any disadvantage;

3. The data will be destroyed at the conclusion of the project but any raw data on which the results of the project depend will be retained in secure storage for five years, after which time it will be destroyed;

4. The results of the project may be published and available in the library but every attempt will be made to preserve my anonymity. Any information I may want to be omitted from being published will be removed;

I agree to take part in this project.

....
.

    (Signature of participant)   (Date)
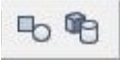
QUESTIONS

Part A General

1. Are you/Have you ever been engaged in any kind of urban design project? Yes / No

2. If you answered Yes to Question A1, what software or non-digital tools do you use in the urban design process?

3. Do you feel the need to apply 3D techniques in your work? Yes/ No

Part AI CAD

1. Have you used any Computer Aided Design (CAD) software? Yes / No (If yes, please answer questions 2 to 6. If not, go straight to Part AII CAD Tasks).

2. What sort of computer aided design software have you utilized (e.g. BricsCAD, AutoCAD, 12D, CivilCAD ...)?

3. Have you ever utilized 3D function(s) of CAD in your design? Yes / No (If yes, please answer question 4 to 6. If not, go straight to Part AII).

4. If yes, what is the major purpose(s) for which you used 3D during the design process?

5. What aspects do you like most about the CAD you have used?

6. What aspects do you like least about the CAD you have used?

Please complete following task and questions.
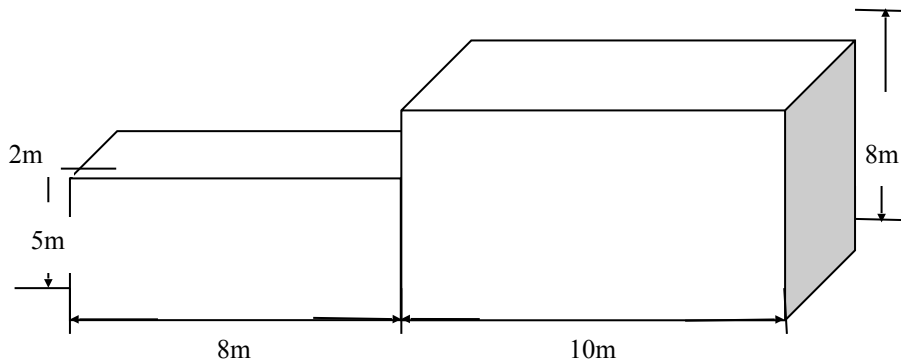
Part AII CAD Tasks

1. Open the attached file (test1.dwg) in CAD and change your design view to 3D by clicking the button under **View** tab.
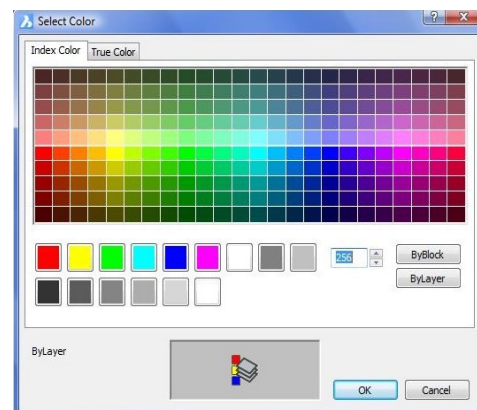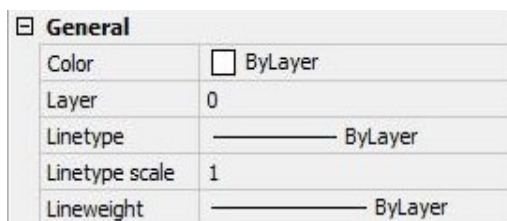
2. Add 3D editing toolbars (hover over a blank portion of the toolbar area and **right click**), then choose **Solids**.
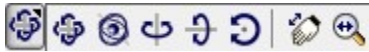

