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USABILITY-ENHANCED COORDINATION DESIGN OF GEOVISUALISATIONS TO COMMUNICATE COASTAL FLOOD RISK INFORMATION

A Dissertation Presented

BY

HUANG HAIBO

Submitted To The Department Of Geography And
The Committee On Graduate Studies Of
National University Of Ireland, Cork
In Partial Fulfillment Of The Requirements For The Degree Of

Doctor Of Philosophy

January 2014

Head Of Department Professor Donald Lyons
Supervisor Mr. Darius Bartlett
Professor Fan Hong

Declaration

I hereby declare that the work described in this thesis is, except where otherwise sated, entirely my own work and has not been submitted as an exercise for another degree at University College Cork or elsewhere.

Signed,

_____

HUANG Haibo

January 9th, 2014

Abstract

For at least two millennia and probably much longer, the traditional vehicle for communicating geographical information to end-users has been the map. With the advent of computers, the means of both producing and consuming maps have radically been transformed, while the inherent nature of the information product has also expanded and diversified rapidly. This has given rise in recent years to the new concept of geovisualisation (GVIS), which draws on the skills of the traditional cartographer, but extends them into three spatial dimensions and may also add temporality, photorealistic representations and/or interactivity.

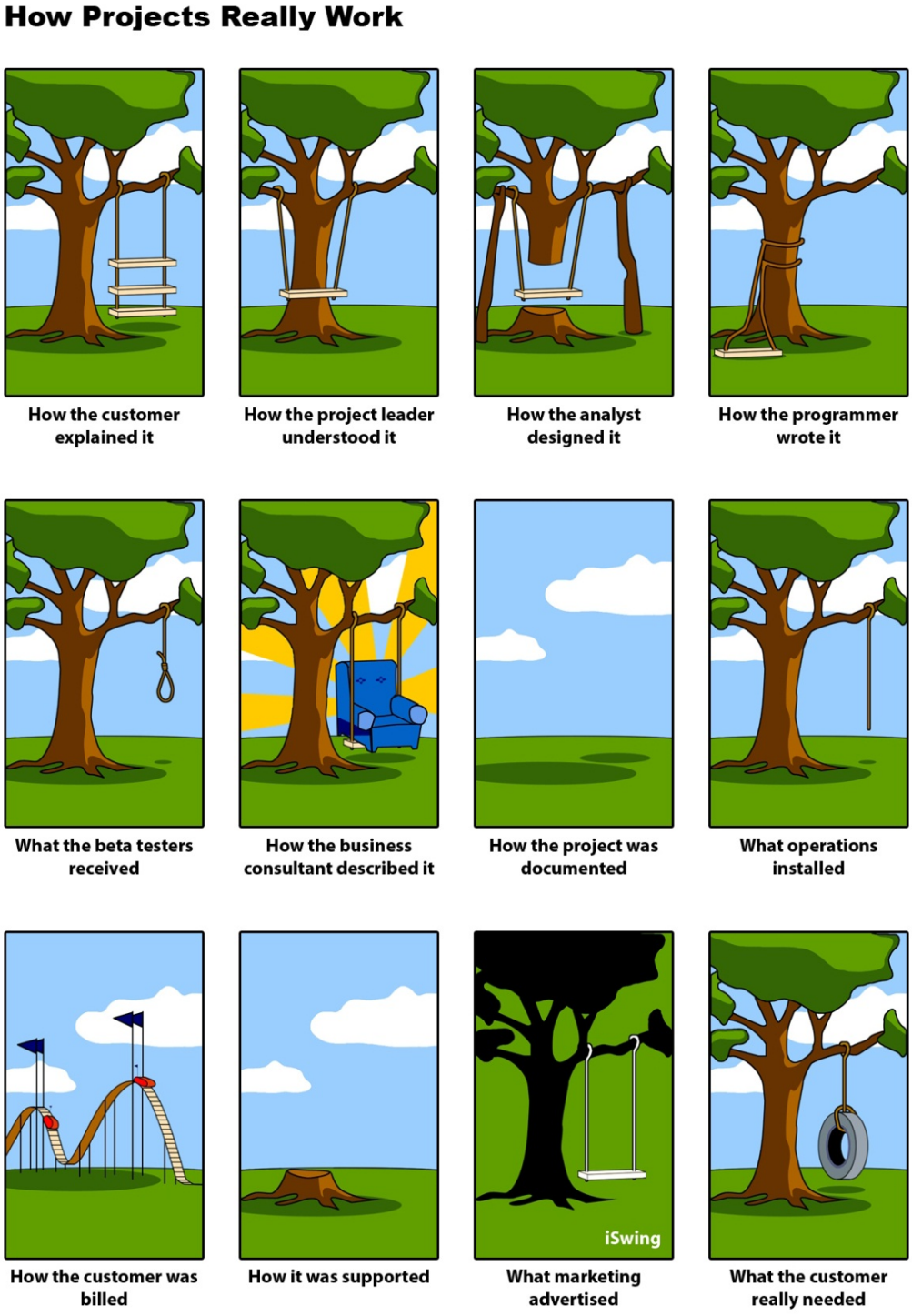
Demand for GVIS technologies and their applications has increased significantly in recent years, driven by the need to study complex geographical events and in particular their associated consequences and to communicate the results of these studies to a diversity of audiences and stakeholder groups. GVIS has data integration, multi-dimensional spatial display, advanced modelling techniques, dynamic design and development environments and field-specific application needs. To meet with these needs, GVIS tools should be both powerful and inherently usable, in order to facilitate their role in helping interpret and communicate geographic problems. However no framework currently exists for ensuring this usability. The research presented here seeks to fill this gap, by addressing the challenges of incorporating user requirements in GVIS tool design.

It starts from the premise that usability in GVIS should be incorporated and implemented throughout the whole design and development process. To facilitate this, Subject Technology Matching (STM) is proposed as a new approach to assessing and interpreting user requirements. Based on STM, a new design framework called Usability Enhanced Coordination Design (UECD) is ten presented with the purpose of leveraging overall usability of the design outputs. UECD places GVIS experts in a new key role in the design process, to form a more coordinated and integrated workflow and a more focused and interactive usability testing.

To prove the concept, these theoretical elements of the framework have been implemented in two test projects: one is the creation of a coastal inundation simulation for

Whitegate, Cork, Ireland; the other is a flooding mapping tool for Zhushan Town, Jiangsu, China. The two case studies successfully demonstrated the potential merits of the UECD approach when GVIS techniques are applied to geographic problem solving and decision making.

The thesis delivers a comprehensive understanding of the development and challenges of GVIS technology, its usability concerns, usability and associated UCD; it explores the possibility of putting UCD framework in GVIS design; it constructs a new theoretical design framework called UECD which aims to make the whole design process usability driven; it develops the key concept of STM into a template set to improve the performance of a GVIS design. These key conceptual and procedural foundations can be built on future research, aimed at further refining and developing UECD as a useful design methodology for GVIS scholars and practitioners.



Source: www.projectcartoon.com

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Dedication

To the beach of Inchydoney

To the fresh pints at Old Oak

To the lamb stew at Farmgate

To the lighthouse at Mizen Head

To the Blarney Stone I kissed twice

To the Titanic legacy stayed in Cobh

To the black pudding from Clonakilty

To the pulsing music and dance at Triskel

To my second home - Cork

Abbreviations

A	**AGI**	Association of Geographic Information
	AGV	Adaptive Geovisualisation
	AI	Artificial Intelligence
	AR	Augmented Reality
C	**CAD**	Computer Aided Design
	CBR	Case-Based Reasoning
	CCA	Canadian Centre for Architecture
	CG	the Chinese Group
	CHASE	Cork Harbour Alliance for a Safe Environment
	CHI	Computer-Human Interaction
	CGIS	Canada Geographic Information System
	CLI	Canada Land Inventory
	CNY	Chinese Yuan
	CT	Computer Tomography
D	**DNA**	Deoxyribonucleic Acid
E	**EDA**	Exploratory Data Analysis
	EPA	Environment Protection Agency
	ESRI	Environmental System Research Institute
	ECU	Experimental Cartography Unit
G	**GVIS / GV**	Geovisualisation
	GI	Geographic Information
	GIS	Geographic Information Systems
	GOMS	Goals, Operations, Methods and Selection
	GPS	Global Positioning System
	GSI	Geological Survey of Ireland
H	**HCI**	Human-Computer Interaction
	HFRG	Human Factors Research Group
I	**ICA**	International Cartography Association
	IG	The Irish Group
	InfoVis	Information Visualisation
	IPCC	Intergovernmental Panel on Climate Change
	IS	Information System
	ISO	International Standards Organisation
	IaaS	Infrastructure as a Service
K	**KDD**	Knowledge discovery in databases

	KLM	Keystroke Level Modelling
L	**LBS**	Location Based Service
	LREIS	Lab of Resources and Environmental Information System
N	**NCGIA**	National Centre for Geographic Information and Analysis
O	**OPW**	Office of Public Works
	OSI	Ordnance Survey Ireland
P	**POI**	Point of Interest
R	**RS**	Remote Sensing
	RRL	Regional Research Laboratory
	RTT	Rendering to Textures
S	**SECAD**	South & East Cork Area Development
	SLR	Sea-level Rise
	STM	Subject Technology Matching
	SUMI	Software Usability Measurement Inventory
	SVis	Scientific Visualisation
T	**TIN**	Triangulated Irregular Network
U	**UCD**	User-Centred Design
	UECD	Usability-Enhanced Coordination Design
	UNEP	United Nations Environment Programme
V	**VDM**	Vegetation Distance Model
	VDTs	Visual Display Terminals
	VE	Virtual Environment
	Vis	Visualisation
	ViSC	Visualisation in Scientific Computing
	VR	Virtual Reality
W	**WFS**	Web Feature Service
	WIMP	Windows, Icon, Menu and Point
Z	**ZTAC**	Zhushan Town Administrative Committee

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Section 1

Context, Rationale and Methodology

Chapter 1

Introduction

1.1 Foreword

The early years of the 21st Century have seen the emergence and rapid development of three dimensional (3D) visualisations in many areas of popular culture, including the cinema and television, as well as in a growing variety of academic, professional and industrial settings. While the origins of this interest in 3D visualisation may be traced back to the days of analogue methods, their current success relies heavily on the advent of new, digital technologies. Thus, for example, the first experimental 3D movies can be traced back to film-makers' explorations in anaglyph film back in the 1920s (Zone, 2007), but it is only after the huge success of the epic movie Avatar (2009) that 3D has moved into the mainstream of contemporary film-making. A similar transformation may also be recognised as taking place in the discipline of geography, in particular through the expression of the art and science of cartography, where maps and other representations of the world that would traditionally have been made in 2D formats are increasingly being created as 3D displays instead.

The hardware and software required to construct a 3D display is no longer considered sophisticated and the 3D virtual environments presented on movie screens can be also found in university laboratories or even personal workstations, making it easier than ever before for general public to access all kinds of 3D representation. Adopting advanced visualisation

technologies encourages presentation and analysis of data for multiple purposes and users, such as for interpreting spatial patterns and for communicating complex ideas in a broader and more informed way among academia, government and other stakeholders (Slocum, *et al.*, 2009).

This rediscovered interest in representing and portraying the third spatial dimension raises important research questions, the most fundamental of all being whether the benefits of 3D are as real as they are sometimes claimed to be? And, leading from this, how can these claimed benefits be optimally realised?

Several cases are documented in the literature of advanced visualisation tools failing to meet users' needs and the latest display technologies do not always guarantee better performance (see, e.g., Slocum, *et al.* 2001, Fuhrmann, *et al.* 2005, Andrienko 2006). Application usability has become a critical challenge for effective geovisualisation development, and there is an urgent need to provide appropriate solutions for designing and delivering useful tools.

The research presented in this thesis seeks to address this need. It addresses core questions, such as what should be known about usability issues in geovisualisation, the significance of understanding users' requirements, how can their needs be blended into tool design and what kind of solutions can be proposed to combine all of these elements.

The initiative to explore the above questions and concerns was later consolidated during discussions with local citizens, communities and authorities in the Cork Harbour area, on the south coast of Ireland, concerning the preparation and adaptation for the likely consequences of global climate change and specifically the threat of rising sea-levels. It was found that while stakeholders need and want easy access to information about the sea and wish to learn the potential risks of flooding, they have varying expectations and requirements regarding how that information should be delivered: in some cases they expressed a wish for very detailed, immersive visualisations that would allow them to place themselves virtually in the scene; while among other interest groups, the need was for less sophisticated but more detailed visualisations, suitable for scientific analysis and/or decision support. Common to these and related conversations was the implied need for more effective ways of communicating the

potential impact of flooding to the intended audience. This provided the opportunity for this research to examine the pros and cons of different mapping tools through users' eyes and more importantly, what kind of implications can be posed for an innovative approach to enhancing the usability of geovisualisation design.

1.2 Overview of concepts

The research presented in this thesis lies at the intersection of three key domains, namely scientific visualisation, human-computer interaction and geographical information science (Figure 1.1). *Scientific visualisation* is a broad paradigm that emphasises the use of computer-assisted visualisation technologies in scientific research (MacEachren, 1995). Representational technologies, visual interpretation and analysis and visual cognition are all important research domains belonging to this sphere. Geovisualisation can be seen as a branch of scientific visualisation in the sense of applying visualisation technologies to geographic problem-solving (Kraak and Ormeling, 2003). *Human-computer interaction* is a broad area that looks specifically at all the matters involved in the process of using computers. In many cases the research focus is posed on the interface between design and evaluation. Usability is a very critical indicator in evaluating the interface, while user-centred approach is a philosophy within the sphere looking at the design of interfaces that concentrates on user requirements and expectations (Johnson, 1998). *Geographic information science* is the science behind the technology that applies computer technologies to acquiring, processing, storing and managing geographic information.

The boundaries between these three core concepts are relatively blurred, but they provide points of focus for the setting and orientation of the study. Within this general framework, specific concepts linked to the core are defined and examined in the following two chapters of this thesis. However, looking beyond the central elements of geovisualisation and usability, the exploration actually spans more general fields such as psychology, artificial intelligence and communication on the one hand, as well as product design, interoperability, organization and management on the other.

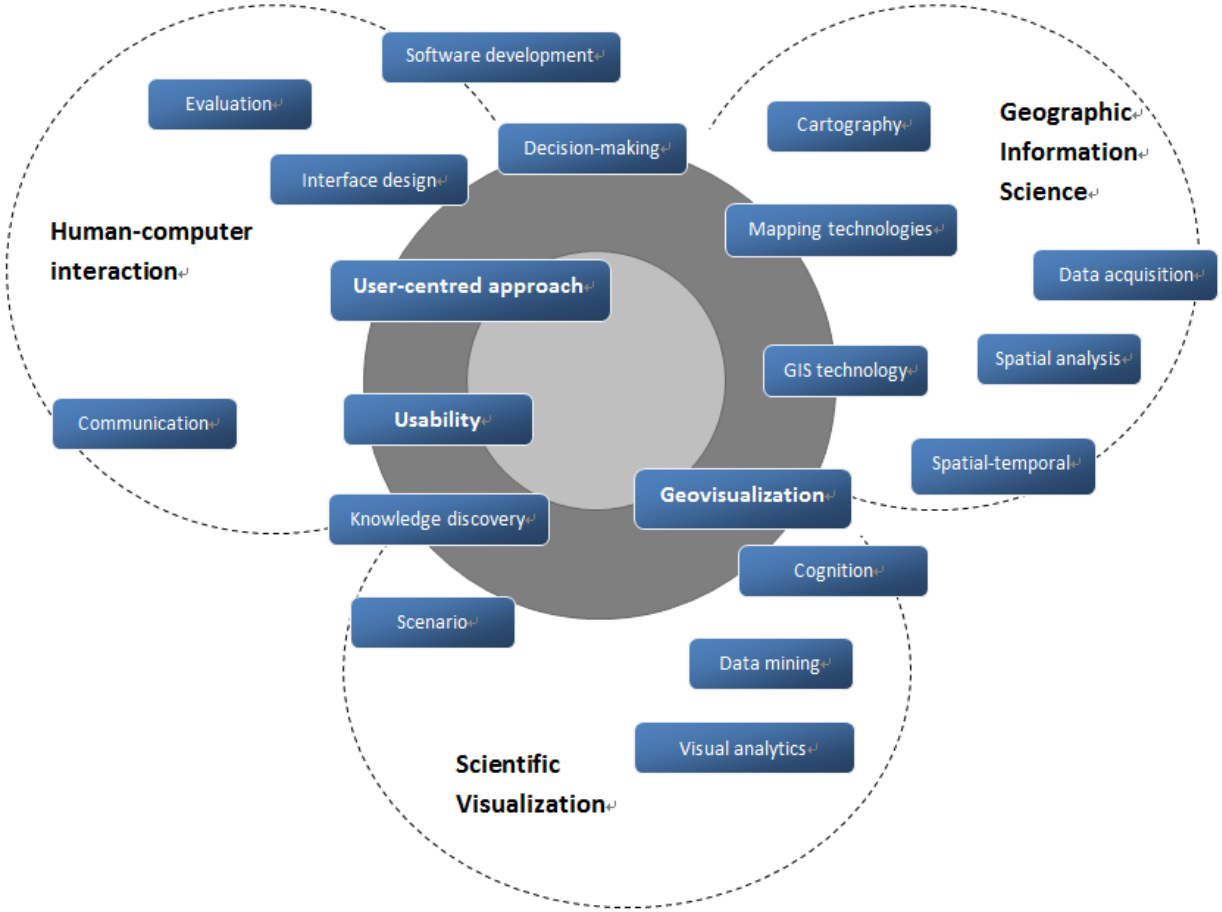


Figure 1.1 Wider scope of concepts and research themes related to this study

1.3 Research Questions

The overall aim of this research is to address two interrelated challenges: 1) evaluate the concept of geovisualisation usability from a theoretical perspective; 2) develop a practical framework through which geovisualisation usability can be enhanced from an operational product development perspective. These two challenges can be divided further into a series of specific research questions as follows:

Question 1: How can geovisualisation usability be conceptualised and measured?

Usability is hard to define because it is not a physical feature (e.g., size or colour) that can be observed and captured directly and it is intuitive because only the person who uses the product is entitled to determine its usefulness from his/her own particular perspective. It is often the case that different users count the usability of the same products from their own interest and there is no standard or universal measurement for it. Geovisualisation is a very special field *per se*, where advanced graphic technology and spatial analysis meet and provide windows for understanding geographic issues. The investigation of usability issues in the realm of geovisualisation needs to take into account the unique features of this application domain. Although many recorded studies have been carried out looking into usability evaluation of specific geovisualisation tools (Andrienko, 2006, Mülder, et al., 2007, Milosz et al., 2007, Woronuck, 2008), as reviewed later in this thesis, very few have actually managed to provide a comprehensive and systematic description of geovisualisation usability at the more generic level.

Geovisualisation and usability are two key elements of this part of the research. Geovisualisation is linked with fields such as cartography, computer graphics, image processing, data modelling and GIS, while usability is a cross-cutting concept involved in fields like human-computer interfaces (HCI), quality design, artificial intelligence, cognition, perception and psychology. Properly understanding the combined concept thus requires the appreciation of the multi-dimensional nature of the two subjects and it leads to a number of questions to be dealt with in this thesis. For example, how are the terms geovisualisation and usability

conceptualised? How, why and to what extent is geovisualisation different from other computer applications? What are the essential features of usability that should be addressed? How to properly understand the concept of geovisualisation usability? Is geovisualisation usability different from the usability of regular computer applications?

Generally in order to correct / improve a human-computer interface, one must find a way to first evaluate and give an appropriate judgement on its usability. From a usability engineering perspective, one has to select the correct measurables that reflect usability of a tool and the suitable methods of collecting data on these measurables. As to how a geovisualisation tool can be judged useful or not, this thesis seeks to establish, how usability evaluation is usually approached in geovisualisation studies and whether there are established or emerging good practice guidelines that might inform the geovisualisation design process?

Question 2: How to enhance usability of geovisualisation tool from a product development perspective?

Enhancing usability has been widely accepted as a vital task that needs to be carried out throughout the product design cycle and each stage of the design cycle should provide room for users' involvement (Gould and Lewis, 1985; Nielsen, 1993; Norman, 2006; Dumas, 2007; Kulyk, *et al.*, 2007). It is assumed that only by doing so the output of the design can be as close as possible to users' expectation. Geovisualisation tools are meant to help users view, explore and explain geographic problems, make appropriate and practical decisions accordingly. Most of the current efforts of improving usability are in relation to technology innovation, which presumes that technology will advance its capacity as well as its usability. This makes designers often ignore the importance of addressing users' needs and reflecting them in a design and development process. It has been noticed that a lot of geovisualisation tools designed, though equipped with the latest technologies, eventually fail to meet their users' needs (Slocum *et al*, 2001; Fabrikant, 2005; Fuhrmann, *et al.*, 2005; Dykes *et al*, 2008). Therefore, usability enhancement is not merely a matter of upgrading technology, but more importantly a matter of how to involve users at appropriate levels in the design process. A second strand of the present

research is to explore how this greater engagement with the user might be achieved in practice.

The idea of making user needs central to the design process is originally due to the emergence of so called technology-driven development that shifts the focus of a product design from *creating a product to be used to making use of available technologies*. The problem with such a mode is that features carried by a product are based on the designers' understanding of what is required rather than the users'. Designers presume new technology can meet what are needed, thus new technology is used for the sake of the technology itself and this has to be solved by effective and constructive communication between users and designers. This leads to the next strand of the research, which investigates how to make users' requirements more understandable to designers, how to make users more informed during the development process and how to narrow the knowledge gap between designers and users? These questions are addressed in this thesis through the exploration of a specific, potentially useful approach, with a specific focus on geovisualisation product design.

In opposition to technology-driven development is the idea of making a design that is driven by the user's needs (Nielsen, 1993), which is then gradually expanded and systemised into the theory of user-centred design. User-centred design stresses that in order to enhance product usability, designers need to take full consideration of users' demands throughout a design and development cycle and have greater involvement of users, directly or indirectly, in order to voice out their views on the design. In this sense, users need to be involved in a cognizant and effective manner so that their needs and expectations are fully embodied in the design and thus their contributions aid the design. This research intends to explore the possibility of maximising users' involvement in a more practical manner.

The mass application of visualisation technologies in geography-related fields such as urban planning, archaeology, forestry and environment research have certainly raised new and higher requirements on geovisualisation design, which are expected to carry more functions, deliver better performance and provide a friendlier interface. There are increasing demands on usability which need to be addressed not just by innovative techniques, but also by an

innovative design and development process. Therefore the exploration is further extended through responding to questions such as how to make the best out of current geovisualisation practices? How to avoid design blindness, or in other words, design without being aware of other relevant designs? How to make prototyping more effective in reflecting users' needs? How to transfer knowledge and experience to subsequent designs? In fact, when the bigger picture is taken into account, answers to these questions also have implications for general usability studies.