3. Use the primitive shapes offered in the **Solids** to create the object below:

4. Change the colour (texture) of your object. **Left** click on your object and choose **Color** under **General** tab (on your right side).
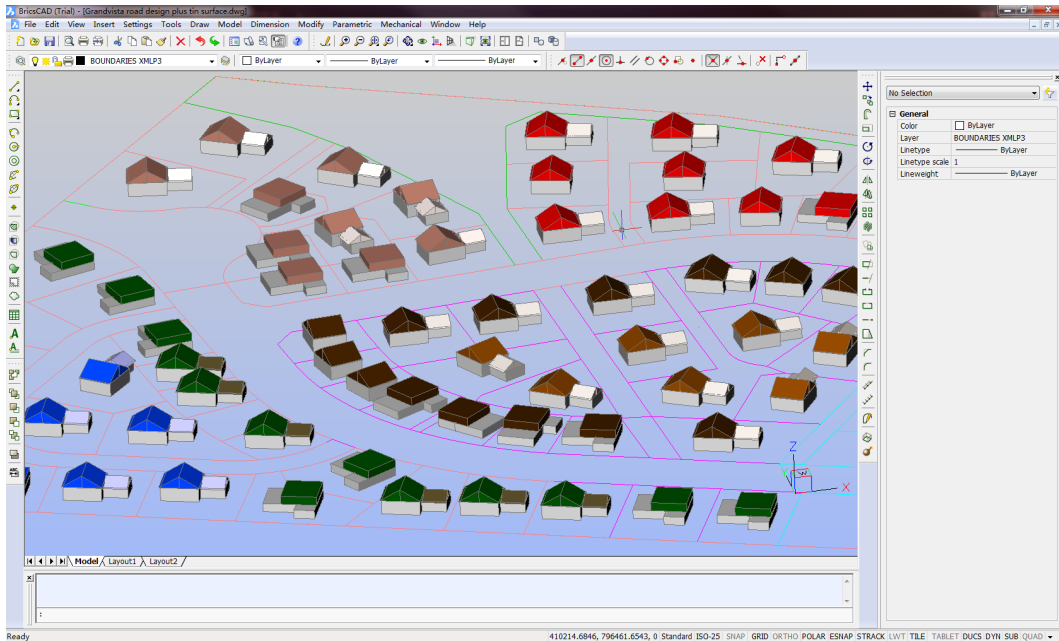
5. Pan and rotate your object. Click the button on the **View** tab.

You can use these buttons to view your object from a different point of view.

6. Evaluate the realism of the 3D object in CAD (see below for screenshot).

Part AIII Questions

For Q 1 to Q 10, please circle the answer which best indicates how you feel.

1. The CAD interface is user-friendly for a novice.

   Completely Disagree   1   2   3   4   5   Fully Agree

2. It is simple to gain a feel for and master the basic operations of CAD.

   Completely Disagree   1   2   3   4   5   Fully Agree

3. It is straightforward to master 3D operations in CAD.

   Completely Disagree   1   2   3   4   5   Fully Agree

4. It is easy to add/modify details in CAD.

Completely Disagree   1   2   3   4   5   Fully Agree

5. I can use editing tools in CAD to visualise my attempts accurately.

    Completely Disagree   1   2   3   4   5   Fully Agree

6. I can produce 3D products from CAD rapidly and efficiently.

    Completely Disagree   1   2   3   4   5   Fully Agree

7. The 3D models in CAD have high fidelity (degree of realism).

    Completely Disagree   1   2   3   4   5   Fully Agree

8. The design environment facilitates the estimation of possible need for earth
    works and land use.
    Completely Disagree   1   2   3   4   5   Fully Agree

9. CAD is/would be useful for professional work.

    Completely Disagree   1   2   3   4   5   Fully Agree

10. Compared with the current design tools, I think that CAD will save me time in
    the design process.
   Completely Disagree   1   2   3   4   5   Fully Agree

Part BI GIS

1. Have you used any Geographical Information Systems software (e.g. ArcGIS) in your work? Yes / No (If yes, please answer the questions 2 to 6. If not, go straight to Part BII GIS Tasks).

2. What sort of GIS software have you utilized (ArcMap, ArcScene, ArcGlobe, MapInfo…)?

3. Have you ever utilized the 3D function(s) of GIS for analysis or visualisation? Yes/ No (If yes, please answer question 4 to 6. If not, go straight to Part BII GIS Tasks).

4. If yes, what is the main purpose(s) for which you employed GIS in your work?

5. What aspects do you like most about the GIS software you have used?

6. What aspects do you like least about the GIS software you have used?

Please complete following task and questions.

Part BII GIS Tasks

1. Open **ArcMap** by clicking on Start…Programs…ArcGIS…ArcMap 10 and set the Default Geodatabase for this map to geodatabase D:\test\Test.gdb. In ArcMap, click on the **Catalog** tab on the right side of the display.

2. Create a new 2D polygon feature class and digitize a 2D polygon (right click on the geodatabase—**new -- feature class**…—**name** it <test> and **import** the Coordinate system from D:\test\Test.gdb\house_location—keep other things as default settings). Then go to **Editor** Toolbar—**Start Editing**. Choose the layer need to edit and start to digitise a Rectangle (Length 8m, Width 5m, you can check that at the left bottom side of the screen). **Save** your editing and **Stop editing**.
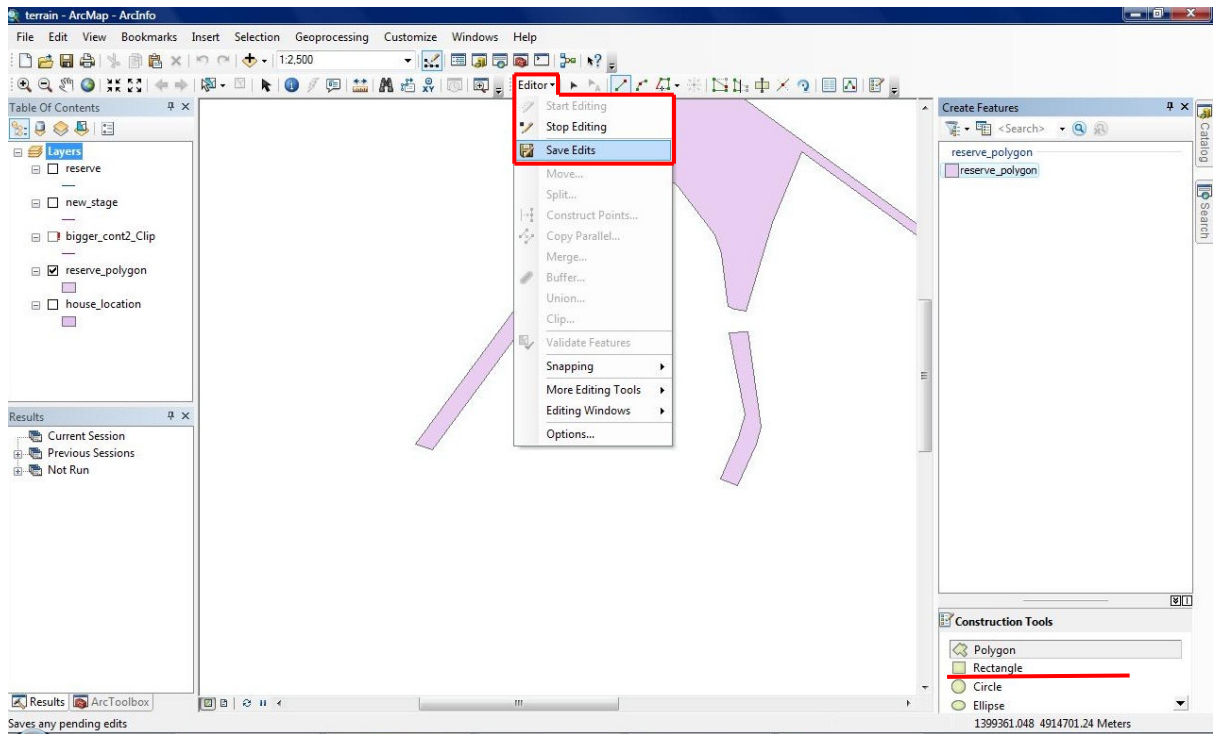
3. Open **ArcGlobe** and set the Default Geodatabase to geodatabase D:\test \Test1.gdb.