1.4 Research Objectives

In order to achieve the research aims and answer the questions presented above, the research sets out the following objectives:

- To present a comprehensive study that extends and deepens the insights of usability in the geovisualisation sphere, especially its up-to-date developments and challenges, in expectation of developing new practical theories that will contribute to related science research.
- To demonstrate the influency of usability concepts throughout the product development process and the adaptation of user-centred design in the field of geovisualisation design.
- To advance the usability of geovisualisation, by developing a robust and comprehensive framework for that can be applied throughout the product development process.
- To demonstrate the benefits of this new approach by applying advanced geovisualisation technologies and user-centred design approaches to empirical data collected for one specific application domain, namely flood mapping.

Specific aims include:

- To present state-of-art knowledge of geovisualisation including its definition, the conceptual and technological evolution and the challenges currently on the geovisualisation research agenda.

- To deliver a systematic study of usability in geovisualisation and to create a well-grounded knowledge base built upon existing findings in relevant domains.
- To undertake an experiment, with a specific focus, to investigate geovisualisation usability problems with participants and gain in-depth insights into the problems.
- To develop a generic geovisualisation design conceptual framework that incorporates the concept of usability into product design and provides a clearly defined methodology to leverage the participation and communication of users.
- To facilitate the conceptual framework in real-context case study applications and explore its performance as well as associated issues.

1.5 Structure of the Thesis

The thesis is structured into four sections: Context, Literature Review, Rationale and Methodology (Section 1); Developing the Conceptual Framework (Section 2); Case Studies and Potential Applications (Section 3); and Discussion and Conclusions (Section 4) (Figure 1.2). Chapter 1 gives a brief synopsis of the research motivation, the concept involved, research questions, research objectives and aims and the overall organisation. Chapter 2 and 3 review the literature covering the two key aspects of geovisualisation and usability. Based on the reviewed principles and concepts, Chapter 4 explains the methodology of this research. Chapter 5 presents the analysis of the user requirement studies and points out the stratagem of how to meet user's demands. As a follow-up the Chapter then proposes the idea of subject-technology matching as a solution prompted by the need to reflect user requirements in the design. Based on this solution, the new usability-enhanced coordination design framework is then proposed at the end of the chapter. Chapter 6 presents two case studies, one in Ireland and another in China, intending to show the application of the new design in real-context. All the findings of this research are then summarised in Chapter 7 along with additional discussions and reflections.

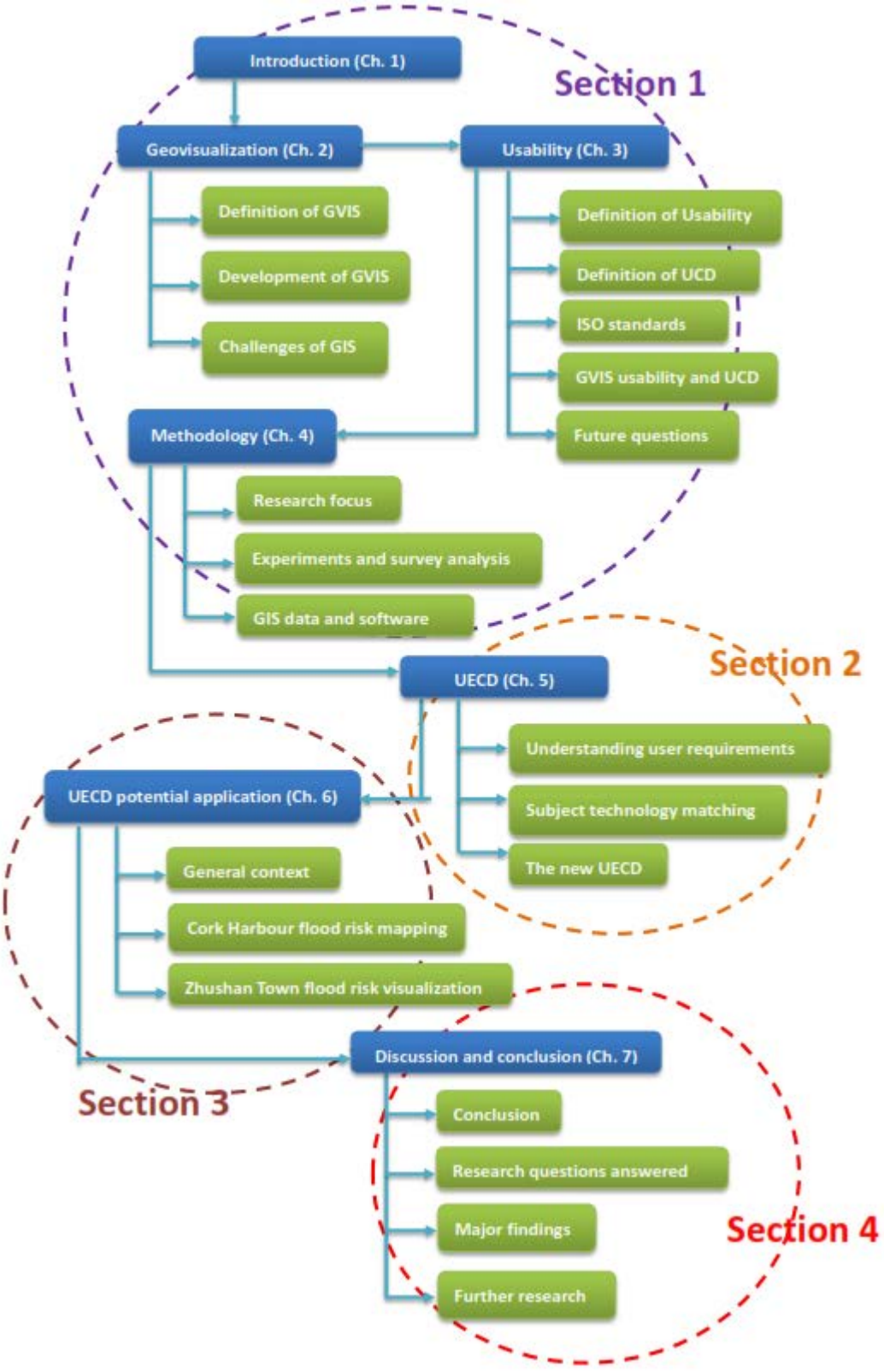


Figure 1.2 Structure of the thesis

Chapter 2

Geovisualisation: Conception, Application and Challenges

2.1 Introduction

Although the term *geovisualisation* (short for *geographic visualisation* or *geographical visualisation*) is relatively new, its origins can be traced back to the origins of cartography, many thousands of years ago (Hornby, 1985). Its earliest examples can date back to antiquity with map-like wall painting depicting the surroundings of our ancestors. However, geovisualisation involves more than simply cartography, since it gets its driving force from its integration with many other modern technologies and shows its application potential in a variety of fields.

In this chapter, the nature of geovisualisation, its development and application are explored at length with a review of published research in this area. As geovisualisation is an interdisciplinary subject, its linked branches of visualisation and information analysis, as well as the development and functions of those, are also examined to show how they are each interrelated. Visualisation, cartography and Geographic Information System (GIS) are the basis for the birth and evolvement of geovisualisation.

The chapter is structured as follows. Section 2.2 explains the definition of geovisualisation and its origin supported by scientific visualisation, cartography and GIS. How the conception of geovisualisation has evolved is investigated through a review of key literature. Section 2.3 then focuses on the development of geovisualisation application functionality. A separate discussion in this section emphasises one of the most significant development transitions – going from two-dimensional (2D) display to three-dimensional (3D) display. Section

2.4 states the main challenges of geovisualisation and the implication of usability and bridges the next chapter.

2.2 Definition of Geovisualisation

2.2.1 "The boiling soup"

> *"Almost everything that happens, happens somewhere. Knowing where something happens can be critically important (Longley, et al., 2005, p.4)."*

Geographic information is critically important, as indicated in the above quote, because most of the activities of human beings happen either on the surface or on the near-surface of Earth (Goodchild, 1992). This explains why we are so sensitive about location and the information at that location.

Data from medical and psychological research show that up to 80% of the information received from the outside world comes through people's eyes (Seiderman and Marcus, 1989; Haupt and Huber, 2008). This is because visual observation is the most basic way to capture information. Visualisation has thus become such an important aspect of studying location-based geographic problems that it possibly makes more sense to make a small change to the original quote above, so that it becomes, "*Almost everything that happens, happens somewhere. Seeing where something happens can be critically important*." This realisation has led to a specific growing field of study and application known as – geovisualisation.

Geovisualisation is a much broader discipline than simply cartography, as it absorbs elements from many other scientific fields as indicated symbolically in - "the boiling soup" illustration (Figure 2.1). The upper half of the picture includes several containers of different sizes, which represent those key fields that are involved in the conceptualisation of geovisualisation. Those arrows "poured out" from them highlight some of the key connections between geovisualisation and each separate field. The "ingredients" eventually merge into "a bowl of soup" suggesting the multi-dimensional nature of geovisualisation. Below this pot of boiling soup is a "camp fire" which simply suggests that, like any other system, geovisualisation gains its dynamic nature through inputs – in this case derived from the activities of researchers and practitioners; while this fire is supported by a bunch of firewood, which stands for some of

the most popular fields where geovisualisation technologies are widely applied.

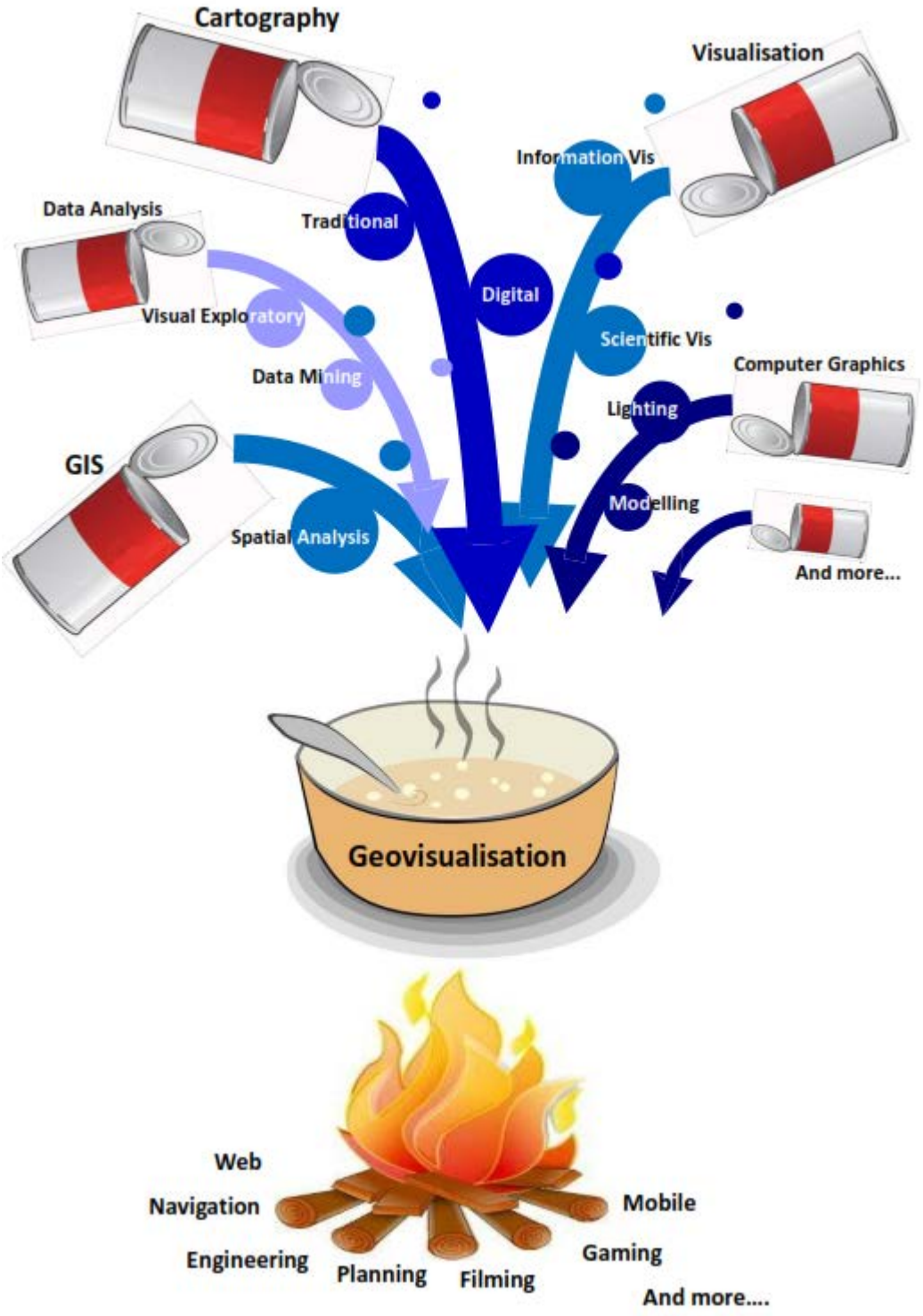


Figure 2.1 Geovisualisation – "the boiling soup"

The most widely accepted definition for geovisualisation is given by two pioneers – Alan MacEachren and Menno-Jan Kraak in the following description:

"GVIS integrates approaches from visualisation in scientific computing (ViSC), cartography, image analysis, information visualisation, exploratory data analysis (EDA), and geographic information systems (GISystems) to provide theory, methods, and tools for visual exploration, analysis, synthesis and presentation of geospatial data (MacEachren and Kraak, 2001, p.3)."

These two scholars also, for the first time, use "GVIS" as the abbreviation for *geovisualisation* and for the sake of simplification, GVIS is also used in the rest of the thesis. Different definitions are also proposed by other scholars, but only with a slightly different focus. For example, it is described in Longley *et al.* (2005, p.292) as:

"…the creation and use of visual representations to facilitate thinking, understanding and knowledge construction about geospatial data."

While Kraak (2003, p.398) describes the term as:

"…the use of visual geospatial displays to explore data and through that exploration to generate hypotheses, develop problem solutions and construct knowledge."

The definitions emphasise that GVIS is a tool for scientific exploration and *understanding* of (sometimes complex) datasets, as much as it is for *communicating* ideas or concept to a variety of audiences: GVIS is an approach that integrates a range of ideas and concepts. In order to gain a better understanding of this "this soup", the rest of this section investigates the origin of GVIS by explaining its involvement with those three main "containers" in the picture – visualisation, cartography and GIS. By doing so it hopes to present a clear image of what should be known about GVIS.

2.2.2 Visualisation

Visualisation is apparently the key word in the term of *geovisualisation*. It means in general "to make visual" and "to bring something as a picture before the mind" (Hornby, 1985; MacEachern and Taylor，1994, p.53) and the term emerged for the first time in the cartographic literature in an article written by Allen K. Philbrick in 1953,

"…not only is a picture worth a thousand words but the interpretation of phenomena geographically depends upon visualisation by means of maps (Philbrick, 1953, p.11)."

Given the mentioning of maps, visualisation clearly had a strong connection with the cartographic activities at that time. As a matter of fact, visualisation through mapping has long been treated as a fundamental geographic method describing the formation of mental visual

images relating to place or space and thus fulfils the requirement of MacEachren that visualisation involves the act or process of interpreting in visual terms or of putting into visual form (MacEachren 1994). But with recent developments in science and technology, especially the integration of computer graphics, a dramatically increasing use of visualisation has been observed during the past five decades. Between the 1960s and 80s, visualisation was considered a primary challenge in almost all computer graphics studies (Sutherland, 1966; Heckbert, 1987; Blinn, 1999). Later, the concept of *Visualisation in Scientific Computing (ViSC)* was prompted by the U.S. National Science Foundation as the integration of image and signal processing, computer vision, computer graphics, computer-aided design and user interface (McCormick, *et al.*, 1987). The term closely related to the parallel concept of *Scientific Visualisation (SVis)*, which means the production of concrete visual representations by computer technologies (MacEachren, 1995). It was since 1990s that tasks like modelling, animation and real-time 3D were added into visualisation research (Blinn, 1999) and visual quality, integration, interaction and abstraction were believed the four primary development orientations of visualisation (Hibbard, 1999).

Visualisation has been applied widely to research fields such as medical image processing (Mayerich, *et al.*, 2011), life science (Trafton, 2009) and physics and engineering (Clarkson, 2009). In the sphere of urban planning, for example, visualisation provides dynamic display and simulation of geographic phenomena, allowing patterns to be represented and revealed effectively (Grant Associates, n.d.; Figure 2.2). The extensive application of visualisation enormously enhances people's capabilities of exploring their surrounding environment. Scientists can now fairly easily turn non-visible (digital) data, collected via measuring devices or generated by computer models, into visual representations. In the development of SVis applications, the multi-disciplinary nature of visualisation has also been investigated by other scholars, who have attempted to formulate general concepts and principles that might govern or direct the contents and goals of visualisation as a technique. For example, Earnshaw (1992) states that SVis focuses on exploring data and information in a more understandable and

insightful manner. The goal is to deepen the level of investigation on underlying patterns, features and processes more quickly and easily. Robertson and De Ferrari (1994) stress that the goal of SVis is to systematically generate visual representations according to users' interpretation aims, which define the characteristics of the data and the relations between data variables.

Figure 2.2 Examples of visualisation used in the design for New Cross Gate NDC Centre London (Grant Associates, n.d.)

Closely related to the above terms and concepts, another branch of visualisation known as *Information Visualisation (InfoVis)*, is concerned with the art and technology of designing and implementing highly interactive, computer supported tools for data mining and knowledge discovery in large non-spatial databases (Card, *et al.*, 1999). The job of InfoVis is to make it possible, through visual analysis, to discover implicit information and patterns hidden in datasets typically encountered in financial, communication and a number of other commercial activities (Veerasamy and Belkin, 1996; Keim, 2002). In terms of its difference from SVis, Card *et al.* (1999) explains that SVis involves the use of interactive visual representations of scientific data, typically physically based, to amplify cognition, while InfoVis is the use of interactive visual representations of abstract, non-physically based data to amplify cognition. In other words, InfoVis refers to exploratory data analysis and SVis refers to confirmatory data analysis (Keim and Ankerst, 2001). However, SVis and InfoVis obviously share the same goal, which is to explore and present data, concepts, relationships and processes through visual communication and it

will be far more sensible to emphasise the common force between the two concepts rather than try to stress the separation, which is of little benefit to the development of both. Rhyne (2003, p.612) argues that the definition scheme is rather an unfortunate event of history because "*scientific visualisation is not uninformative and information visualisation is not unscientific.*"

2.2.3 Cartography

If visualisation gives GVIS the "soul", then cartography gives the "body", as it is cartography that shapes today's GVIS. Among all the "ingredients" shown as containers in Figure 2.1 above, *cartography* is likely to be the most influential one. In historical terms, cartography is probably one of the earliest human activities (ICSM, n.d.), but interestingly, the discipline has undergone at least two fundamental redefinitions and readjustments of subject matter during its long history. Before 1960s cartography was simply understood as producing maps (Taylor, 1991). The mapping techniques pioneered by Babylonian scholars were further improved in ancient Rome, Greece, China and the Arabic and Islamic worlds, along with the scientific development of geography and mathematics (Harley and Woodward, 1987; Liebenberg and Demhardt, 2012). Thousands of years of development has made cartography the art and science of making maps that are both useful and beautiful. For example, a Western Han (183-168 B.C.) map made of ink on silk was considered the very first map that employs a grid system (Barbieri-Low, 2007:147; Figure 2.3). Maps have been seen as important ever since because there has been no better way to get an overview of a place other than by reading a map.

Figure 2.3 A Chinese topographic map dated to early Western Han period (183-168 B.C.) showing the territory of the Kingdom of Changsha (Barbieri-Low, 2007)

The field of cartography involves not only the *making,* but also study of the *use* of maps, because investigating the use of maps and their contained information will be the only way to know if a map has represented the information effectively. This leads Thrower (1996, p.245) to re-define the concept of a map based on the information carried, as "*…a representation, usually on a plane surface, of all or part of the earth or some other body showing a group of features in terms of their relative size and position (Thrower, 1996, p.245)*." This descriptive definition indicates a conventional view of maps, seen as a model or mirror of reality. All the features from the real world are intentionally reduced in size and their attributes are represented symbolically (and sometimes conforming to convention or standards, such as portraying water in a blue colour).

Cartography, as a business of making maps, started to face a dramatic transition in the 1960s when new computer-assisted mapping techniques emerged, including software for creating maps, plotters for generating hard-copy output and digitizing tables as devices for converting analogue maps into digital data (Gemma, 2011). In such technology transition, various alternative ways of representing maps were offered and a new definition for cartography gradually began to emerge as an information transfer "that is centered about a spatial data base which can be considered in itself a multi-faceted model of geographic reality. (Guptill and Starr,

1984 cited in Wood, 2001, p.80)." Later a more systematic and modern definition of *cartography* appeared in Taylor (1991, p.4) as,

> *"…the organisation, presentation, communication and utilisation of geo-information in graphic, digital or tactile form. It can include all stages from data preparation to end use in the creation of maps and related spatial information products."*

At the same time, the definition of map was also updated, as Board (1990 cited in Kraak and Ormeling, 2003, p.35) suggested,

> *"[A map is] a representation or abstraction of geographic reality. A tool for presenting geographic information in a way that is visual, digital or tactile."*

Taylor's definition emphasises that the nature of cartography is to make spatial data and visually present it with essential interaction to deal with geospatial issues, thus the term is connected with the previously mentioned key word – visualisation. As a matter of fact, maps were and still are, considered as a form of scientific visualisation, though maps had long existed even before visualisation developing into a specific field of interest. Hearnshaw and Unwin (1994) clarify that scientific visualisation is more about analytical capacity than communicative functionality, while an emphasis of cartography will be placed equally on the two. This statement is supported by Kraak and Ormeling (2003, p.24) (Figure 2.4).