4. Import the 2D feature class you just edited to **ArcGlobe**. **Left click** on the Test 1 geodatabase and the drag the layer to the blank screen in the middle.

5. Set the symbology to extrude by a height in metres (Layer properties—Globe Extrusion—tick **Extrude features in layer** and input 5 as extrusion value)

6. Convert the polygon layer to **Multipatch** (ArcToolBox—3D Analyst— Conversion—Layer 3D to feature class)

 (On the left hand side of display)

7. Replace the Multipatch feature class with the attached file D:\test\test-housetype1.dae (3D house building, which has been constructed in Trimble SketchUp 8). Choose the Multipatch feature class to **start editing**. Select your object and then click on the **Edit placement** tool on the editor toolbar.
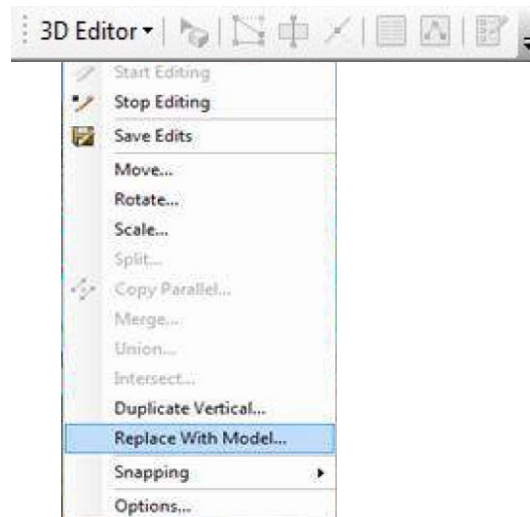
8. Evaluate the realism of the 3D models in GIS (see below for screenshot).
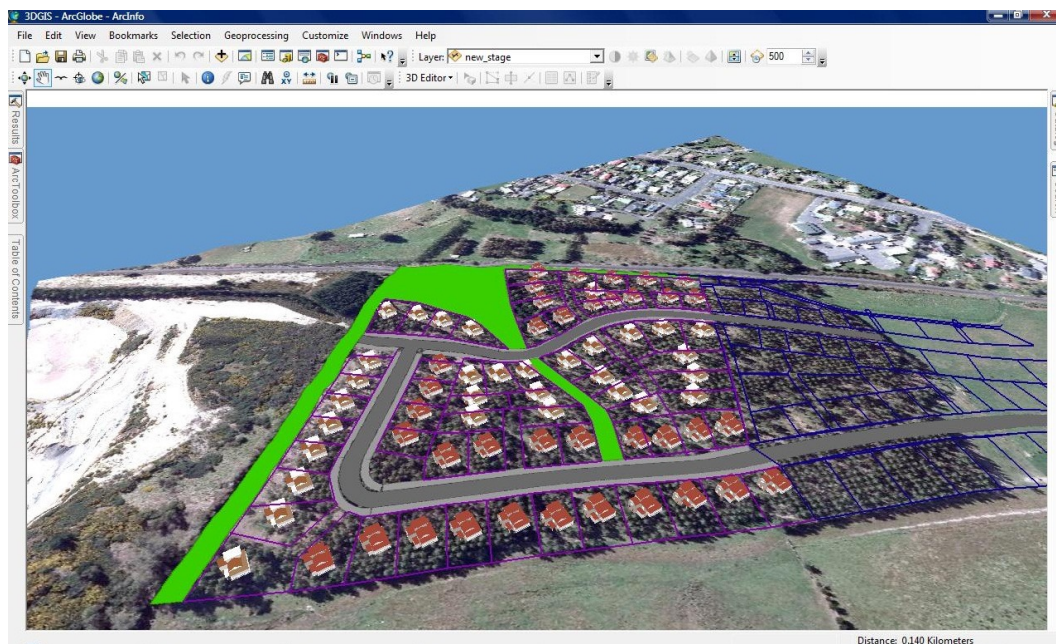
Part BIII Questions

For Q1 to Q10, please circle the answer which best indicates how you feel.