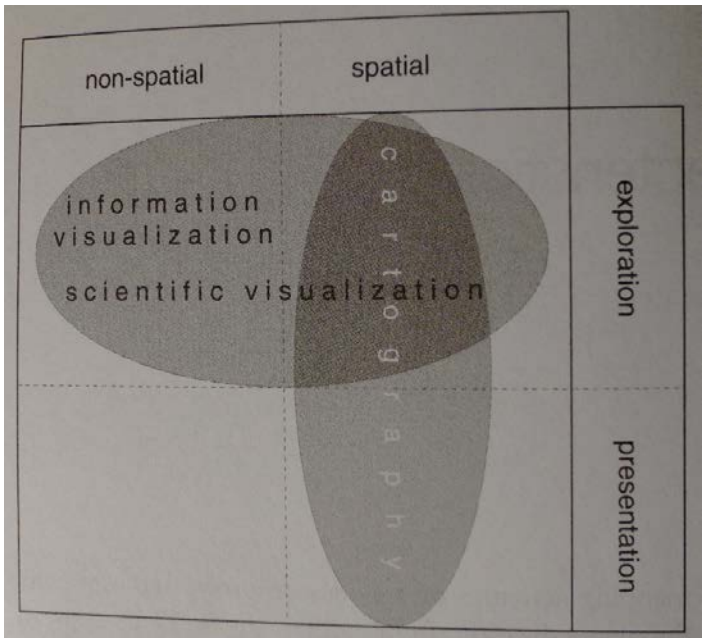


Figure 2.4 Relation between scientific visualisation, information visualisation and cartography (Kraak and Ormeling, 2003)

Based on the brief review of visualisation and cartography, the birth of GVIS can be seen as, but not limited to, the application of visualisation in cartography. As reviewed, cartographers were the first group to take up the challenge of applying new technologies to visualising both known and unknown patterns of the world. An increasing amount of the data that modern society dealt with involved a spatial component (which is still the case nowadays) and visualisation for such spatial data became generally known as GVIS. At the same time, visualisation started to show its great potential in the presentation and analysis of geographic information. From a technical perspective, the combination of different visualisation techniques has greatly improved the graphic presentation of geographic data and from a theoretical point of view, beyond graphic expression of data, visualisation was seen essentially as an in-mind imaging process by human beings towards particular things (or people) or, in other words, a cognition and communication process between human beings and geographic information. Such a process would certainly help people acquire geoscience knowledge and understand geoscience disciplines.

2.2.4 Geographic Information Systems

If visualisation and cartography are the core ingredients of GVIS, then it is Geographic Information Systems (GIS) that gives GVIS its maturity and innovation. GIS is also closed linked to cartography and was given birth to by the development and expansion of applications of computer assisted automated mapping programs in 1950s (Chrisman, 2002). The conceptualization of GIS was approached by pilot cartographers and computer scientists in Europe and North America from the 1960s (Chrisman, 2002) and parallel developments happened afterwards in both these regions, where the focus was more on spatial analysis in North America but cartography in Europe (Longley, *et al.*, 2005;).

It is agreed generally that the term GIS was first coined in the 1960s during the development of the Canadian Geographical Information System (Longley, *et al.*, 2005; Tomlinson, 2007), followed by many attempts by different scholars of trying to define GIS. Generally these attempts were made according to the performance of a system in handling

geographic data, which was likely to be influenced by another concept in the same period – *Information System (IS)* (Aronoff, 1991). The definition of IS was formalized in the 1970s by system designers as a system needed for decision making that contains subsystems for *collecting*, *sorting*, *processing* and *distributing* information (Langefors, 1971). Marble (1990) thus stated that a GIS system must include a data input subsystem, a data storage and retrieval subsystem, a data manipulation and analysis subsystem and a data reporting subsystem. Similarly Aronoff (1991, p.39) defined GIS as,

> *"…a computer-based system that provides the following four sets of capabilities to handle georeferenced data: 1 input; 2 data management (data storage and retrieval); 3 manipulation and analysis; and 4 output."*

At the same time, GIS can also be defined according to the type of data that a GIS involves. More specifically, there are three key features of geographic data based on its way of describing an object in terms of its position with respect to a known coordinate system, its physical attributes associated with the geographic position and the spatial relationship of the object with surrounding geographic features (Artimo, 1994). Therefore it can be understood as "a computer-based system that processes geographical information (Artimo, 1994, p.49)." One of the most widely used definition comes from Longley *et al.* (2005, p.28), where GIS is defined as,

> *"A spatial data oriented, integrated, analysing and management information system that integrates hardware, software and data for capturing, managing, analysing and displaying all forms of geographically referenced information."*

GIS is a good example of the type of innovation that starts in a specific environment, but later spreads to a broad use given it has been successfully expanded in fields such as landscape planning, civil infrastructure design, land use management, environmental monitoring, telecommunication, electricity grids, logistics, weather forecasting, real estate marketing and many other fields (Longley, *et al.*, 2005). Thanks to the mass application of GIS in all those above areas, GVIS is offered a massive and diverse platform to test its own innovation and it is also growing to be an umbrella concept that encompasses a lot of other systems such as advanced visualisation systems and artificial intelligence (AI) systems that help process

geographically referenced data. For instance, with the assistance of visualisation techniques, GIS is now able to provide many different ways to display spatial analytical results according to different purposes (Figure 2.5), while at the same time any new demands emerging from actual use of such GIS systems provide opportunities for the development of new or improved visual display. It is due to such "win-win" practice that GVIS makes itself matured, extended and leveraged. More examples of how GIS help shape up GVIS will also be given in later sections such as 2.2.5 and 2.3.1.

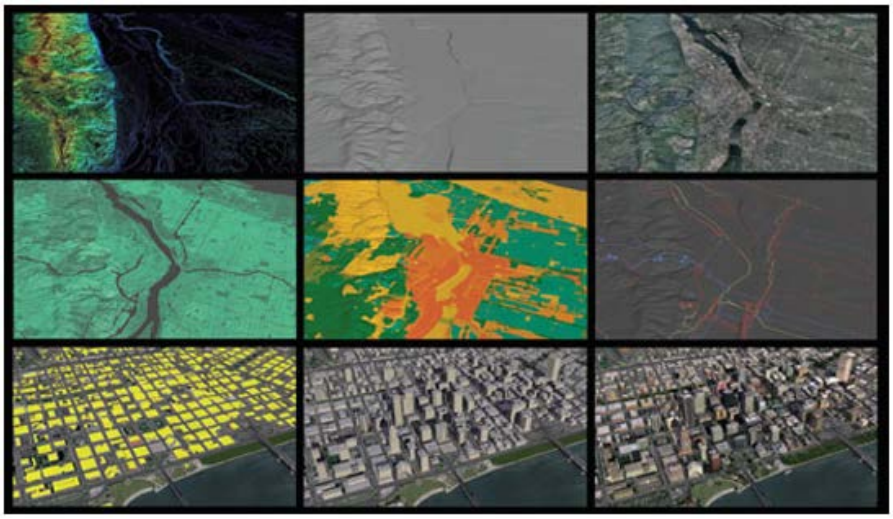


Figure 2.5 GIS analysis of Portland created to support various purposes (Nozik, 2009)

2.2.5 The evolving concept

Understanding GVIS started from the depiction of cartographic visualisation research process proposed by DiBiase (1990) based on exploratory data analysis, where GVIS was mainly considered as an effective analytical approach to investigate data. What he presented was a process that goes from the private realm of visual thinking to the public realm of visual communication (Figure 2.6). In the private realm, GVIS is used to explore data, develop hypotheses and carry out analysis to access the hypotheses, while in the public realm, GVIS is used to synthesize results, support evidence and present the results (Robinson, 2011a). GVIS carries out different types of works when moving from private realm to public realm, which means the analyst changes its focus in the meanwhile. The curvy line in the picture depicts the research sequence clearly at two ends: maps and other graphics at the exploratory end act as a

reasoning tools for private visual thinking while at the presentation end, the visualisation plays a facilitating function for public visual communication. It implies that GVIS pays strong attention to analytical tasks but relatively less attention to synthesis which is helping the development of the technology. Apparently DiBiase (1990) claims that the communication part (synthesis and presentation) should never be seen as a separable work with GVIS tools. Instead it should be an important part of GVIS to synthesize and present findings. His model also emphasises the fact that due to the rapid changes of relevant computer technologies (e.g., GIS), not only the tools used for visualisation and exploration, but also the interaction between users and these visualisations will start to change.

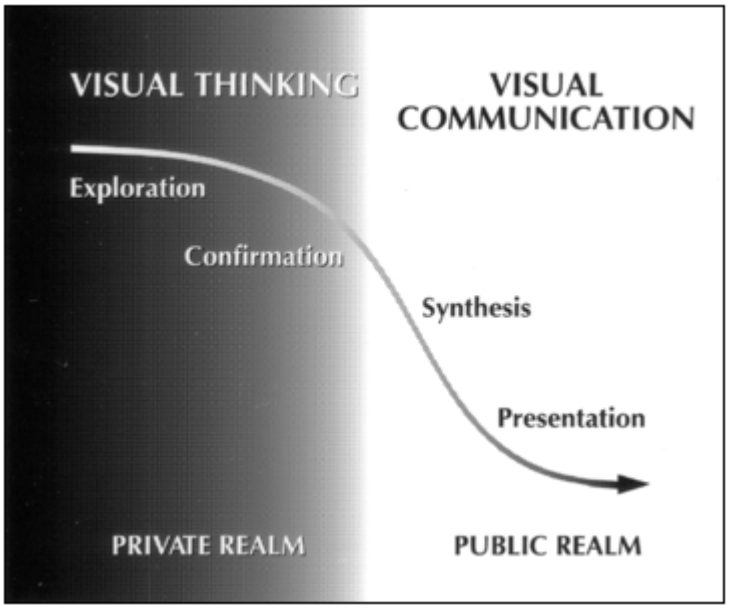


Figure 2.6 Role of maps in scientific visualisation (DiBiase, 1990)

In a parallel effort trying to address such change, MacEachren and Ganter (1990, p.70) develop a cognitive model that identifies the key aspects of the interaction between a user and a visualisation that occurs during a map-based visual analysis process (Figure 2.7). This model shows a pattern-matching approach with "high level of interaction between viewer and map display and its emphasis on searching for unknown patterns versus interpreting a predetermined message (MachEachren and Ganter, 1990)." The key of this model is on the development of cartographic visualisation for pattern identification as well as on the potential of visualisation flaw. The associated topic of data quality and reliability issues in visualisation also

triggered a series of research later in the field (Buttenfield and Beard, 1994; Fisher, 1994).

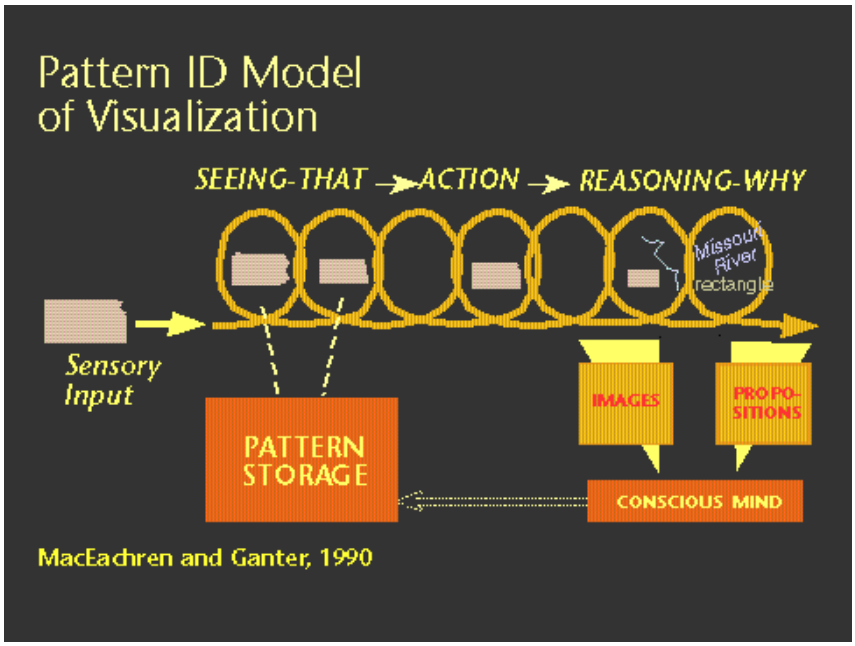


Figure 2.7 Pattern-ID model of cartographic visualisation (MacEachren and Ganter, 1990)

Taylor (1991a) explores the place of visualisation in the structure of cartography as a discipline. He places visualisation as the centre of contemporary cartography, as the meeting ground of research on cartographic cognition, communication and formalism. These aspects associated with visualisation are further illustrated as a triangle-like graph in his book, as shown in Figure 2.8a. In this sense, cartographic visualisation becomes the field of applying computer-aided mapping to enhance cartographic analysis and communication. Taylor (1991a) that among these three aspects of visualisation, the attention to formalism had dominated the discipline at the expense of cognitive and communication issues. A modification of the model (Figure 2.8b) appears later (Taylor, 1994), where he urges for considering visualisation as a distinct, rather than equal, development in cartography impacting on each of the above three aspects.

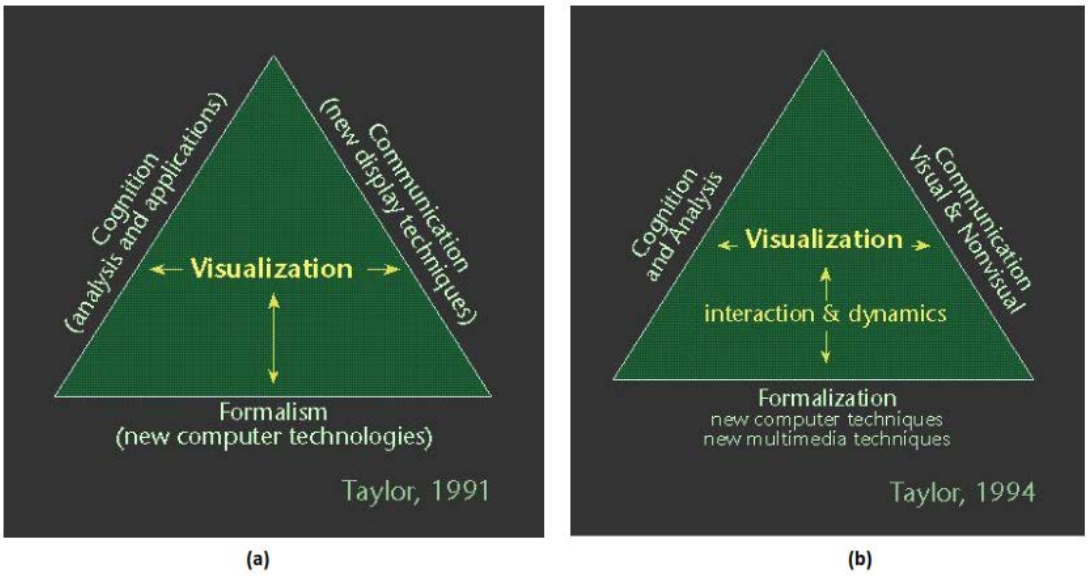


Figure 2.8 Conception of visualisation in cartography (a) and its revised version (b) (Taylor, 1991a; 1994)

The concepts of the "private" and the "public" realms, as proposed by Dibiase in 1990, are elaborated by MacEachren (1995, p.358). Here visualisation and communication are placed as end points on a continuum, which he depits as a diagonal line of a cube box (Figure 2.9), whose three edges represent task, interaction and users respectively. In such a cubic map-use space, visualisation and communication occupy opposite poles. In this conception, visualisation is considered as the complement of communication. All mapping applications would involve both visualisation (visual thinking) and communication (information transfer), whereas the use of an application could vary along this gradient depending on what is emphasised. By this MacEachren (1994, p.5) stresses the shift from knowledge construction to information sharing as,

> *"…display use starts without hypotheses about the geospatial data and the visualisation tools assist in an interactive, unencumbered search for structures and trends, with one goal being to prompt hypotheses. Maps and graphics in this context do more than make data visible, they are active instruments in the users' thinking process."*

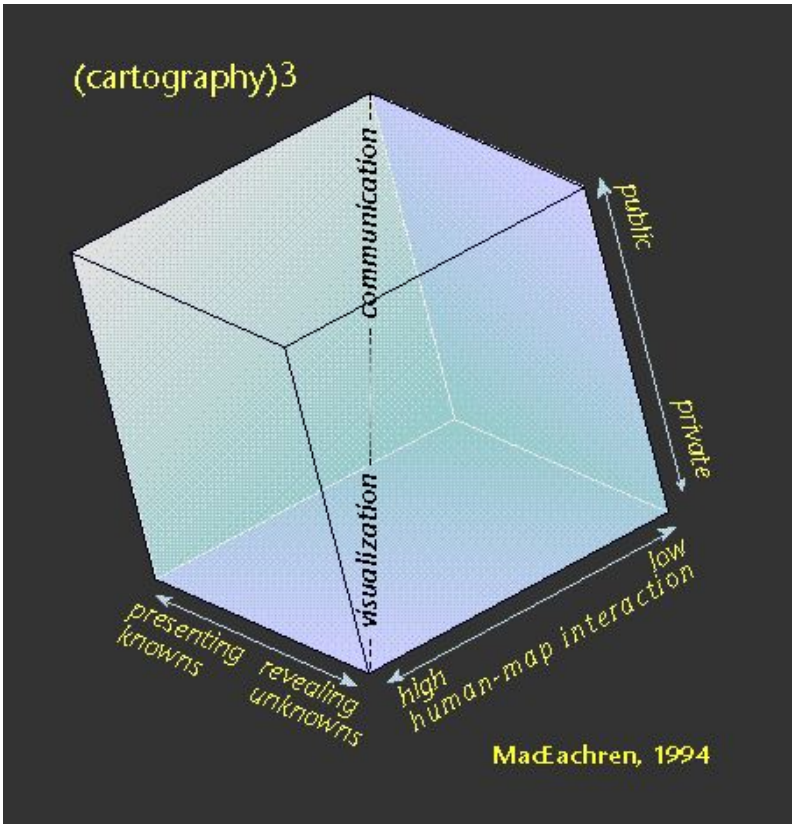


Figure 2.9 The cartographic use cube (MacEachren, 1994)

He further explains the corners of the cube through a matrix (Figure 2.10). Communication-oriented cartography emphasises the use of maps with low interaction designed for public use to extract specific pieces of existing information (e.g., online map service such as Google Map), whereas visualisation-oriented cartography targets the other end, which is to apply highly interactive mapping techniques for individuals or small groups to support hypothesis generation, analysis and decision-making (e.g., spatial analyst of ArcGIS). Efforts of cartographic visualisation research focus on the combining of both.

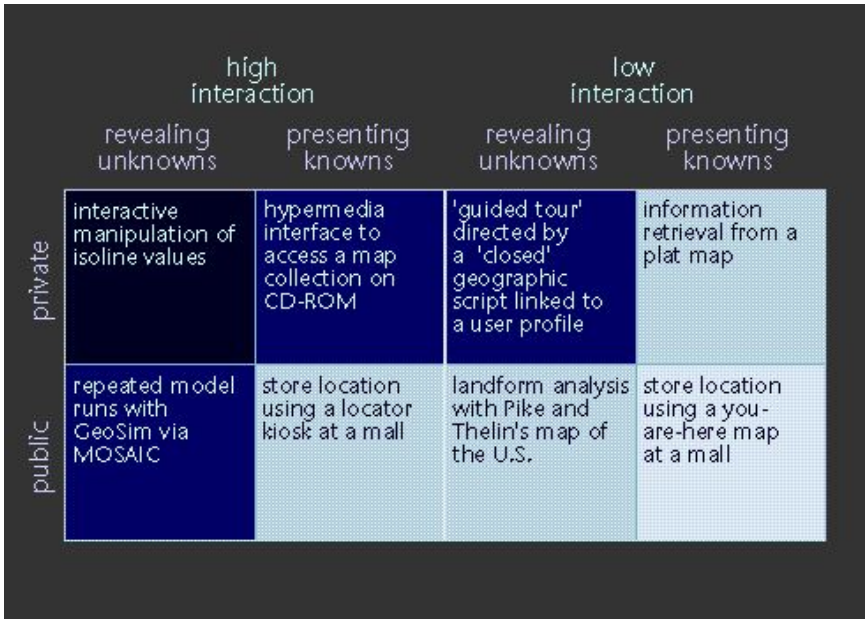


Figure 2.10 The matrix that explains the cartographic use cube (MacEachren, 1994)

In 1995, the International Cartography Association (ICA) established the ICA Commission on GVIS, which mainly focuses on the use of interactive maps and cartographic techniques to support visual analysis of complex, voluminous and heterogeneous information involving measurements made in space and time. In 1997 the Commission introduced a comprehensive research agenda that aimed to set up those priorities of research that would develop GVIS in the 21st century (MacEachren and Kraak, 1997; Table 2.1). The active research activities on cartographic visualisation application have made a great contribution to the evolution of GVIS conception. Contemporary cartographic studies often include electronic map, map animation, multi-media electronic atlas, dynamic interactive map and the design and production of virtual reality mapping. In contrast, GIS visualisation focuses more on human-computer interaction, mass data processing and management, temporal-spatial data interpolation, visual data model design, 3D and multi-dimensional display and analysis, dynamic simulation and hyper media technologies.

Table 2.1 Research agenda of ICA Commission on Visualisation for the 21st century (MacEachren and Kraak, 1997)

1. Representation	2. Interface Design
1.1 Extending the object of representation	**2.1 Typology of visualisation operations**
1.2 Extending forms of representation	**2.2 Controls for operations**
	2.3 Facilitating information access in complex hyperlink information archives
	2.4 Intelligent GeoAgents
	2.5 Collaborative visualisation
3. Database-visualisation links	**4. Cognitive aspects of visualisation tool use**
3.1 GIS-GVis integration	**4.1 Cognitive aspects of dynamic representation**
	4.2 3D representation and virtuality
	4.3 Schemata, metaphors and human – computer interaction
	4.4 Hypermedia navigation
	4.5 Expert – novice distinctions
	4.6 Influence of GVis methods on the scientific process/science understanding
	4.7 Role of visualisation in decision-making

Parallel to the maturing of the conception and theoretical foundation, GVIS enters a rapid innovation period since the end of last decade. This innovation has been greatly pushed forward by the rapid development of GIS. Figure 2.11 illustrates the major influential GVIS applications developed during this period, namely CDV (Dykes, 1998), Descartes (Andrienko and Andrienko, 1999), SAGE (Haining, *et al.*, 2000), CommonGIS (Andrienko, *et al.*, 2002), GeoViz (Gahegan, *et al.*, 2002), GGobi (Swayne, *et al.*, 2003), SomVis (Guo, *et al.*, 2005), ESTAT (Robinson, 2005), GeoDa (Anselin, *et al.*, 2006), Improvise (Weaver, 2006), STARS, GAV (Jern, *et al.*, 2007) and commercial specialised GVIS platforms such as GeoViz, DecisionSite, Instant Atlas, Spatial Key, MapAnalyst, VSM, C-Vu Project, Terrain Bender, Spatial FX and VNS 3. Each block represents one product and the different elevation of these blocks indicates whether functionally they are more like a cartographic visualisation or data visualisation. For example, GeoDa is powerful at spatial regression (Figure 2.12), while VNS is good at creating 3D immersive environment (Figure 2.13). Most of these products are of limited use and only by professional analysts in order to process large and complicated datasets and help discover patterns through intensive computation. Products like Google Map, on the other hand, are the sort of GVIS applications that are aimed at a larger and wider audience.

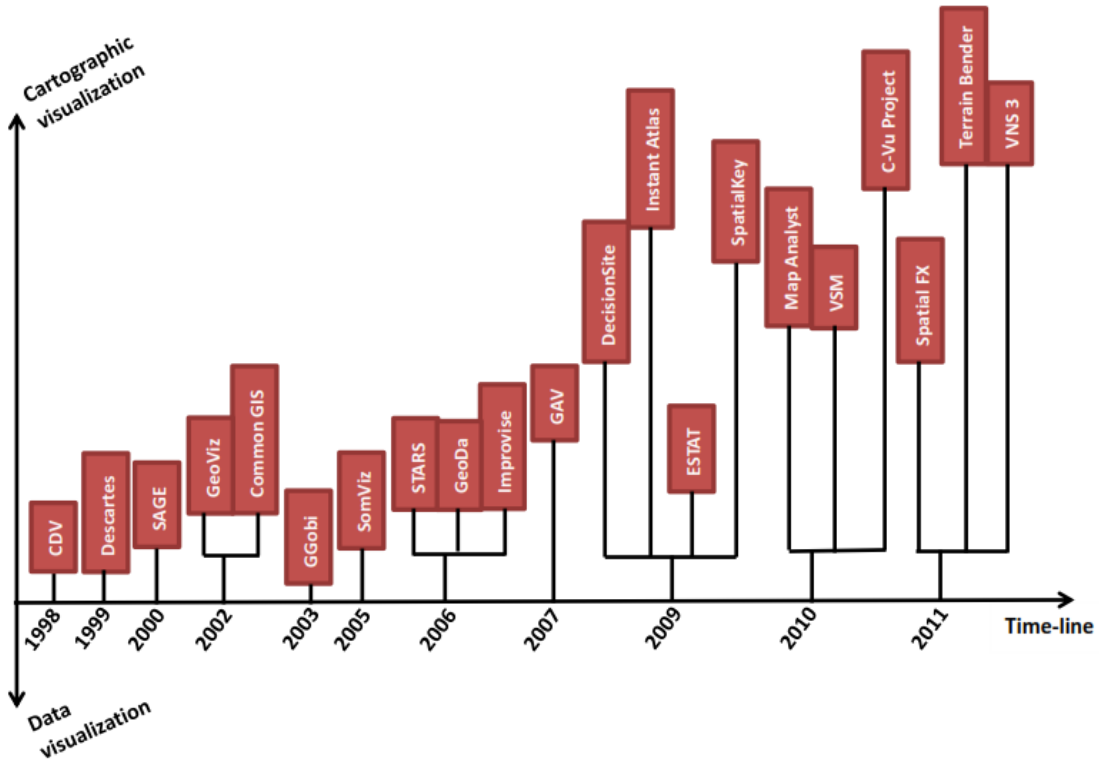


Figure 2.11 Principal examples of GVIS applications from the last decade

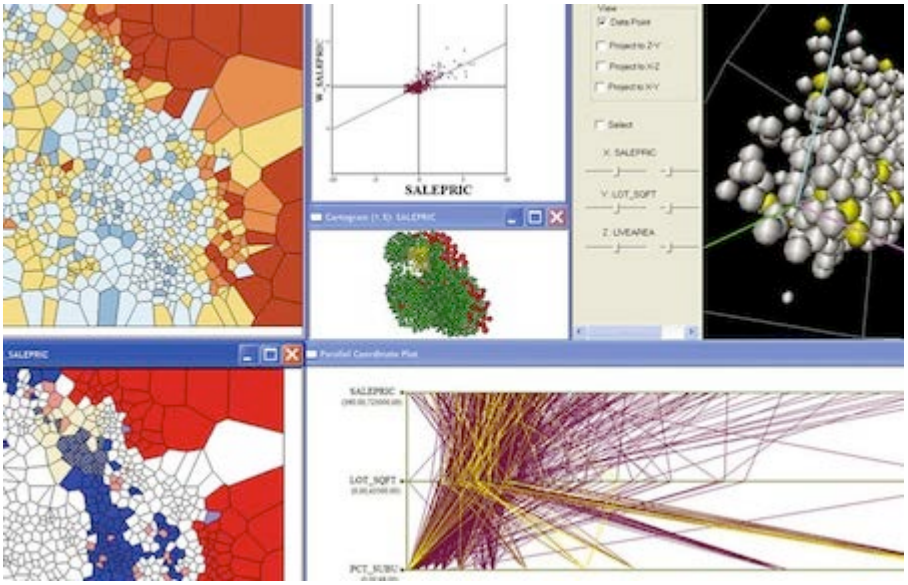


Figure 2.12 GeoDa used for spatial regression / spatial econometrics (Anselin, *et al.,* 2006)

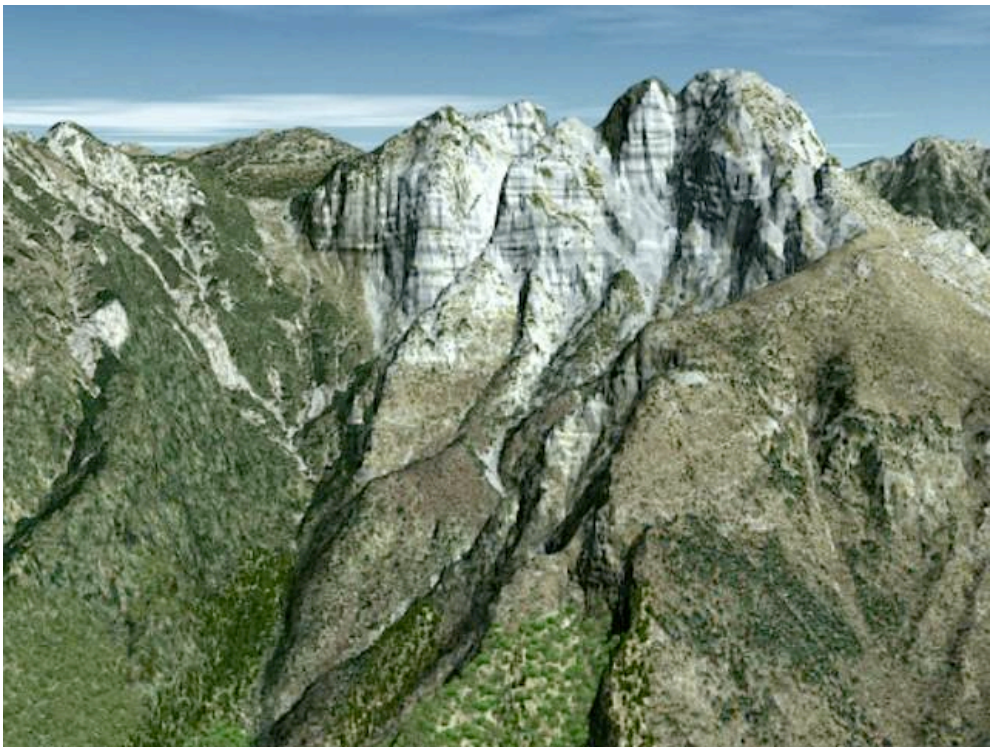


Figure 2.13 VNS used in creating animation for the Italian Dolomiti Bellunesi National Park (3D Nature, n.d.)

GVIS is emerging as a composite enterprise that integrates the heritage of cartography, the essence of GIS as well as inputs from other related fields and "*envisages the use of multiple components compromising both spatial and non-spatial elements to achieve the exploratory objectives of its users* (Lloyd, 2009, p.29)." Given its multi-disciplinary nature and combination of different characteristics, a knowledge gap has been formed between practitioners and end users and becomes the active field for follow-up studies (van Wijk, 2006). Modern studies on GVIS conception put increasing efforts on its characteristics reflected particularly in the human-display interaction processes. For example, Marsh (2007) identifies a number of factors that help characterize GVIS, which are divided into four categories – users, interaction, tools and layout, which are the four key aspects used to differentiate HCI applications (Figure 2.14). The position of the lines in this graph indicates whether the software places an emphasis on certain aspects. Most of the differences between GVIS and InfoVis fall into the latter two categories, such as technological change, multiple views, display constraints, scales, etc. and they are the features that make GVIS special.

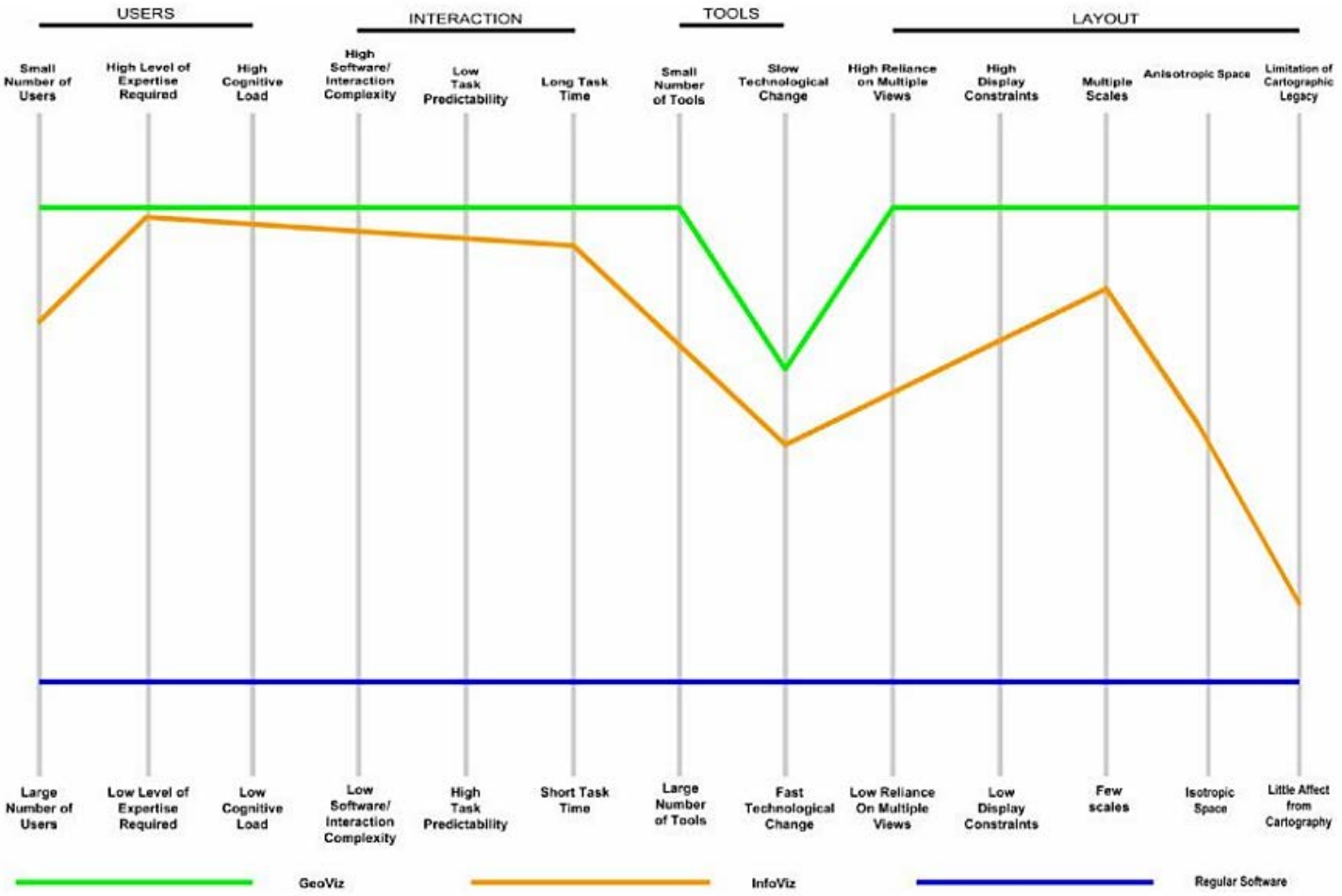


Figure 2.14 Qualitative comparison of the differences between GVIS, InfoViz and regular software (Marsh, 2007, p.32)

A more recent and inspiring exploration of GVIS conceptualization comes from Amstrong and Densham (2008), who state that the intra-group comparison of maps is not necessarily covered by DiBiase's classic model. They claim that DiBiase's framework should be extended with group decision-making contexts, which led to the adding of a third realm (Figure 2.15). With this extra realm, it is emphasised that the current decision-making process is increasingly collaborative, which leads to increasing cognitive complexity due to the combination of different individual's input as well as the associated consensus building process. This new "*evaluative realm*", as a unique part of group decision-making, contains decision re-confirmation and summarization.

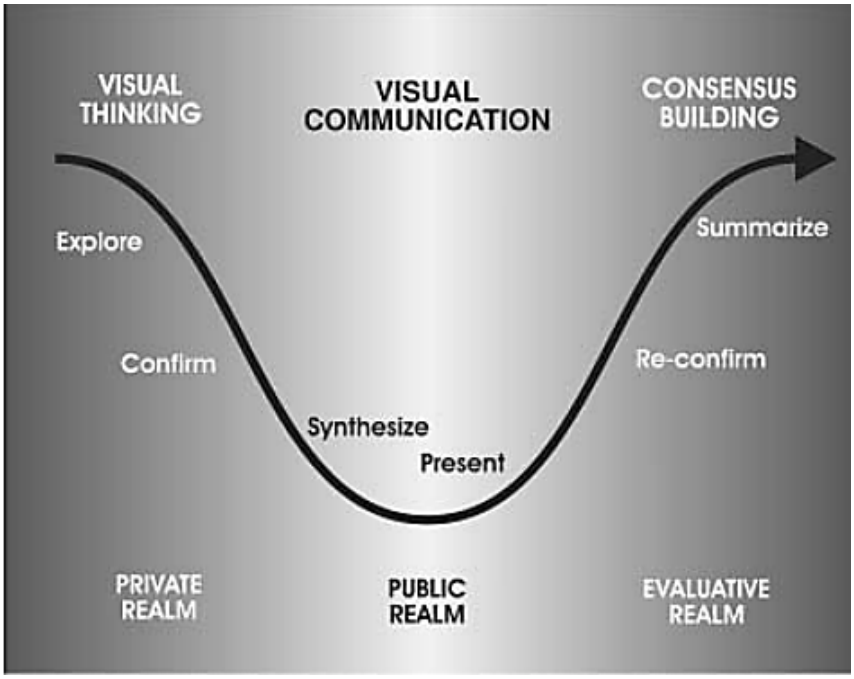


Figure 2.15 Extending DiBiase's model with additional evaluative realm (Amstrong and Densham, 2008)

2.3 Development of Geovisualisation

2.3.1 The evolving functionality

According to MacEachren and Kraak's definition, it is required that GVIS design pays particular attention to the interface between computer and user, as well as the actual usage of the products. In a GVIS environment, maps are used not only to present the spatial information, but also to stimulate users' visual thinking about those spatial relationships and patterns through viewing geospatial dataset in a number of different ways. Early GVIS applications usually provide an orthographic viewing angle – looking straight down from above – which performs poorly in terms of enabling such stimulation. However, GVIS is able to provide users with many more choices regarding seeing and understanding the data and reducing the mental constraints (Keller and Keller, 1993). Choosing an alternative method of visualising data could bring a better understanding of the information, such as showing a video of a piece of landscape or an interesting story of the place next to a topographic map. Similarly new and creative photographs and graphics can offer different insights into the interest information contained in maps and they are likely to pose more and stronger impacts than traditional mapping methods.

In 1988, former U.S. Vice President Al Gore outlined the concept of Digital Earth and looked into the future of a geographically data-rich and data-interactive globe. Wood (1992) anticipated that the world would become a map-saturated world and by saying this, he did not only refer to the increasing use of conventional maps, but also the tremendous potential of map-like spatial media such as the aerial photograph and 3D models. GVIS systems now can cover a wide range of scales of data, from individual buildings up to vast landscapes. Some of these systems use conventional cartographic design, while many employ modern visual

elements. Some applications can be very effective but many reveal poor design, with weaknesses in r layout, positioning and provision of tool buttons and choice of colour theme. A lot of the visualisations can serve practical uses for scientific analysis, but many tools could be "useless" on this aspect. This diversity of GVIS approaches is summarised in Dodge *et al.* (2008) into three broad categories:

- "Looking" – the presentation graphics, thematic maps and charts which display data according to spatial coordinates;
- "Querying" – the visual interfaces designed for information access; and
- "Questioning" – the full visual discovery and modelling structures.

In this context, the functionality of a GVIS environment is to enable users with the ability to explore data with alternative views. The technologies behind GVIS are usually meant to deal with one specific geographic problem. One of the very first visual exploration tool for geospatial data was invented by Mark Monmonier in 1989. In this tool, a link is established between the scatterplots, a map and a temporal bar (Monmonier, 1990, p.42). Moving either one of the three brushes will cause a simultaneous response of the other two. This work became one of the earliest experiments of alternative visualisation approaches in presenting geospatial data.

As concluded by Kraak and Ormeling (2003), generally speaking, an ideal GVIS system should provide facilities for several key functionalities, namely:

- Basic display. The main body of the tool are map displays which allow users to pan, zoom, rotate, etc. so as to provide an interactive mapping environment.
- Orientation and identification. They are important because users should always be

able to know where the view is located (orientation) and what those symbols in the view represent (identification).

- Query data. The users should have access to the spatial database behind the displays and perform queries to view the data required
- Multi-scale. GVIS usually contain different datasets and it is unlikely that these data will have the same level of abstraction. The solution to this is also called generalization in geo-information studies.
- Re-expression. To stimulate visual thinking stated earlier, the visualisation tool should provide more than conventional cartographic display, in other words, different mapping methods for displaying will be provided or users will have the option to manipulate the data behind the map, such as re-classification of the data.
- Multiple dynamically linked views. This emphasises the need for providing a combination of multimedia in displaying the geospatial data. Different windows will be used to show different aspects of the data and users will view and interact in the windows. The idea behind this is indeed the brushing techniques already mentioned above.
- Animation. Maps can be “shorthanded” when presenting complex geographic processes and expressed more effectively through map animation. Animations are often used when the temporal changes of the spatial data are important.

Gewin (2004, p.376) claims that users “have turned computer mapping into a powerful decision making tool” and he believes that ”geo-technology” has become the third most rapidly developing new technology after “bio-technology” and “nano-technology”. Thanks to the

emergence of powerful hardware, software and new technologies applied to visualisation, cartography and GIS, GVIS has been witnessing a number of new changes. These may be summarised as follows:

Being mobile is the first growing field that might completely change people's way of using GVIS tools in the future (Liarokapis, 2005). The term expresses how mobile technology extends computer applications to various different types of mobile terminals including tablet computers, vehicle-mounted devices, Windows smart phones and Apple iOS devices. Mobile technology has already become an essential element in the field of GIS, where mobile devices are available for spatial data collection, with the help of GPS and simple processing on the field. A relevant field of mobile technology is the Location Based Service (LBS), or location aware service, that focuses on providing precise and pervasive spatial information via mobile and field units (Liarokapis, *et al.* 2005). Most GIS software vendors now offer mobile versions of their products.

The second change is **being real-time**, which means all the collecting, processing, storing, analysing and representing activities in relation to spatial data which have to be operated simultaneously with the evolvement of events. This is particularly important in terms of visualising dynamic and complex geographic events such as a cyclone disaster. A real-time display of a cyclone can help calculate the moving route and create an emergency evacuation plan (Zerger and Smith, 2003). If the real-time technology is matured for daily use, imagine the future where people in Cork would consult an online map service (e.g., Google Map) for real-time road traffic conditions in the city before they decide their immediate travel plan. The realization of real-time visualisation will ask for a fast and seamless way to capture, analyse,

process and transmit data, as well as the need for high-performance hardware and software.

Working in the "Cloud" is the very latest growing field driven by "Cloud Computing". The core of cloud computing is a new approach to increase capacity or add capabilities for computing systems in processing tasks (Knorr and Gruman, 2011). Cloud computing offers an optimized solution for some of the key elements of GVIS, such as mass data storage and retrieval, data share and complex modelling. Serving GVIS applications in the cloud can deploy the tools and spatial information more easily and effectively, significantly reduce the hardware and software requirements and improve the accessibility of the outputs (Oestreich, 2009). Therefore it is very much like an updated – more flexible and more extensive – web-based service.

Being easy to use is another important goal for GIS in the near future. GIS used to be a tool only for professionals, but now it is being made available and accessible to a much wider audience (Marble, 1999). Considering the diverse characteristics of the audience, a very challenging task for GIS is to simplify the complexity of the technology use and improve user experience. The improvement could be made in any aspect of the product, for example, a friendlier user interface, a more efficient system response, a re-designed geo-processing tool, optimized visual effects, etc. The significance of doing this is to provide users with ready-to-go and out-of-box tools and avoid complex learning, training and working processes.