1. The GIS interface is user-friendly for a novice.

   Completely Disagree   1   2   3   4   5   Fully Agree

2. It is simple to gain a feel for and master the basic operations of GIS.

   Completely Disagree   1   2   3   4   5   Fully Agree

3. It is straightforward to master 3D operations in GIS.

   Completely Disagree   1   2   3   4   5   Fully Agree

4. It is easy to add/modify details in GIS.

   Completely Disagree   1   2   3   4   5   Fully Agree

5. I can use editing tools in GIS to visualise my attempts accurately.

Completely Disagree   1   2   3   4   5   Fully Agree

6. I can produce 3D products from GIS rapidly and efficiently.

    Completely Disagree   1   2   3   4   5   Fully Agree

7. The 3D models in GIS have high fidelity (degree of realism).

    Completely Disagree   1   2   3   4   5   Fully Agree

8. The GIS environment facilitates the estimation of possible need for earth works and land use.

    Completely Disagree   1   2   3   4   5   Fully Agree

9. GIS is /would be useful for my professional work.

    Completely Disagree   1   2   3   4   5   Fully Agree

10. Compared with the current design tools, I think that GIS software will save me time in the design process.

    Completely Disagree   1   2   3   4   5   Fully Agree

Part DI Virtual Reality

1. Have you ever heard of virtual reality or virtual environments? Yes / No (if no, please go straight to part DII)

2. Do you have any experience with virtual reality software (e.g. OpenSim / Second Life)? Yes / No (It no, please go straight to Part DII)

3. If yes, what sorts of virtual reality software have you utilized (OpenSim, Quest3D…)?

4. What is the main purpose(s) for which you employ VR technology in your work?

5. What aspects do you like most about the virtual reality software you have used?

6. What aspects do you like least about the virtual reality software you have used?

Please complete following task and questions.

Part DII Virtual Reality Task

1. Login to the virtual environment via the Hippo viewer/Imprudence viewer. Firstly, set it up so that it accesses the Surveying Grid. Click on **Grids**. Click **Add** and specify the following as the Login URI: **http://survgrid.otago.ac.nz:8002/** Click **Get Grid Info** and most of the other fields should be filled in. Click **OK**.

2. Search for **GrandVista** on the **map** (on the bottom of the screen). Teleport to the GrandVista_2_2 tile (GrandVista is an isolated 768m by 768m virtual plot, 3x3 tiles). It will take several minutes to download the environment, depending on your Internet speed.

3. Do environment setting allowing you experience different times during a day (**World—Environment Setting**—Sunrise/Midday/Midnight).

4. Edit your avatar's appearance to a normal size (right click on the avatar—appearance). You can edit the height, body shape of your avatar, etc.

5. Walk around the island, using **mini map** as a navigation tool, and familiarize yourself with the basic operations on the sheet provided. e.g.:

- Page up continuously/fly—for a faster mode of transport

- Page Up/ Page Down – adjust your flying height

- Using the mouse wheel – alter perspective, from far behind the avatar to "inside the avatar's head"

- **Land** tab (in **Build** panel) – modify terrain (rise, flat)