Supporting cognition is the change that aims to help users understand known and unknown patterns through the use of different types of visualisation technologies (Lloyd, 1989), which has been amplified in GVIS particularly when used to explore complex geographic events. GVIS does not only serve spatial-temporal related visualisations (e.g., all types of mapping), but

also associated data visualisations (e.g., data tables, graphs). A GVIS system usually includes both so that users are able to quickly view data elements from multiple perspectives. Many of the new GVIS techniques are designed with the aim of delivering better cognitive functions (Lloyd, 1989; Peterson, 1994). One example of this is the colour-based highlighting technique (Figure 2.16) which provides a special visual cue during rollover on a data element, which is defined as the transient visual effect that is applied on data items across views when a mouse cursor or other input device has moved overhead (Robinson, 2006; 2011). As suggested by Baldonado *et al.* (2000, p.116), the design should use "*perceptual cues to make relationships among views more apparent to the user.*"

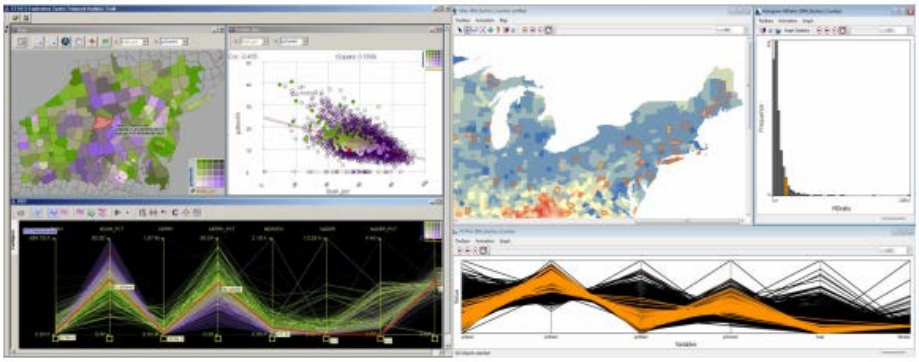


Figure 2.16 Colour highlighting used in ESTAT (left) and STIS (right) (Robinson, 2006)

The next change is **being dynamic and animated**, which refers to the fact that future GVIS tend to have a more dynamic and animated looking interface rather than static as traditional cartography does (DiBiase, *et al.*, 1992; Clarke, *et al.*, 1997). Many of today's significant research challenges, such as environment monitoring and resource management, depend on capturing, analysing and representing dynamic geographic processes, which increase the demands for technical tools to recognize and track changes in complex physical systems (Harrower and Sheesley, 2005). There are two types of animation: temporal animation and non-

temporal animation. The former one deals with the depiction of dynamic events in chronological order, for example population growth, diffusion of diseases, fire spreads and glacier movements, while the latter one shows attribute changes of a dynamic phenomenon, for example, a drive-through in between the 3D buildings (animation of camera motion). It is emphasised by Ogao and Kraak (2002, p.23) that animations

> *"enable one to deal with real world processes as a whole rather than as instances of time. This ability, therefore, makes them intuitively effective in conveying dynamic environment phenomena."*

A good example of a dynamic and animated mapping tool can be found from Arnaud and Davoine (2009) that displays spatial and temporal relations between multiple hazardous events, where users can see the expanding of flooded areas and falling of rocks in animation during one specific flood event (Figure 2.17).

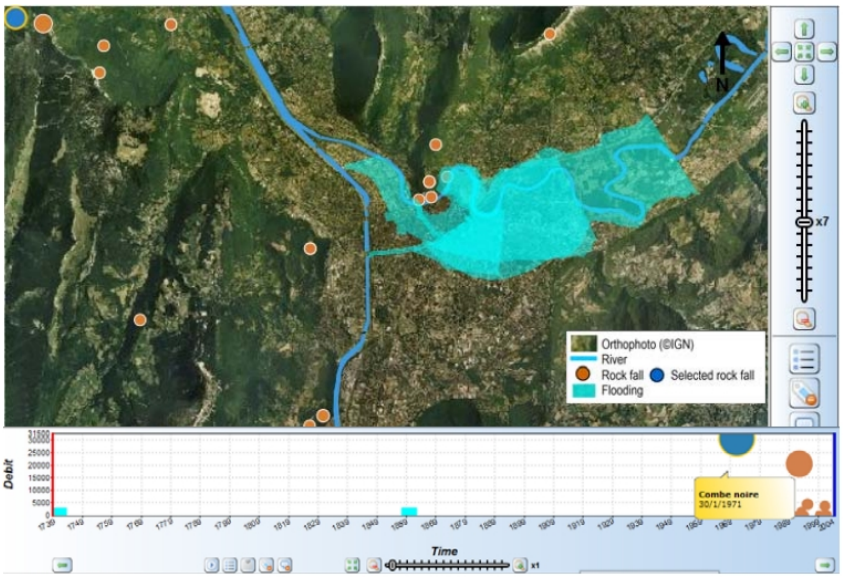


Figure 2.17 Displaying flooding and rock falling together (Arnaud and Davoine, 2009)

The last but not the least change is **being realistic and immersive**, which suggests that contemporary GVIS technologies now concentrate on reproducing realistic features from the real world. The adoption, combination and integration of different modelling techniques have

helped GVIS make progress towards advanced realism and immersion of the viewer in the scene. It is believed that doing so can help users gain a better spatial perception of the characteristics of those visualised features. The use of 3D representation has been the most significant leap taken towards realism and immersion augmentation, which will be extended as a separate discussion in the next section. At the same time, the use of Virtual Reality (VR) and Augmented Reality (AR), which are basically advanced 3D, but growing to be the future of GVIS in this aspect. Many researchers are now adopting AR and VR to investigate research problems, which have been dealt with by other GVIS techniques before, with the purpose of looking for optimized decision making. For example, in the case of flooding studies, VR has so far delivered a satisfying performance both in the area of enhancing visualisation and evaluation (Gouda, *et al.*, 2002; Zhang, *et al.*, 2010) and in the area of public communication and participation (ESPACE, 2006).

2.3.2 "The great leap" – from 2D to 3D

It was stated at the very beginning of the thesis that this whole research was motivated by the controversy surrounding 3D cinematics. The extra visual dimension increases people's capacity to tell a story visually. The same transition is happening in the mapping geographic spaces. Due to the availability of 3D, the amount of information that a map can carry has significantly increased, the techniques that cartographers use to make a map have been so modernised and the way a map is displayed and used has also changed dramatically. This section looks specifically at the pros and cons of this most influential innovation of GVIS.

The introduction of the third dimension in the field of GVIS is driven by the wide use of interactive 3D computer graphics. Almost half a century ago, Sutherland (1964) created the

Sketchpad system - a CAD-like toolkit that generated three-dimensional drawings. The emerging use of the third dimension which developed subsequently was reviewed by McCormick, *et al.* (1987) and by Raper (1989). The booming period of interactive 3D computer graphics began from the 1990s in the areas of such as architectural design, general industrial design and film-making and was really made affordable and became a widely used application by video game creators[1]. As the pioneer of contemporary 3D development, the gaming industry has immersed itself into the joy of creating 3D worlds, most of which are only fictional rather than mirroring the real world. But interestingly many of those advanced gaming engines were later introduced into the GVIS sphere and the purpose of such collaboration was to create more detailed and realistic 3D models and enhance visual effects (e.g., illumination, water reflection). At the same time, the computer-aided design area started to embrace the appearance of many specialized 3D software such as 3ds Max, Maya and Softimage, which were applied across the manufacturing, architecture, building, construction and media and entertainment industries. Thanks to the innovation happening in these areas, future GVIS tools can host powerful spatial exploration, perception and analytical functions with an incredible photo-realistic interface.

Technological breakthroughs in 3D data collection, automation and management advancements enable the display of large amount of photo-realistic information, with which users can make fast and correct responses. In other words, 3D visualisation helps transform those highly abstract concepts and spatial phenomena beyond immediate recognition into visual contents. Increasing numbers of areas have become the active playground of 3D visualisation,

[1] Generally it is believed that *Wolfenstein 3D*, a first-person shooter game, which was released by id Software in 1992, triggered the mass development of 3D computer games. This success was followed in 1993 by *Doom* and in 1996 by *Quake* with full 3D engine (id Software, 2007).

for example underground structure, historic event inversion, future development prediction and many complex spatial-temporal phenomena such as typhoon evolution, flooding and earthquake monitoring, the spatial impacts of air pollution, radiation, noise transmission and temperature and wind site variation (Batty, *et al.*, 2001; Lee, *et al.*, 2002; Pleizier, *et al.*, 2003; Kim, *et al.*, 2006; Mysorekar, 2006; Pajorova, 2007).

Most of the new and improved 3D functionalities of GIS systems are believed to be in the visual enhancement sphere (Haklay, 2002). 3D visualisation is increasingly becoming an effective medium for users with various backgrounds to communicate and analyse spatial information, for example, in military information systems (Environmental Systems Research Inc., 2005). 3D GIS provides different types of interactive dynamic viewing functions, for example, *fly-over* is the function to quickly investigate the general spatial information such as topographic variation and surface features' distribution while *walk-through* is another function to identify micro change of landscape and details of surface features (Figure 2.18). In order to support these interactions, providing multiple viewpoints and multiple viewing modes have become the typical interface features of a 3D GVIS environment (Verbree, *et al.*, 1999; Zlatanova, *et al.*, 2002).

Figure 2.18 "Fly-over (a)" and "walk-through (b)" of visualising the town Tübingen, Germany (Max-Planck-Gesellschaft zur Förderung der Wissenschaften e.V. n.d.)

Interactive 3D visualisation can never succeed without the support of powerful computer software and hardware. Particularly regarding to a fully immersive 3D visualisation platform, the essential support usually includes multiple flat screens or curved screens, projectors as well as computers/workstations. Such specialized high-end hardware is not affordable by most users and software associated with such professional platforms often requires large amounts of training. Many practitioners are dedicating to make 3D spatial information more accessible to ordinary users, the visualisation software packages more affordable and thus advanced 3D effects realised with basic software and hardware requirements.

However looking beyond the considerable deployment of the third dimension in contemporary GVIS, there are two good reasons to reconsider the use of 3D, just like to reconsider the use of 3D in film industry. The first reason is the danger of repeating the misconception of technology-first, or sometimes called 3D for 3D's sake tendency (Shepherd, 2008). This issue is closely linked with another very popular term in scientific research – technology-driven, which means to use a technology simply for using it. The core issue in this aspect is the recognition of circumstances in which 3D is more appropriate than 2D. The second reason is that 3D visualisation has only recently become part of the mainstream cartographic and GIS systems and most current practices are still rooted in the 2D legacy. To undertake a critical view towards the effectiveness of 3D visual data analysis is thus hugely important, given the fact that many GIS and GVIS practitioners have not fully appreciated the principles of effective data visualisation.

2D representation of the 3D world usually leads to interpretive drawbacks. Specifically,

the highly abstracted topography and symbols require a significant amount of learning efforts by occasional GVIS users. Besides, 2D maps provide only fixed vertical viewpoints, which is completely different from the common way of people seeing the world. This could become a considerable problem when symbols are too abstract to be recognized in comparison with real world objects. Since the 1990s, scientists have started to claim that a natural or familiar way of presenting data which users find easy and comfortable to interpret (Robertson, 1991), still remains the motivation for continuous efforts devoted to improving the realism of visualisation. In many areas such as urban planning (Döllner, *et al.*, 2006; Figure 2.19), landscape design, tourism and power grids, task processing have been proven to be supported much better in 3D scenes (Shepherd, 2008).

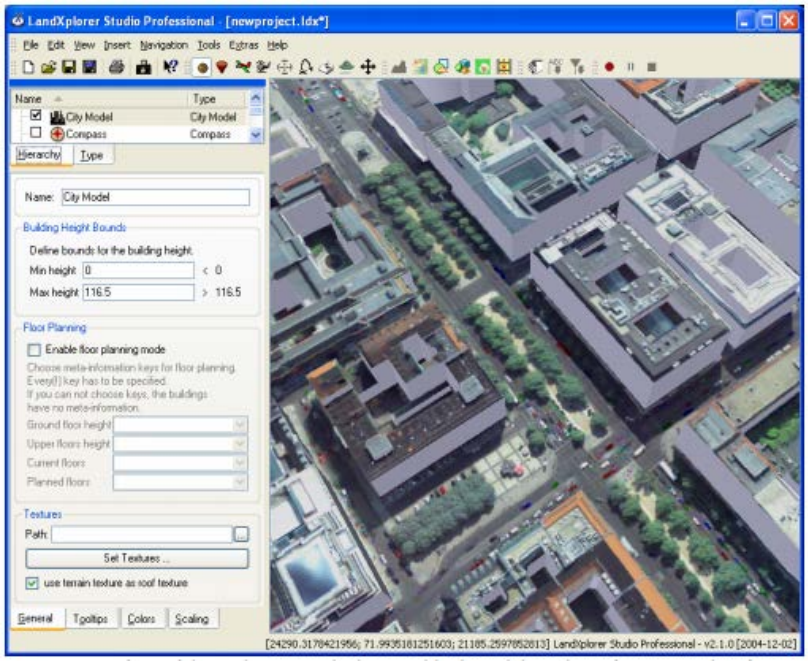


Figure 2.19 User interface of authoring tool of a 3D city planning toolkit (Döllner, *et al.*, 2006)

The three dimensions of space are usually referenced according to the three axes (*x*, *y* and *z*) of cartesian co-ordinate system for cartographic or mathematical modelling purposes (Longley, *et al.*, 2005). The third dimension, representing the height (or Z-axis value), will be an

attribute of any *x*, *y* location when used in a 2D spatial database, but in 3D modelling there may be any number of permissible z values for a single x, y pair. This makes the data truly three-dimensional and allows both much richer visualisation and also more complex spatial modelling. For example, the concept of a *skyline* is very important for city planning, especially when designers are trying to "squeeze" new developments (e.g., landmarks) under a proposed curve.

However, a currently-unsolved technical problem is that most of the display terminals are still designed for 2D visualisation. The perspective view, which is used by 2.5D and 3D visualisations, makes it difficult to make accurate visual comparison of objects in a 3D scene. This problem was discovered in the early days when 3D display was just introduced into the mapping area (Philips and Noyes, 1978). It is very unlikely that flat visual terminals would be replaced soon with fully 3D oriented, thus this projection of a 3D representation onto a 2D plane will continue the problem where depth is likely to be underestimated by the viewer (Plumlee and Ware, 2003; Swan, *et al.*, 2007), with an associated loss of the observer's sense of orientation. A critical review regarding the relation between stereo and visual perception was given by Cutting and Vishton (1995), who pointed out that stereo is only one of nine major visual depth cues and certainly not the most important one.

Another issue is the visual interference within 3D scenes. Although 3D visualisation is meant to help show those hidden features, users might still find symbols easily blocked by other symbols to a certain extent in the scene, which means somehow they are not fully revealed. This is due to the alignment of objects in the scene in relation to the user's viewpoint (Figure 2.20). Techniques such as displacement, distortion and transparency provide good solutions to these problems. Luckily this problem can be solved to an extent in an interactive viewing environment,

for example, through rotating objects or moving their viewpoints.

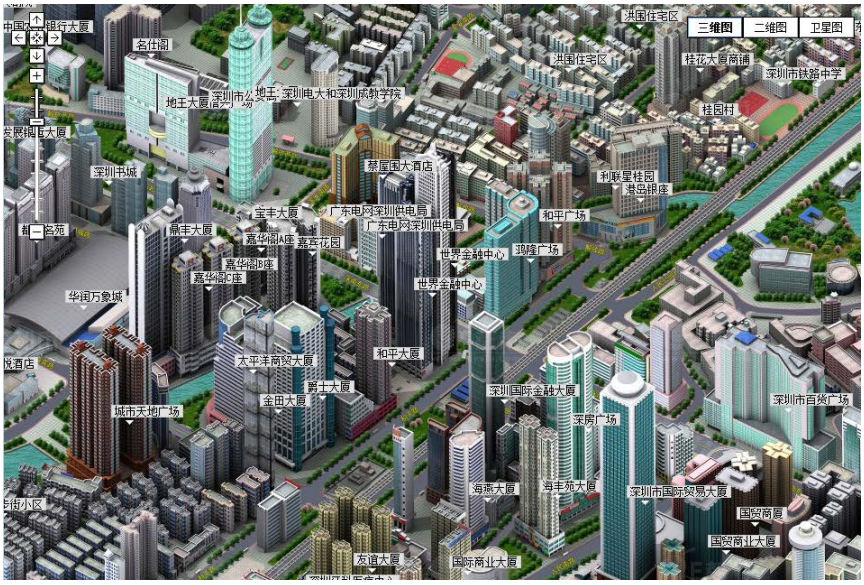


Figure 2.20 To identify hidden features is not easy in a “busy” 3D map (Courtesy of EDuShi)

Traditional 2D maps contain a lot of textual messages that help identify or emphasise the features, but annotations are not used extensively in most current 3D visualisations. The major reason behind this is the technical difficulty of displaying texts in a satisfying way within 3D scenes. For example, street names are always labelled very carefully in 2D mapping, but in a 3D mapping context, they are not easily seen. Figure 2.21 presents an example showing the same area (Parliament Square, London) as shown in 2D Bing Maps and 3D Google Earth respectively. It is very easy to capture the names of all streets in the 2D scene and the variable font size helps make them easier to read. These names, however, are not displayed in the 3D scene. By leapfrogging from 2D to 3D in GVIS, visualisation systems have largely solved the problem of displaying a very large amount of objects through employing advanced algorithms and powerful computer hardware. However, the limitation still exists for the number of dimensions (i.e. variables, fields or attributes) to be displayed in a 3D viewer. Empirical studies have found that graphic systems can only display a limited number of variables in a single scene.

This remains the case with 3D and augmented reality visualisations (Shepherd, 2008). A popular strategy, used widely in the 3D data visualisation realm, developed to address this problem is to combine spatial and non-spatial visualisation in a multiple linked views environment (Guo, *et al.*, 2005). Finding a satisfying way to incorporate the visualisation of other variables in fully immersive 3D environments still remains a technical difficulty.

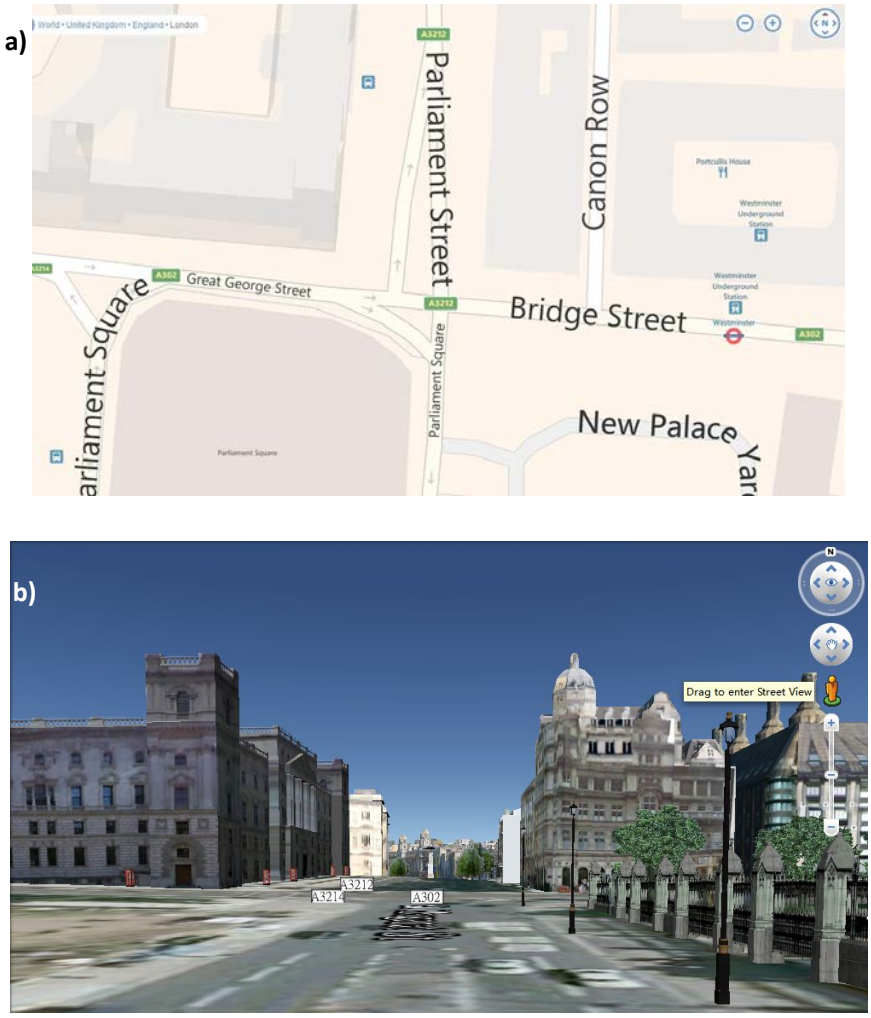


Figure 2.21 a) 2D Bing Map (and b) 3D Google Earth display of a street scene near Parliament Square, London, UK, showing how street names are displayed in each (Courtesy of Bing Map and Google Map)

A long-term pursuit of 2D GVIS is the depiction of abstract attributes of data (Nöllenburg, 2007, p.261). Traditional cartography can draw on hundreds of years of successful

experience of depicting abstract thematic data. In contrast, the focus of modern 3D mapping continues to be on production of increasingly detailed and realistic images and virtual representation of environments that correspond to geographical features the viewer is likely to observe in reality.

Despite many impressive recent advances and developments in 3D, there is a long way to go before day-today visualisation is completely in 3D format. For GVIS, 3D will be increasingly important in all aspects of development and application, but 2D still plays a significant role in knowledge discovery and decision-making processes. Paul Morin from USGS suggests a correct attitude towards 3D visualisation by stating, “Choose tools carefully, and be seduced by the increased understanding you extract from the data, not the pretty pictures” (as quoted in Rusby, 2008, p.13). Rusby (2008) presents a useful summary and suggested research agenda for addressing current issues and opportunities for 3D visualisation (Table 2.2).

Table 2.2 Issues and opportunities for 3D visualisation (Rusby, 2008)

Data issue	• Effective data management for large-volume and multidimensional dataset, which is particularly true for large spatial database.
	• Data integrity and meta-data particularly for domain data as well as quality control of data input and update.
	• Open systems and open standards for integration of all types of data as well as data sharing and collaboration.
Cost issue	• When expectation is very high but budget is very low, how to also reuse technologies to speed up product development?
Usability	• Intercommunication of application and better cross-platform operation
	• Simple to use, intuitive, easy to learn and flexible, which all refer to the strong need of reflecting human limitations in interface design.
	• Better desktop solutions and wireless solutions.
	• Cultural obstacles regarding how to reflect cultural elements and how to introduce technology into a different culture.
	• 3D glasses has the problem of discomfort.
	• Bring visualisation to the open, which means visualisation should not always stay in dark rooms with noise.
Software/hardware	• Human-interface improvement refers to further advanced technologies such as touch screens, 3D menus and voice command.
	• Performance indicators, which is a question of how do we measure the benefits of employing certain visualisation?
Network	• Communication bandwidth/latency, to be solved in order to support intensive rendering works.
	• Secure connection can be particularly important for sharing highly valuable dataset especially over distance.

2.4 Challenges of GVIS

It is apparent that GVIS becomes a rapidly growing field because people are depending on the technology to cope with geographic problems, which are often complex and dynamic. It has never been an easy job because to visualise a problem usually means to visualise its causes, trends, influences and countermeasures. Therefore the “geo” aspect brings up the complexity of the nature of those problems to be tackled. At the same time, a lot of data and information visualisation techniques have been introduced into the area and yet there has been no solid principles established with regard to the appropriate use of GVIS for spatial perception. The “visualisation” aspect thus leads to the complexity of the techniques to be used to tackle the

problems. Putting the two together explains the “rough” and challenging context of GVIS application and development.

Taking coastal inundation as an example, as developed in greater detail in Section 3, GVIS has to address and resolve several issues, including:

1) The varied application requirements. Studying coastal inundation can be carried out through various application areas such as flooding simulation, vulnerability assessment, water level monitoring, coastal zoning, inventory management, etc. These specific areas will raise different requirements for the actual GVIS products.

2) The complexity of an event. Coast lowland inundation is a consequence of many factors acting at the same time, including local sea-level rise, storm surge, sediment migration, ground sink (due to nature or human behaviour such as underground water extraction). How to display these factors altogether in an effective visually analytical environment still remains a question.

3) The choice between static or dynamic representation. Usually static maps and images still serve as the most effective way of communicating the problems. However inundation is a dynamic process and it requires the presentation of change over time (e.g., water level, flood routing) and the change of the impacts (e.g., inventory damage, lowland loss), where dynamic displays show significant advantages.

4) The use of multiple data source. To present the inundation process, multiple data sources are often required, including such as RS imagery, aerial photograph, field survey and GIS base maps. For applications like flood monitoring and emergency response, real-time data, sometimes obtained through public participatory approaches, are also essential.

5) Availability and use of multiple modelling and display techniques. To display a problem like coast inundation involves the use of different techniques. Presenting the flood in designed visual settings and providing supportive results all ask for specific and unique data processing and geo-computational modelling. Those advanced visualisation environments such as VR and AR are even more demanding on the integration of different techniques.

This leads to the important question of what types of GVIS should be used within such a challenging context, and when is any one type more or less appropriate than another? This research believes that in order to answer all these challenges, GVIS products in the near future will have to become more pictorial, more straightforward, more immersive, more interactive, more convenient and more user-friendly. These “6 Ms” provide goals to be achieved by GVIS development so as to facilitate the transformation from data to information and from information to knowledge. They also remind practitioners of the need for a more important and wiser use of technology, that puts usability high on the research and development agenda. Ths is shown in Figure 2.22, where different factors meet and push forward the need for the “6 Ms” shown in the red box. The blue box underneath emphasises the fact that this complexity calls for the idea of enhancing usability of GVIS design. This provides one of the focal points for the current research, and will be addressed by the concept of Subject-Technology Matching (STM), which will be discussed in detail in later chapters of this thesis.

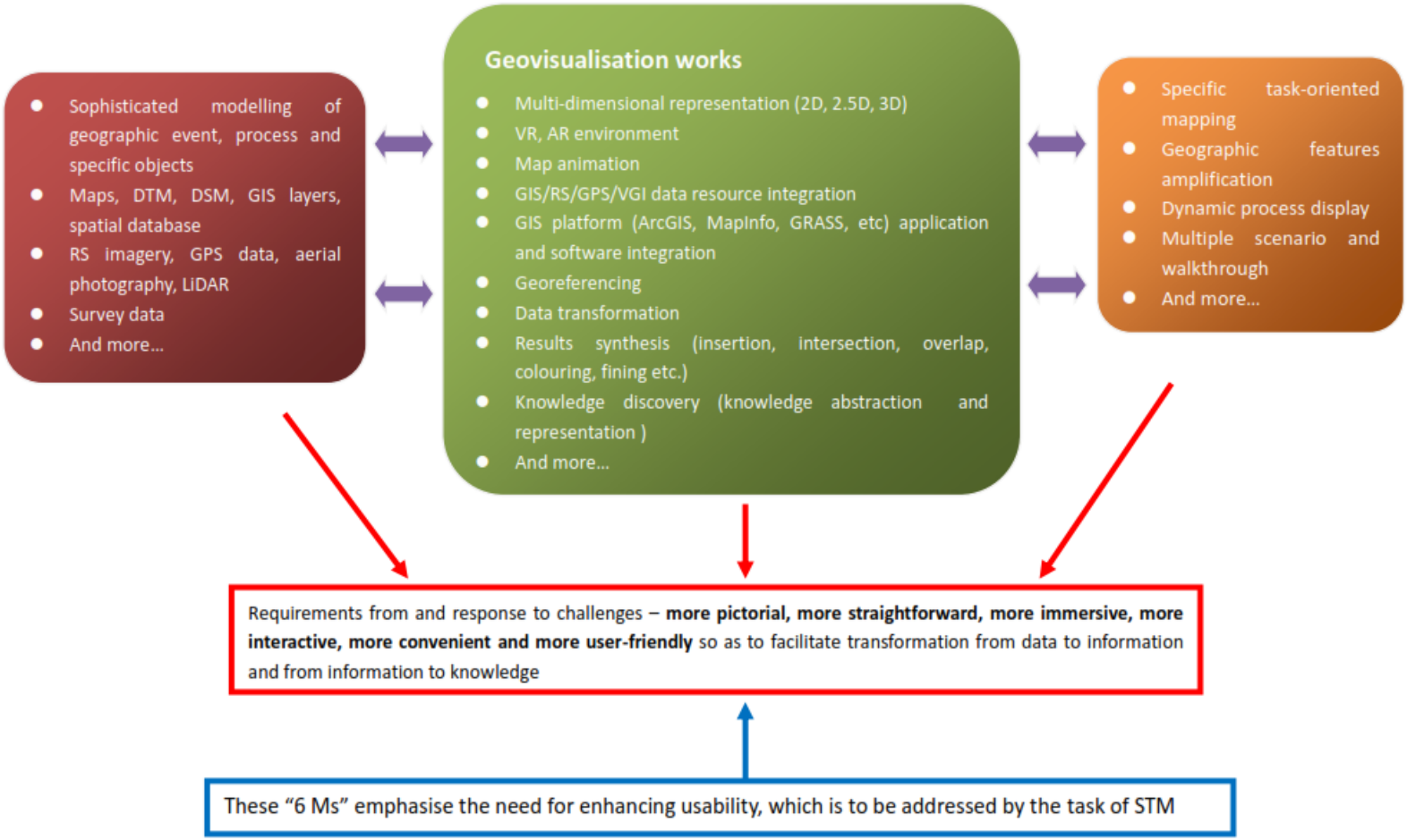


Figure 2.22 The need for addressing usability in the challenging context of GVIS

A number of significant problems remain in the development and use of GVIS. These problems are not because of insufficient technological innovations, but more about the design and development process, and the difficulties of technology being put into practice.

Firstly, design is often reduplicated with low efficiency. This is often due to lack of consultation and promotion for typical technologies, high quality software platforms and successful solutions. In the real world, developers seem to be more interested in developing new technologies to fit specific geographic problems, but less interested in "recycling" the technologies based on substantial evaluation of their performance. How to make visualisation modular, extensible crossing the boundaries of software, devices and individual use is a challenge to be faced (Shalf and Bethel, 2003). In practice, considering the time, manpower and money spent on system development, a critical consultation of good application cases and making use of available technologies and platforms is always a beneficial way to reduce duplicate development and significantly shorten the development cycle.

Secondly, many products still come from a technology-driven development process. It can be noticed that the development is still one way and technology dominated, in other words, the functions of a product are designed to maximize the use of the technology instead of to meet user requirements. New technologies are constantly being used but barely questioned regarding why they are used, although it is clear that new technologies are not always meant to be superior to older technologies. For example, to scientifically monitor deforestation on a large geographic scale would be fairly easy to be worked in a 2D environment, because in a 3D environment it would be hard to observe or measure. It is not sensible either to employ virtual environment for the management system even though that could help visualise tree species and

detailed forest structure.

Thirdly, there is a lack of communication among users, developers and GVIS experts. In a technology-driven development process, there is not enough communication between developers and users. A standard procedure from the beginning to the end would be where users go to the developers and explain their requirements and where developers hand over the product to the users and conduct software tests if necessary. In such a one way process that involves two parties (users and developers), users usually become the passively receiving party after giving out the requirements, thus how to make them more actively involved remains an important question. On the other hand, the participation of GVIS experts is inadequate or even absent in the whole process. The significance of experts as a medium between developers and users has been recognized, whereas exactly how to consolidate the role of experts and facilitate the three-party development process is still uncertain.

Lastly, the usability is still constrained due to a lack of collaboration in the development process. This problem is linked closely to the previous one as here the 'collaboration' does not refer to the teamwork of developers, but the coordinated workflow contributed by the three parties involved. In a development process, visualisation production is mainly carried out by developers and there is no direct involvement by the other two parties. However contributions from the other two parties can be equally critical to the final product output. In this case it has to be clarified what are the specific roles played by and the jobs carried out, by each party. However these issues have not been investigated in depth by recent research.

Therefore in order to cope with these problems, it is important to step back and look into the development process as a whole and see how to scientifically arrange the different

components of the workflow. It is often the case that currently working with geospatial information involves different groups and the coordinated effort by groups has a direct contribution to final outputs. A good GVIS application requires full consideration of the cognitive, social and usability issues of visual interface mediated dialogue, not just between human and computer but also among humans. To bring users to the development and find a mechanism (or another party) to strengthen their collaborative work is a key solution and will becomes a significant move beyond the current “build and they will come” approach.

2.5 Summary

This chapter has reviewed the concept of GVIS including its history, development, application, connection with GVIS, evolution in the 3D arena and these challenges to be addressed in the near future. Pulling all these aspects together provides context and a solid foundation for the discussion in the next chapter. This moves the focus to usability and user-centred design and extends the investigation into how to incorporate usability thinking in GVIS design.

Chapter 3

Usability, User-centred Design and Their Application in Geovisualisation

3.1 Introduction

Usability is an important quality attribute of a user interface, especially for computer-based interactive applications such as websites. For example if a required button is difficult to find, the text on the page is hard to read, or the images are visually boring, users will tend to stop using the site because it cannot meet their needs. Usability thus can be an important condition for survival of a product.

In this sense, the idea of promoting usability needs to be reinforced in the design process, which is then linked to another important term – *user-centred design* (Woodson, 1981; Norman and Draper, 1986; Norman, 1988; Norman, 2002). As a type of interface design methodology, user-centred design gives extensive attention to end-users' demands and places them in the centre of the whole process. Interestingly there has never been the appearance of the term *usability-centred design*, whereas user-centred design has become the mostly widely

accepted approach for improving usability. Both concepts are now essential in computer application production. Over the past decade, they have also triggered an increasing amount of discussions in the field of GVIS technologies (Slocum, *et al.*, 2001; Fuhrmann, *et al.*, 2005; Andrienko, 2006).

This chapter will review the key aspects of usability and user-centred design and will link them to the application of visualisation tools in geographic problem-solving. Section 3.2 defines the concept, and associated practices of evaluating product usability. Section 3.3 looks at the conceptualization of user-centred design. The next section presents key international standards regarding usability and its engineering available to industry. Section 3.5 explores the significance of usability and user-centred design in the area of GVIS. Examples of current and recent research in this area are also presented. The last section of this chapter lists several questions that should be included in future usability and user-centred design studies.

3.2 Definition of Usability

3.2.1 Usability

The usability of a product tends to be taken for granted if the product performs as expected. While usability may thus be seen as a desirable property of a product, especially in the application of computer technologies, awareness of usability issues is more likely to be felt when the product fails to deliver the required qualities or functions. Usability can also often be a mostly subjective determined by the immediate experience of the individual user.

A product can be called useful if it helps users achieve specific goals. However, among useful products, one might work better than the other and the degree of usefulness of each might rest on different criteria (for example one might be more intuitive to operate, while the

other may perform more efficiently). Although the idea of making things useful has long been adopted in many industrial design fields, the concept of usability is particularly relevant in the development of human-computer interfaces (HCI).

A good example of the role of usability in HCI design is the principle known as Fitts's Law (Fitts, 1992) which suggests that interaction between user and information on a computer screen will be more productive (with the mouse) when the target objects are closer in distance and larger in size. A large part of the success of the Mac OS operating system designed by Apple (Apple Computers Inc., 2001 as cited by McGuffin and Balakrishnan, 2005) has been attributed to its commitment to Fitts's Law (McGuffin and Balakrishnan, 2005; Coolen, 2008; Göktürk, 2013), which explains why its later products such as the MacBook, iPod, iPhone and iPad, have all become synonymous with "simple and easy to use" industrial design.

Because of the inherent subjectivity of usability as a quality, there is still no universal definition for usability despite several decades of research into the topic. One of the earliest statements that involve the idea of usability comes from Woodson (1981), where it was understood as the type of product design with which the users can perform intended use with the maximum of efficiency and minimum of stress. The inspired follow-up discussions also involve what is a better product design and what a critical view of functionality, usage experience and efficiency should comprise.

Discussions of the concept continued into the 1980s, when the study of human reaction to computer applications was being pioneered (Dumas, 2007). Much of the research at this time was undertaken by psychologists and human factor researchers and led to a significant body of literature on the interaction between humans and computers (see, for example, Dumas, 1988;

Shneiderman, 1998). However the research mainly focused on experimental work and the production of associated guidelines and checklist reviews, while “usability testing was still seen as a variation of the research experiment” (Dumas, 2007, p.55). Gould and Lewis (1985, p.300) suggest that “any application designed for people to use, should be easy to learn (and remember), useful, that is contain functions people really need in their work, and be easy and pleasant to use.” Butler (1996) defines usability as the effectiveness of the interaction between humans and computer systems and specifically, how well potential users can perform and master tasks on the system.

A completely new approach in the area of usability engineering through product design and evaluation emerged in the late 1980s (Whiteside, *et al.*, 1988). This approach promoted the development model of goal setting, prototyping and iterative evaluation. These works later became the foundation of contemporary usability methods for product design and also triggered an explosion of interest from the 1990s in the area of developing new techniques and work practices to improve product usability (Dumas and Redish, 1993; Gould, 1998; Dumas, 2007; Wassink, *et al.*, 2009).

The definition of usability produced by the International Standards Organisation (ISO 9241-11) has widely been adopted within the HCI community of practice. According to the ISO, usability refers to “the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use (ISO, 1998, p.2)”. This definition of usability was accompanied by the publication by the ISO of a series of usability standards (see, for example, ISO 9241-10, 1996; ISO 9241-17, 2000; ISO 9241-151, 2008) that have since gained general use within the industry. Adherence to these standards

has become a common measure of the quality of a user's working experience with an interactive product such as a website or a piece of stand-alone software. Although the ISO has taken a lead in this regard, there is no consensus as to how many factors should be included to measure of the usability of a product, nor agreement on what these factors should be (see, for example, Nielsen, 1993; Norman, 1986, 2002; Quesenbery, 2001).

The three factors included in the ISO definition also become the key measures used for usability *evaluation*. Rogers *et al.* (2011) suggest that usability may be decided by whether or not users can carry out their tasks safely, effectively and enjoyably. In contrast, Nielsen (1993) proposed a five-attributes system: learnability, efficiency, memorability, error rate and user satisfaction (Figure 3.1). Quesenbery (2001) also advocates applying five dimensions of usability: effective, efficient, engaging, error tolerant and easy to learn (5 E's). Quesenbery (2001) takes one more step and stresses that although these five factors should ideally take up equal proportions in the whole design, in the real world some of them will be emphasised more than others. This is determined by the product features (Figure 3.2).

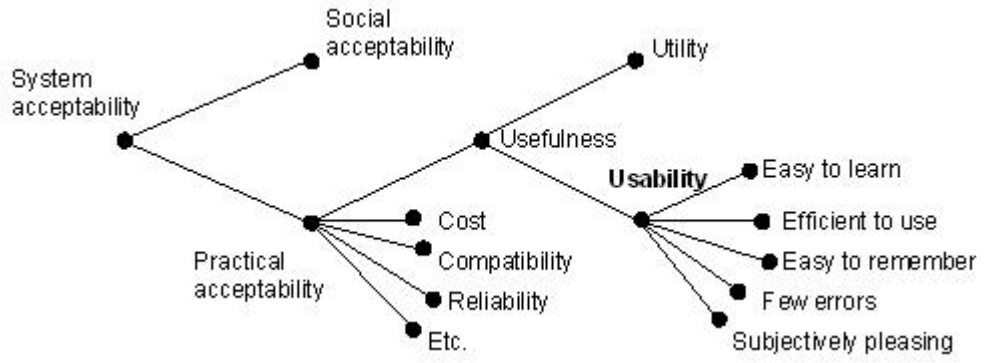


Figure 3.1 A model of the attributes of system acceptability (Nielsen, 1993)

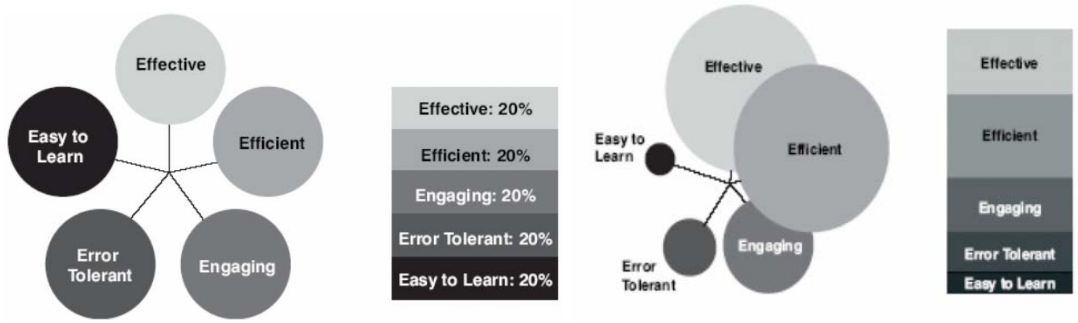


Figure 3.2 The "5 E's" of usability and the matter of balancing them (Quesenbery, 2001)

No matter how many aspects (or dimensions) are proposed, these different attempts agree with the multi-dimensional nature of usability. Sometimes different terms are used to describe one attribute of usability, while they actually point to the same meaning. Table 3.1 collects and lists some of these frequently used terms and their associated definitions appear in different literatures. Some of them, such as effectiveness, efficiency and satisfaction can be considered most widely accknlowedged, but still there seems to be hardly agreement on what exactly usability should be. This unsolved problem of usability will be revisited in Section 3.6.

Table 3.1 Different definitions on factors included in usability

Key words	Definitions
effectiveness, effective	• The accuracy and completeness with which users achieve specified goals (ISO 9241-11) • How completely and accurately the work or experience is completed or goals reached (Quesenbery, 2001) • Effectiveness represents the accuracy and completeness with which users achieve certain goals (Kulyk *et al*, 2007) • Once the user has learned the system, a high level of productivity is possible (Nielsen, 1993)
efficiency, efficient, throughput, efficient to use	• Resources expended in relation to the accuracy and completeness with which users achieve goals (ISO 9241-11) • The tasks accomplished by experienced users, the speed of task execution and the errors made (Rogers, *et al.*, 2011) • How quickly this work can be completed (Quesenbery, 2001) • Efficiency is the relation between (1) the accuracy and completeness with which users achieve certain goals and (2) the resources expended in achieving them (Kulyk *et al*, 2007)
satisfaction, pleasant to use, user attitude, user's satisfaction	• Freedom from discomfort and positive attitudes towards the use of the product (ISO 9241-11) • Users are subjectively satisfied by using the system; they like it (Nielsen, 1993) • User's satisfaction is the user's comfort with and positive attitudes towards the use of the system (Kulyk *et al*, 2007)
learnability, easy to learn	• The users can quickly go from not knowing the system to getting some work done with it (Nielsen, 1993) • How well the product supports both the initial orientation and continued learning throughout the complete life-time of use (Quesenbery, 2001)
easy to remember	• The infrequent user is able to return to using the system after some period of not having used it, without having to learn everything all over (Nielsen, 1993)
few errors, error tolerant, error to tolerance	• Users do not make many errors during the use of the system, or if they do make errors they can easily recover from them. Also, no catastrophic error should occur (Nielsen, 1993) • How well the product prevents errors and can help the user recover from mistakes that do occur (Quesenbery, 2001)
engaging	• How well the interface draws the user into the interaction and how pleasant and satisfying it is to use (Quesenbery, 2001)
Flexibility	• Variations in task completion strategies supported by the system (Rogers, *et al.*, 2011)

3.2.2 Usability evaluation

A usability evaluation refers to a systematic procedure used for recording data relating to end-user interaction with a product and analysing the data to determine the usability of the product (Rogers, *et al.*, 2011). Wixon and Wilson (1997) suggest that usability evaluation should be prioritized in the whole product design and such evaluation is critical because:

- It provides the engineering community with a good understanding of the user's viewpoint of a system;
- It helps the financial community to quantify the benefits;
- It allows the marketing community to justify the features of the product;
- It allows buyers to evaluate the system in terms of their requirements.

As reviewed previously, usability is a general term that contains several different attributes that possibly help make the design more useful. In this sense, to evaluate usability means to evaluate these different attributes. For instance, Kulyk *et al.* (2007, p.20) suggest measuring effectiveness with error rate; efficiency with resources used to complete tasks; learnability with the time used to reach a specific level of effectiveness/efficiency and memorability with the level of effectiveness/ efficiency after a period of time without using the system; user's satisfaction with the successful utilization of a system.

Apparently most of the attributes are rather qualitative rather than quantitative, making usability evaluation the frontier where many different techniques meet. These different evaluation methods are available to designers and each of them has the characteristics. It can be difficult to decide which method(s) should be used and at what stage of the development process should the methods be applied to achieve reasonably high usability. The main

evaluation methods in usability engineering are discussed by Whitefield *et al.* (1991), Nielsen (1993), Dix *et al.* (2004) and Rogers *et al.* (2011) and the main approaches are summarised in Table 3.2 (based on Fitzpatrick, 1998). These methods provided the guidance for the research into GVIS usability undertaken in this thesis.

Table 3.2 Composite list of HCI usability evaluation methods (Fitzpatrick, 1998)

Fitzpatrick (1998)	
Observation	A usability evaluation specialist acts as the observer of users as they interact with computers, noting user successes, difficulties, likes, dislikes, preferences and attitudes.
Questionnaire	The use of a set of items (questions or statements) to capture statistical data relating to user profiles, skills, experience, requirements, opinions, preferences and attitudes.
Interview	A formal consultation or meeting between a usability evaluation specialist and user(s) to obtain information about work practices, requirements, opinions, preferences and attitudes.
Empirical methods	The testing of a well-defined hypothesis by measuring subject (user) behaviour while the evaluator manipulates variables.
User groups	Availing of the wealth of knowledge and experience of organised (user forum) and selected (beta site) end users
Cognitive walkthrough	A step by step evaluation of a design by a cognitive psychologist in order to identify potential user psychological difficulties with the system.
Heuristic methods	The use of a team of usability evaluation specialists to review a product or prototype in order to confirm its compliance with recognised usability principles and practice.
Review methods	The review and reuse of the wealth of experimental and empirical evidence in the research literature and in the de-facto standards established by the software industry.
Modelling methods	The use of models like GOMS (goals, operations, methods and selection) and KLM (keystroke level modelling) to predict and provide feedback on user interactions and difficulties.