- **Create** tab (in **Build** panel) – create simple 3D objects

6. Using primitives provided in **Build** tab to create the following object.
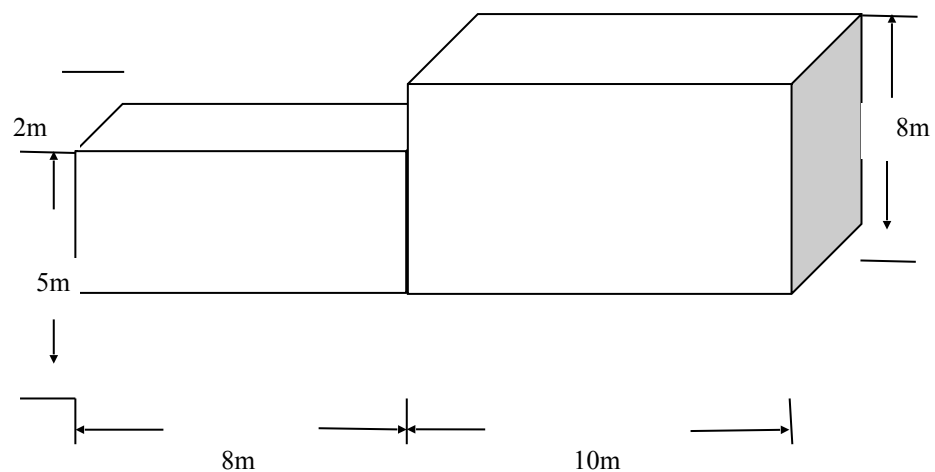
7. Upload the image below (E:\Test\test-texture.jpg) and setting it as a texture for your object (Uploading: **File—Upload**—Image; Editing texture: **Build—texture**)

8. Link (**Tools**—Link) and duplicate your completed entity (Hold **Shift** and drag your mouse across both blocks).

9. This island (GrandVista) contains existing surroundings and a site for urban design in the centre. Teleport to GrandVista 2_3. Please walk around and evaluate realism and quality of this environment.

10. Evaluate the realism of the 3D models in VR (see below for screenshot).

Part DIII Questions

For Q 1 to Q 19, please circle the answer which best indicates how you feel.

1. The interface of OpenSim (this is the program that generates the virtual environment) is user-friendly for novices.

   Completely Disagree   1   2   3   4   5   Fully Agree

2. It is simple to gain a feel for and master the basic operations of OpenSim.
   Completely Disagree   1   2   3   4   5   Fully Agree

3. It is straightforward to master 3D operations in OpenSim.

    Completely Disagree   1   2   3   4   5   Fully Agree

4. It is easy to add/modify details in OpenSim.

    Completely Disagree   1   2   3   4   5   Fully Agree

5. I can use editing tools in OpenSim to visualise my attempts accurately.

    Completely Disagree   1   2   3   4   5   Fully Agree

6. I can produce 3D products from VR rapidly and efficiently.

    Completely Disagree   1   2   3   4   5   Fully Agree

7. The 3D model has a high fidelity (degree of realism).

    Completely Disagree   1   2   3   4   5   Fully Agree

8. This virtual environment facilitates the estimation of possible need for earth works

    and land use.

    Completely Disagree   1   2   3   4   5   Fully Agree

9. This virtual environment is/ would be useful for my professional work.

    Completely Disagree   1   2   3   4   5   Fully Agree

10. Compared with the current design tools, I think that virtual reality software will

    save my time in the design process.

    Completely Disagree   1   2   3   4   5   Fully Agree

Part E Additional VR questions

1. I can see the potential of applying VR software to present my design concept in

    my future project.

    Completely Disagree   1   2   3   4   5   Fully Agree

2. I can gain a comprehensive understanding of GrandVista's design contexts/

    surroundings.

    Completely Disagree   1   2   3   4   5   Fully Agree

3. I have an awareness of my overall position in the virtual environment whilst

    exploring it with my avatar.

    Completely Disagree   1   2   3   4   5   Fully Agree

4. It is simple to navigate myself from one place to another/specific location.

    Completely Disagree   1   2   3   4   5   Fully Agree

5. I can modify details precisely via the tools offered in OpenSim.

   Completely Disagree   1   2   3   4   5   Fully Agree

6. A 3D model of my development has advantages over a 2D model of the same.

   Completely Disagree   1   2   3   4   5   Fully Agree

7. The graphical quality of the 3D environment is good enough for my urban design purposes.

   Completely Disagree   1   2   3   4   5   Fully Agree

8. The use of an avatar makes me feel more engaged than I would normally be with digital data.

   Completely Disagree   1   2   3   4   5   Fully Agree

9. This software is "real-time" enough for urban design purposes.

   Completely Disagree   1   2   3   4   5   Fully Agree

Part F Summary

1. Are there any particular features or functions that you would like to see in this 3D model and environment?

2. Any other questions or comments?