Another way of classifying evaluation methods is to associate them with each stage of a development process. The advantage of doing so is to avoid the possible problems caused by incorrectly sorting user groups and resources. Table 3.3 summarises the major evaluation methods that are mainly used by practitioners in a typical ISO suggested six-phase system

development (Kossiakoff, *et al.*, 2011, p.72). The choice of using certain methods or a combination of methods would be different if the project is facing problems such as limited time and resources, no direct access to users and limited skills and expertise, but this type of classification does make it easy for usability practitioners to choose and follow. The problem with this classification is that a system development is not always a fixed process of six phases and the actual organisation of each phase could easily affect the employment of methods. Therefore choosing a suitable method for each specific phase of the development process is usually open.

Dix *et al.* (2004, p.361) points out that any classification "is intended as a rough guide only – some of the techniques do not fit easily into such a classification since their use can vary considerably." In practice, it is up to designers to make use of these available evaluation techniques and the outputs of using different techniques can be varied. The major drivers behind evaluation method selection are project budget and sample size and in order to work out a solution, designers usually combine the methods. It is thus suggested by Sauro (2012) that designers should ask themselves the following four questions:

1) Does the product being tested need responses from an international audience?
2) Does the product require in-depth and in-person responses?
3) Is a single function being asked, where simple questions and answers suffice?
4) Are the tasks designed close-ended and easy to understand and perform?

Table 3.3 Methods that can be used during the design and development (Source: Kossiakoff, *et al.*, 2011)

Planning and feasibility	Requirements	Design	Implementation	Test and measure	Post release
Getting started	User surveys	Design guidelines	Style guides	Diagnostic evaluation	Post release testing
Stakeholder meeting	Interviews	Paper prototyping	Rapid prototyping	Performance testing	Subjective assessment
Analyse context	Contextual inquiry	Heuristic evaluation		Subjective evaluation	User surveys
ISO 13407	User observation	Parallel design		Heuristic evaluation	Remote Evaluation
Planning	Context	Storyboarding		Critical incidence technique	
Competitor analysis	Focus groups	Evaluate prototype		Pleasure	
	Brainstorming	Wizard of Oz			
	Evaluating existing systems	Interface design patterns			
	Card sorting				
	Affinity diagramming				
	Scenarios of use				
	Task analysis				
	Requirements meeting				

3.3 Definition of User-centred Design

3.3.1 User-centred design

As is implied in the name, in *user-centred design* (UCD) end users of a system are involved in its development from the very beginning of the planning stage. The aim is to preventing potentially serious defects from appearing in the product. This compels developers to think in terms of utility and usability (Olmos, *et al.*, 2009; Figure 3.3). The figure also gives an example of the communication exchange that happens between designers and users during a computer system development process. Certain types of activities happen at different stages of this process. Woodson (1981) suggests that designers should make their design fit the users rather than the opposite or vice versa, which could be seen in the earliest statement about UCD. A widely accepted definition of UCD comes from Abras *et al.* (2004) as a broad term to describe design processes in which end-users influence how a design takes shape.

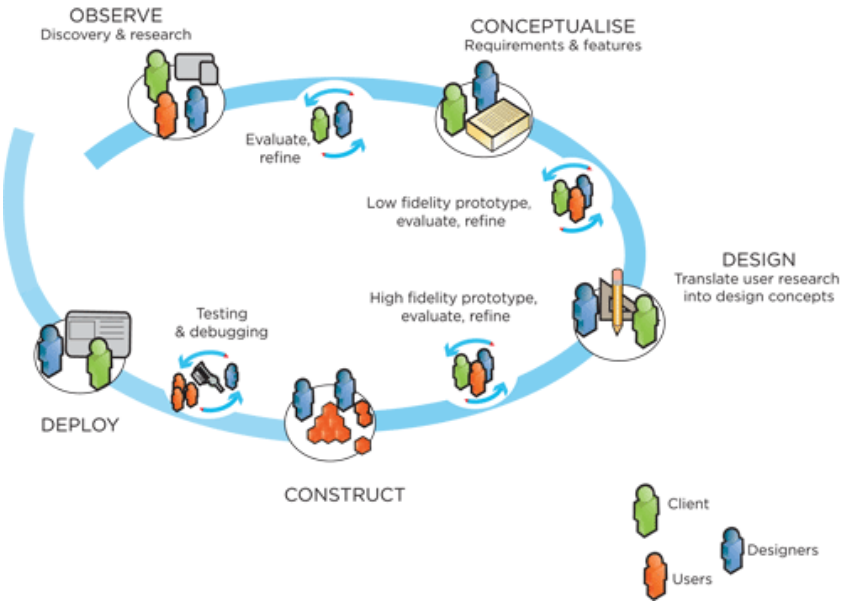


Figure 3.3 A UCD process of the Canadian Centre for Architecture (CCA) website (Olmos, *et al.*, 2009)

The central premise of UCD is that the best design outputs result from understanding the needs of the people who will use them. In practice, UCD often means a general development flow that composes iterative processes, which include a number of activities that require the incorporation of users' inputs (Limina, n.d.; Figure 3.4), that aims to makes adjustments by exploring, testing and turning the design until these needs are satisfied. The result of this is a high level of usability and it is suitable for all design practices with the aim of providing a good user experience such as architecture design (Bass and John, 2003), service design (Story, 1998) and web design (Palmer, 2002). The figure gives an example of the communication exchange that happens between designers and users during a computer system development process. Certain types of activities happen at different stages of this process.

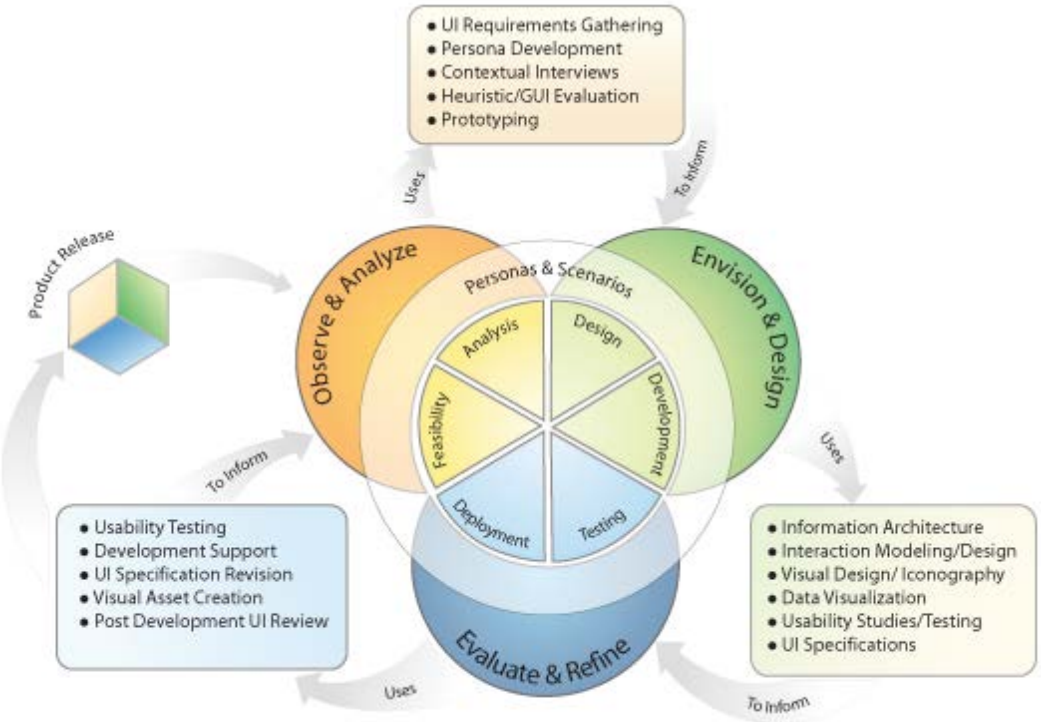


Figure 3.4 Activities involved in UCD process that need users' input (Limina, n.d.)

The very first use of the term “user-centred design” appeared in a co-authored publication by Donald Norman in the 1980s called “*User-Centred System Design: New Perspectives on Human-computer Interaction”* (Norman and Draper, 1986). The concept was further developed in his other books later such as “*The Psychology of Everyday Things* (Norman, 1988)*”* and *“The Design of Everyday Things (Norman, 2002)”*. In order to reinforce his introduction of the intuitive nature of product design in the second book, Norman (1988) proposed seven principles of design that would be essential for the facilitation of usability:

- Use both knowledge in the world and that in the head. Generate clear conceptual models that are easily understandable before the design begins.
- Simplify the structure of tasks. The task should neither overload the short-term nor long-term memory of the users. Supportive tools should be provided to help retrieve information.
- Make things visible. Users should be able to figure out the way to execute an operation with the ease of operating buttons or devices.
- Get the mappings right. Appropriate mapping is provided for the user to make good use of graphics.
- Exploit the power of constraints, in order to make the user feel that there is one thing to do.
- Design for error tolerant. The product designed should be ready for any possible error that might be made.
- When all else fails, standardize. An international standard needs to be created if the design has to follow arbitrary mapping.

A similar set of principles was also proposed by Shneiderman (1998) and further popularized by Nielsen (1993) as basic concepts in his series of articles about usability engineering. Rubin (1994) pointed out that a lot of the explorations at that time were closely related to behavioural design by developing a human-computer interface from the view of the user rather than that of the system and the key concept behind this is still that the focus-on-user is always placed at the centre of the design when products and systems are being developed.

3.3.2 User-centred vs. system-centred

Since the 1980s, the user-centred concept started as a completely new design concept as against a system-centred one, which used to be the dominating design in earlier days (Wilson, 2000; Figure 3.5). The System-centred approach locates the technological system in the primary position of a whole design process (Johnson, 1998). This approach presupposes that there is no necessity for users to get involved in the system development due to its complexity and thus it is thought to be the designers' business to decide the most appropriate designs and technologies and the system is created through a process of prototyping and iterative testing by the designers (or developers). Between system designers and users is the system interface which covers all the complex system technologies, therefore the interface contains a huge amount of data to develop an intelligent and smarter system for users. Designers have to make sure that the interface is friendly enough to be used, or so called user-friendly in most cases (Norman and Draper, 1986). However user-friendly systems should not get confused with user-centred because the interface could be created without any interference of user input. Users, who are far from the central concern of system design, eventually receive the product that represents the ideas of a designer or a group of designers. The problem is if users encounter problems

while working with the system, it would be impossible or very hard for them to give feedback on the design.

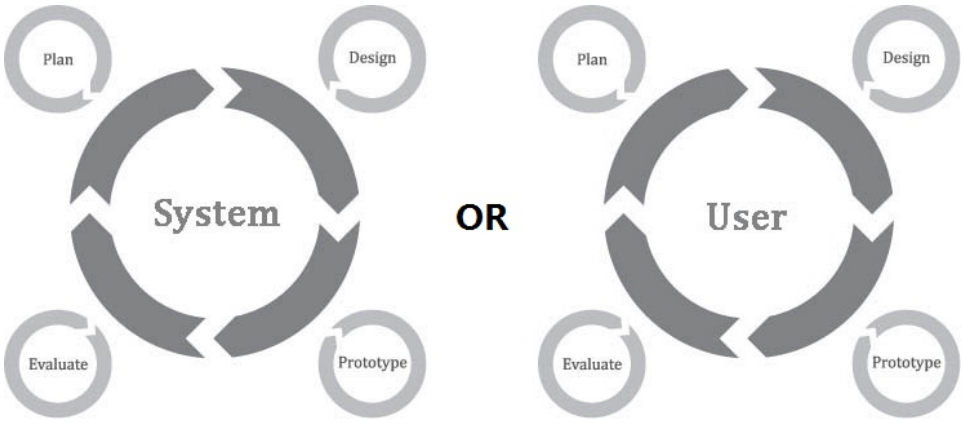


Figure 3.5 System-centred approach or user-centred approach?

Since user-centred was meant to be fundamentally different from system-centred, it gave rise to debates about which approach is more sensible and practical while the technologies were pushing innovation at the same time. The whole HCI sphere started to take an interest in this controversial theory and many pilot studies (or experiments) were conducted afterwards, which mainly tried to prove the advantages of UCD (Gould, 1988). Unfortunately some of the user-centred thoughts at that time still could not escape from the shadow of system-centred ideology. For instance, Johnson (1998, p.29) looks at Norman's advocating of a new user-centred approach for technology design and states that "*the designer must ensure that the system reveals the appropriate system image. Only then can the user acquire the proper user's model.*" What perplexes Johnson is that since user-centred system design (Norman and Draper, 1986) requires designers to keep in mind the users' needs, user-centred design should be embodied in the system and that "the appropriate system" should go before "the proper user's model", which implies that the system is still at the centre and users need to learn what is provided by designers. Johnson (1998) also argues that Norman's user-centred model presents separately

the relation of designers and users with the system interface without mentioning the connection between the two groups. It seems that there is a clear division between the designer and the user, where the former does nothing, but takes full responsibility for system development while the latter takes on his or her shoulders the learning and using of the system without any interaction with designers, which poses the impression again that the system is driving the user.

Nevertheless, nothing could slow the progression of UCD towards becoming matured through continuous efforts and eventually replacing system-centred and thus becoming the guideline for all industries. The significance of approaching users and gaining a better understanding of them started to be recognized increasingly by practitioners. Users should be actively involved in the development and it is necessary to consider intended end-users as the central concern including their abilities and needs, tasks and the environments in which they work (Stone, *et al.*, 2005). What suggested is that a user-centred system design should be adjusted to the user's needs, skills and limitations; engage users; adapt to the context; and work in real life. Norman and Draper (1986, cited in Henneman, 1999, p.136) stresses that,

> *"…the purpose of the system is to serve the user, not to use a specific technology, not to be an elegant piece of programming. The needs of the users should dominate the design of the interface and the needs of the interface should dominate the design of the rest of the system."*

Another important part of UCD development is the scientific view towards users and specifically what they do and what kind of input is needed in the design process. The first clarification on this aspect was articulated by Rubin (1994) where users were put at the centre surrounded by all other activities involved in the development process (Figure 3.6). Unfortunately with this graph, Rubin (1994) only managed to show the potential connection of users with the major aspects of tasks and he did not demonstrate clearly in what way users

could participate in the tasks.

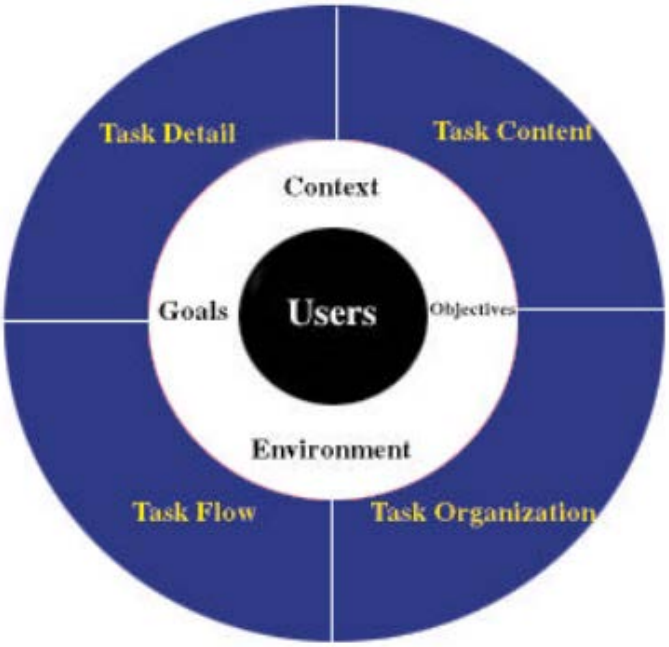


Figure 3.6 The central role of users in the design process (Rubin, 1994)

The steps of a UCD cycle that require user input can also be found in the previously presented Figure 3.6. As the cycle progressed, prototypes can be produced and user tested, where designers had to pay close attention in order to capture those measurable signs of potential users' subjective satisfaction. A reasonably well developed explanation of user participation can be found at Table 3.4, which suggests ways to get users involved in the product development (Rogers, *et al.*, 2011).

Table 3.4 The ways of user-involved design process (Source: Rogers, *et al.*, 2011)

Technique	Purpose	Stage of the Design cycle
Background interviews and questionnaires	Collecting data related to the needs and expectations of users; evaluation of design alternatives, prototypes and the final artifact	At the very beginning of the design project
Sequence of work interviews and questionnaires	Collecting data related to the sequence of work to be performed with the artifact	Early in the design cycle
Focus groups	Include a wide range of stakeholders to discuss issues and requirements	Early in the design cycle
On-site observation	Collecting information concerning the environment in which the artifact will be used	Early in the design cycle
Role playing, walkthroughs and simulations	Evaluation of alternative designs and gaining additional information about user needs and expectations; prototype evaluation	Early and mid-point in the design cycle
Usability testing	Collecting quantities data related measurable usability criteria	Final stage of the design cycle
Interviews and questionnaires	Collecting qualitative data related to user satisfaction with the artifact	Final stage of the design cycle

Nowadays the aim of UCD is to generate a framework, based on which more usable and useful systems can be designed. Gould and Lewis (1985) suggested three key principles to guide the design process: first, to maintain an early focus on the users and tasks involved as well as continued user interaction throughout the whole design process; second, to collect empirical data to measure ease of learning and use throughout the process and in the development and testing of prototypes with actual users; third, to implement an iterative approach in the development so that through early testing of conceptual models and design ideas, the end product and interface can be designed, tested, re-designed and re-tested through each phase until all parties are satisfied.

These principles have been taken by many studies as the basic rules to be followed in organising the design approach. Benefits of doing so are clear, including time and cost saving during development, completeness of system functionality, repair effort saving as well as user satisfaction (Nielsen, 1993; Constantine and Lockwood, 2002). In terms of how to actually implement this approach, many scholars emphasise the significance of involving some sort of medium or platform to enhance user-centred. For example, Carroll (2000) and Rosson and Carroll (2002) introduced the scenario-based design framework which utilizes various scenarios throughout the main stages of system development. These scenarios describe the motivations and experiences of users on specific activities allowing users to see and understand development goals about all different levels of the system. A variant of this design – Goal-Directed Design was then introduced by Cooper (1999) where he proposed the introducing of personas as a design tool given careful description of their needs, goals and tasks. Similarly Gould *et al.* (1997) suggested that for usability, people must participate in all the user-centred activities, to help prevent valuable information being lost in the transitions between the activities. Additionally a few other design approaches are brought forward as well, which are described in different ways (or forms) but with the similar aim of improving usability of the final products. Examples include Contextual Design (Customer-centred Design) by Beyer and Holtzblatt (1998), Cooperative Design by Greenbaum and Kyng (1991) and Participatory Design by Muller *et al.* (1997).

3.4 ISO Guildlines on Usability and User-centred Design

Over the last 20 years, various HCI standards have been developed in the ISO ergonomics, user interface and software engineering communities. These standards set up

consistency and prevent the arbitrary mapping of a design and they are the primary instructive documents to be referenced prior to the design process. Bevan (2006) concludes that in general the HCI standards published so far can be divided into four sections according to their primary concern with product use in contexts, interface and interaction, user centred process and usability capability. Among all different standards, ISO 9241-11 and ISO 13407are most close to the topic of this research.

ISO 9241 – Ergonomic requirements for office work with visual display terminals (VDTs) is a general description of usability and it sets up the context of why and how usability should be incorporated into product design. It is a series of standards that explains the interaction between users and computers covering many different aspects of people's dealings with computers (primarily at work). In ISO 9241, many requirements and guidelines are provided in terms of hardware, software and other working environment elements that can help deliver usability through the development process. From *9241-10 (1996)* to *9241-17 (2000)*, the focus lies largely on software requirements for enhancing usability. *9241-11 (1998)* offers a detailed specification of usability and its associated measures. New sub-standards are being planned to enrich the whole standard system, for instance, *9241-151* was published in 2008 with a particular focus on website user interface.

In *9241-11 (1998, p.6)*, usability is defined as, "*the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use.*" It explains how to identify the information that is necessary to take into account when specifying or evaluating usability in terms of measures of user performance and satisfaction. Guidance is given on how to describe the context of use of the product and the

measures of usability in an explicit way. It includes an explanation of how the usability of a product can be specified and evaluated as part of a quality system and it also explains how measures of user performance and satisfaction can be used to assess how any component of a work system affects the quality of the whole work system in use. Discussions regarding how *9241-11* principles help designers access the conformance of product are given by such as Gediga *et al.* (1999), Oppermann and Reiterer (1997) and Prümper (1999). Besides The ISO 9241 document also clarifies the difference between its definition of usability and the same term used by another standard ISO/IEC 9126 for software quality, which specifically refers to a set of attributes – understandability, learnability, operability, attractiveness, usability compliance (Jung, *et al.*, 2004). However, these attributes can be potentially difficult to measure because they depend on the nature of the user, the task and the environment, as explained further by *9241-11* (1998, p.25) that a product "has no intrinsic usability, only a capability to be used in a particular context. Usability cannot be assessed by studying a product in isolation." The statement highlights that usability can easily be affected by all factors "including organizational factors such as working practices and the location or appearance of a product and individual differences between users including those due to cultural factors and preferences (ISO, 1998, p.25). "

However *9241-11* still has its problems. Firstly essential guidance for the measures of effectiveness, efficiency and satisfaction is not given in the standard. There is certain guidance for deciding qualitative usability goals but very little for quantitative ones. Secondly the standard shows that usability requirements are very complex, such as different user groups with different goals and with different levels of effectiveness, efficiency and satisfaction but how to manage

the complexity is not advised. Thirdly the standard states that "t*he most important user goals may mean ignoring many functions, but is likely to be the most practical approach (ISO, 1998, p.16)*." This is likely to make users confused – how to identify those *important* ones and ignore those *unimportant* ones? As pointed out by de Souza and Bevan (1990), it will be difficult for the designers to integrate detailed design guidelines with their existing experience. Based on their experiments, in order to apply the guidelines successfully, designers need to understand the design goals and benefits of each guideline, the conditions under which the guideline should be applied, the precise nature of the proposed solution and any procedure that must be followed to apply the guideline.

Another important standard to investigate is *ISO 13407 –Human-centred design process for interactive systems* (ISO, 1999). This standard is specifically about UCD and it describes the four principles of human-centred design including, continuous concern for customers (as well as those who are interested in the products), proper duty allocation (to maximize people's capabilities), careful and delicate solution design (iterative procedure in project timetable) and multi-disciplinary design process (but not with the cost of an enormous design team). Based on these principles, the following activities can be critical for the whole development process:

- the application context has to be detailed and fully investigated. This means that objectives of development have to be clear and specific so that no uncertain assumptions are taken when the project is taking place;
- user requirements and other relevant requirements (social, cultural, etc) have to be described in detail and different ideas, thoughts and even bias should be acknowledged;

- the actual project design should be integrated and robust with inspiration from a wide range of aspects;
- it is very important to evaluate the design according to requirements and the evaluation should be based on real testing.

The flow chart of ISO 13407 design process is shown by Figure 3.7 (Abran, *et al.*, 2003). In UCD, the identified user requirements are the most critical input of the design and prototyping would not start without a good understanding and specification of the context of use and user and organisational requirements as showed in the figure. The designs enter an iterative evaluation process until they meet the requirements.

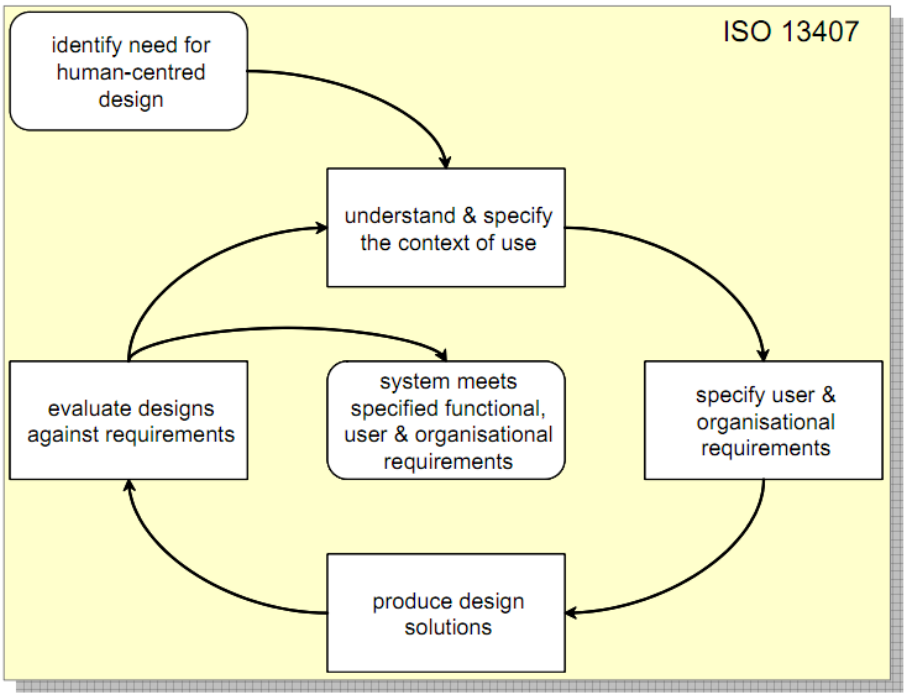


Figure 3.7 Flow chart of ISO 13407 human-centred design process (Abran, *et al.*, 2003)

Because *13407* is a set of abstract guidelines, it can technically be used as instruction for any application which intends to incorporate UCD. However this does not mean UCD would be facilitated in the same way in all occasions, because the standard does not state specific

requirements for those design phases, or specific outputs from the work flow, nor detailed methods applied to evaluations. Due to the loose but flexible definition, actual design practices are able to use the standard as an umbrella, under which project designers can choose available methods and propose customised working plans. In this sense, the core value of this standard is to establish an approach which is widely accepted and easily integrated into system design and the development process and based on this it allows all types of localized and tailored experiments and innovations.

Unfortunately the standard does not manage to explicitly explain all aspects of usability and how to integrate it into the design process, thus it still fails to fully provide practical guidance. For example, a few concepts associated with usability-centred design such as "*user goal"* and "*usability measures"* are used frequently without being clearly defined. It is argued that *13407* provides only limited guidance on putting the idea of usability into a design project. Jokela *et al.* (2003, p.58) points out that *13407* "*does not address the general complexity and specific challenges related to systematic identification of different users, identification of the different goals that users may have, nor determination of measures (effectiveness, efficiency, satisfaction)*."

3.5 Usability and User-centred Design in Geovisualisation

3.5.1 Conceptualizing geovisualisation usability

GVIS has shown its strength in exploring and presenting new and unknown patterns. GVIS tools are being produced and applied to assist spatial understanding of geographic problems. The technology used to be mostly reserved for experts and specialists, but now is becoming more accessible to the public. People have been very immersed in the visual advances

and achievements brought about by using GVIS tools. Only recently the attitude has changed towards user-centred thoughts with the aim of providing useful and usable GVIS tools (Slocum, *et al.*, 2001; Fuhrmann, *et al.*, 2005; Andrienko, 2006). However how the tools (or the tools to be provided) can actually place users in the centre of the design process is as yet an unexplored topic.

From DiBiase (1990) discussion of GVIS applications in private realms and public realms, it is not difficult to see that most of the activities in the private realms involve perception and understanding at an individual level, while activities in the public realm are likely to involve more communication at a population level. The significance of GVIS is to leverage the transformation from data to information and from information to knowledge (van Lammeren, *et al.*, 2007), while visual thinking and visual communication are the processes imbedded in the transformations. Adaptation of traditional usability methods has to consider characteristics of GVIS and its duty of two transformations. Besides, as a visual thinking tool, cognitive aspects such as perception and understanding, which are important parts of GVIS. As Lynch (1960) addressed when discussing the image of a city, the understanding of identical visualisations can differ between users, not only because different perceptions are developed by users, but also they relate these perceptions to different mental maps. Based on these two concepts, spatial cognition can be described as the discipline that looks at issues related to the perception and understanding of spatial environments (Lloyd, 1997; Slocum, *et al.*, 2001; 2005).

Compared with generic product usability, GVIS usability has more concerns on cognitive issues such as attention, attitude, perception, generating hypothesis, problem solving and decision making (Demšar, 2007). To meet user cognitive requirements is the essential goal of

GVIS design and to reach this goal, functionality and performance of GVIS needs to be optimized in a certain way. From this point of view, usability is a unique performance indicator of GVIS because whether a visualisation product is usable or not is a critical reflection of the designed functionalities (enabled by certain technologies) according to user requirements at all levels. Requirements such as more pictorial, more straightforward, more immersive, more interactive, more convenient and more user-friendly should certainly be included in usability considerations for GVIS. There have been very few investigations on preliminary conditions of successful GVIS design and development or its impact on perception and understanding. One attempt is made by Sheppard (2001; 2005) who sets up five conditions for GVIS use in a landscape project to achieve its objectives (Table 3.5). These conditions are set up from a designer's perspective considering what GVIS tools are expected to achieve in a project.

Table 3.5 Conditions of successful GVIS project (Sheppard, 2001)

Conditions	Definitions
accurate	simulate the actual or expected appearance of a landscape
representative	contain the most important characteristic of a landscape
comprehensive	communicate the details, components and overall content of the landscape
interesting	engage and hold the interest of the audience
legitimate	be defensible, including legally

A lot of the latest innovations of GVIS technologies focus on visual enhancements especially with the introduction of new computer graphics such as game engines. The gaming industry is unsurprisingly leading the field with wonderful displays of artificial worlds and more realistic interactions with these worlds. The enhancements escalate the capability of visualisation technologies in displaying geographic data and indeed provide users with new angles to investigate the data. In modernized computer-aided cartography, new visualisation

methods have completely changed the appearance of a map and the way it works. Examples have been given (see Section 2.3.2) regarding the development of GVIS with a particular focus on moving from 2D to 3D. However, when the visualisations become more realistic, the data acquisition, processing, storage and management technologies behind these visualisations become increasingly sophisticated.

At the same time, for those advanced visualisation systems and platforms, the requirements of user interface design and skill training are becoming increasingly demanding as well. In section 2.3.1, the functions of GVIS are fully discussed, echoed with lots of relevant researchers' voices that GVIS should enhance its function on 'visual communication' as most of the works are on 'visual thinking' (DiBiase, 1990; MacEachren, 1995). After more than 20 years of development, there has been a phenomenal enhancement on *visual communication* and scholars are beginning to argue that *visual thinking* should not have been overlooked (Slocum, *et al.*, 2001; Fuhrmann, *et al.*, 2005; Andrienko, 2006; Jones, *et al.*, 2009). Bishop and Rohrmann (2003) point out that the current research interest has been focusing too much on the technology side, whereas there has been rather little research on the user side such as spatial cognition and perception.

3.5.2 Facilitating user-centred design in geovisualisation

Those who argue that GVIS is beneficial to spatial understanding consider it a process, which involves the identification of patterns and knowledge discovery and is supported by interactive software tools (MacEachren and Kraak, 2001). In other words, GVIS is considered as a process that produces a product rather than simply an end product. A user-centred approach would consider this process as starting well before software design and involving fully

understanding its users, their needs and its requirement to meet particular tasks, as well as software design, development, use and evaluation (Lloyd, *et al.*, 2007). This is the prerequisite of understanding the approach and it emphasises again that "*user-centred*" is not achieved at any single point or stage but has to be a constant effort throughout the whole process. Therefore to understand why "*user-centred*" is vitally important to the GVIS design process requires an insight into user-centred knowledge and practice generally. It is claimed in this research that UCD can be employed as the theoretical basis of further proposed usability-focused design for the following reasons.

Firstly, technology-driven development with one-way communication from developer to user becomes the key reason which leads to the reduction of usability. The previous discussion suggests the critical drawback of one-way development mode, in which usability consideration is taken on board only towards the end of the whole development process. Communication does exist but is not sufficient to support a collaborative development environment – users are not involved in the development. The passive role of users leads eventually to the uncertainty of product quality (including usability).

Secondly, to improve usability requires two-way communication and interaction among user, developer and the inter-medium. Introducing an inter-medium is an attempt to establish a better link between developer and user. Originally in the context of HCI, this inter-medium is usually an optimized interface design. However another form of the medium – a third party (GVIS experts) in this case is introduced to bring in more communications and interactions. Compared with a technical inter-medium, the human inter-medium has the advantage of considerably reducing the efforts of sensing each other's needs among the three.

Thirdly, the kind of communication that is back-traceable along the whole process of development and intimately tied to prototyping. To make sure usability is taken care of at all stages of development, the communication has to be sorted and transformed into some sort of guidelines that can effectively work as a source of reference. Using these guidelines it is hoped that all the stakeholders involved will gain a clear picture of progress at each stage and not only look into “what to do” at the next stage, but also “what has been done” in previous stages. The guidelines would be essential to prototyping, making the whole development flexible.

Lastly, the UCD supports the experience and expertise of GV experts, with which they coordinate the process. Many of the requirements within the UCD model ask for experienced input, such as “understand and specify the context of use” and “specify user & organisational requirements”. These requirements are in most cases closely linked to specific knowledge of the application domain. Therefore in applying UCD to GVIS design, there exists a niche for bringing in a third group of people who are experts with the required backgrounds (in this case both GIS and geography). The primary task for them is to bring their expertise and experience into play and conduct extensive coordination in the involvement of users and their communication with designers.

In addition, the significance of usability-focused approach is highlighted in three aspects:

Firstly the usability-focused approach requires designers to effectively identify target users and their characteristics. As a critical component of UCD, this suggests that the key to enhancing usability relies on the full understanding of users. It is then of crucial importance to know who are the end users (targeting audience) and all their backgrounds. The more such

information is acquired, the better the output product will be customised.

Secondly the designers need to elicit user requirements and discover their expectations. As inferred in UCD, the contexts of use and user requirements are the two chief factors to be focused on and specified. User requirements should decide the functionalities presented by the product and thus decide the whole product design. Users' expectations of the product are also linked to how the product is to be used by them, implicating the needs of *usable* and *useful*.

Lastly the usability-focused approach is to enhance the communication and participation of stakeholders involved in decision making. Usability is not only restricted to adding useful features to the product, it is hoped to provide scientific support to decision making. A sensible and sound decision is decided by the actual capacity of the product in service, which is then decided by the designed functionalities. Therefore to provide usability-focused functions is critical to the overall performance of software armed with decision making support.

The attempts of facilitating user-centred thinking in GVIS design started in the 1990s when the term "*user-centred*" was just introduced to cartography. At that time, screen-based cartography had shown its great capacity for displaying spatial information and soon led to the emergence of numerous new mapping technologies. The consequence was, that in order to keep pace with technical revolutions, cartography professionals spent much less time in extending cartographic theories, vocabularies and standards, which gradually caused less and less and sometimes even incorrect, understanding of user demands and user behaviour. As a result, there appeared to be many ill-structured and short-lived mapping products, which never reached their intended users.

This problem then caused researches to start to look at ways of narrowing the gaps between map designers and users and it was believed that a more adaptive environment should be established for data representation, exploration and analysis. However it is difficult to find much substantial research on this aspect except the birth of a new concept in the 1990s – Adaptive Geovisualisation (AGV). Some of the early descriptions of the concept can be found at DiBiase *et al* (1992), Peterson (1993), Holynski (1988) and De Bra and Calvi (1998). During roughly the same period, the term "adaptive" was also widely used in many other fields and created terms such as "adaptive software", "adaptive system" and "adaptive hypermedia". All these different terms and their associated applications share the same idea of adaptability – that is to adapt to different users' needs. As regards to the conception of AGV, Wang *et al.* (2001, p.2) define it as,

> *"the design approach towards a user-centred GVIS system…[which] should have the functionality of self-description, self-evaluation, self-organisation and self-navigation."*

Similar to what is made of a GIS system, an AGV system will contain a series of components such as data acquisition, structuring, preview, user interface, map-based spatial cognition, user behaviour monitoring and adaptive map presentation. Figure 3.8 shows the conceptual model of AGV systems in practice.

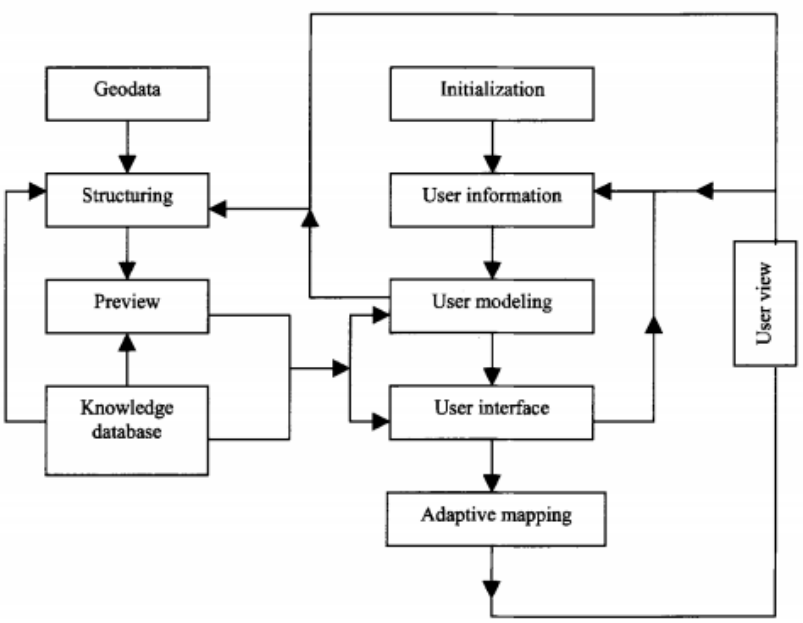


Figure 3.8 The conceptual model of an AGV system (Wang, *et al.*, 2001)

Since computer-aided map making is increasingly favoured by people due to its appearing interface, high-level automation and simple but practical functions, one of the research frontiers is to use new strategies to solve the problem of providing a user-customised spatial information service (Zipf, 2002). In his research, Zipf develops a prototype system – MapAgent. This enables the customising of mapping styles and contents according to user characteristics, interests and other specified requirements. Cai (2008) suggests that research on AGV should focus on three aspects – interaction, navigation and visualisation, in other words, adaptability of HCI, adaptability of information navigation and adaptability of map contents. Till very recently, continuous efforts have been put into the area with advanced and sustainable systems under the concept of AGV (Yu, *et al.*, 2010), but yet the concept has not been carried out extensively in practice, because the AGV model does not clearly explain the methodology of these components such as what kind of user information is to be collected and how users can be modelled.

3.5.3 Examples of usability and user-centred design investigations in geovisualisation application

As mentioned already, there have been a handful of studies, which look into the usability issues of GVIS applications, thus three sample cases are selected and presented in this section. They are meant to showcase how usability issues are approached in actual practices, how GVIS applications are evaluated, as well as how the design of a GVIS application takes into account the end-users' participation.

The first sample comes from Mülder *et al.* (2007) which aims to compare the effectiveness of interactive and non-interactive 3D visualisation in communicating planning information with stakeholders. Controversy between economic opportunities and environmental and social impacts raised by the proposed expansion of Calden Airport in Kassel, Germany, offers the opportunity to elicit people's views via presenting the plan with GVIS tools. The organisation of the study is then based on the assumption that interactive tools are more powerful and effective than non-interactive ones.

It is claimed in the results that interactive tools are proven to be more effective regarding communicating a landscape plan. It is also found that interactivity improves understanding of the plan, makes participants (end-users) more engaged and consequently stimulates discussions within the group. Such advancement is significant when complex spatial settings of the plan are displayed. Non-interactive tools, on the other hand, work better when explaining simple aspects of the plan such as overview of the land-use.

The second case comes from Milosz *et al.* (2007) whose context is similar to that of the first case. The project is to present spatial planning information, specifically new street plans in

the city centre of Warsaw, to the general public. Interactive visualisation tools showing the proposed streets and nearby buildings are given to participants to test their understanding of spatial orientation, in other words the awareness of surrounding space. The assumption is that 3D visualisation will be more helpful than 2D visualisation in assisting users to understand the environment. The core method used in this project is a web-based questionnaire relating to spatial orientation which asks respondents to identify the type of elements that they pay most attention to. The evaluation is focused on effectiveness, efficiency and satisfaction according to ISO 9241's definition on usability.

It is found that without sufficient introduction to the context of visualisation tools, users have difficulties in understanding and interpreting 3D GVIS. 2D elements are found to be more effective than 3D elements in clarifying orientation and helping users examine the planning information demonstrated. Therefore the assumption is not proven correct through this study. It seems that only by very precise and realistic representations can 3D elements be recognized by people and consequently used by them to build their own image of the area that is visualised.

Woronuk (2008) used an experimental approach to investigate whether 3D visualisations provides more effective way-finding guidance for firefighters in emergency management. According to users' responses to the survey conducted afterwards, 3D visualisation showed no significant advantages in terms of overall time used to finish the task, or the level of ease of use.

The above three examples showcase the kind of usability issues that might be encountered in GVIS applications and the way they are approached by usability practitioners. A few lessons can be learned, particularly when linking them with the context of this thesis.

Firstly, interactive and non-interactive tools have become the centre of usability discussion in GVIS application. More specifically, the use of advanced 3D visualisation technologies has been increasingly challenging those traditional visualisation tools. Therefore the debate between the usability features of the two tools will continue to be an interesting field to be explored.

Secondly, end-users take up a huge part of usability investigations and the design of such investigations, particularly, the way to approach the users is critically important. Therefore discussing usability problems should be established on the basis of a good understanding of target users, who should be placed in the centre of the evaluation methodology.

Thirdly, it is important to choose well-defined measures when evaluating the usability performance of visualisation tools. The later two sample cases develop their method based on ISO 9241's definition of usability, thus effectiveness, efficiency and satisfaction become the key measures employed in the survey.

3.6 Questions Brought into the Future

Question 1: Usability – a still confusing concept

Discussions of usability in the literature show that the term has been used with different meanings. It can refer to independent quality attributes such as effectiveness, efficiency and satisfaction or all of them (Bevan and Azuma, 1997). Each expert (or group of experts) appears to have developed their own definition independent of others'. The result is that different terms are used to define the same attribute, while the differences between them still need to be clarified. For example, "learnability" defined by Nielsen (1993) is defined in ISO9241-11 (1998) as a sub-attribute of "time of learning", while in Quesenbery (2001) it is

termed as “easy to learn” and in ISO9126 it is highlighted as an independent factor that can be further decomposed into several attributes such as comprehensive input and output, instruction and message readiness (Seffah and Metzker, 2004). In practice usability can also be interpreted from different perspectives. For example, to an end-user, good usability usually means that the product could facilitate the user to complete specific tasks more efficiently and productively, whereas to a system manager, it could mean a decisive factor in organisational performance.

The various interpretations of usability make it surprising to see that usability has been so widely acknowledged as a critical aspect of product design but without a universal definition. A possible reason is that usability is such a highly abstract concept with a multidisciplinary nature and the understanding of it changes over time. In this sense, rather than being a measure for testing product quality, usability is more likely to be a reflection of people’s pursuit towards an ideal product. Without consistent terminology, or a consensus of opinion from domain experts, product designers and developers are left in an awkward dilemma and lost as at how to fully facilitate usability into the process. It is noticed in this thesis that defining usability has become a knot in the realm of GVIS regardless of the fact that usability in scientific visualisation also waits for clarification. The simplest way is possibly to adopt the ISO 9241-11 definition and state usability as the effectiveness, efficiency and satisfaction of a GVIS product for a user applying to a specific task. Doing so means that GVIS will be treated no differently from other generic HCI products, which still remains as a question to be further investigated.

An increasingly common view shared by most domain experts (e.g., Slocum, 2001, 2005; Fuhrmann, 2005; Fuhrmann and Pike, 2005; Andrienko and Andrienko, 2006; MacEachren, 2005) suggests that a fundamental difference between the usability of GVIS and that of generic

products lies in the former's cognitive requirements. Demšar (2007) further states that such a difference covers something as attention, attitude, perception, generating hypothesis, problem solving and decision making. Relevant explorations made by these experts mainly focus on highlighting the fact that usability engineering principles have to be modified to take into account GVIS characteristics. Apart from these discussions, there is no frontal and direct description of what makes GVIS usability differ from generic product usability. GVIS is unlikely to be the only type of product that has (or is featured in) cognitive requirements. For example, interactive learning tools also require high cognitive functions. Therefore cognitive requirements will not be convincing enough to make GVIS usability special? This questionable aspect has not been fully realised by many GVIS usability followers and further clarification can be quite necessary.

Ultimately users are the only ones who decide whether or not a product is usable and useful. Is it enough that usability could be used as a criterion to measure the success of a product? Is it enough to assure the survival of a product in a competitive marketplace? Meanwhile, one should not ignore other factors such as "likability" and "appealingness" which will pose strong impacts on users' judgements over a product. Are these factors independent of usability or should they be parts of usability? An apt example on this aspect, among so many different online map services, is that users tend to use those that are visually "nice" presented with a "nice" interface, but again it can be very hard to tell to what extent the product can be called really "nice". Rather than putting efforts on repeatedly defining the concept, this thesis believes that it is more sensible to lay the primary focus on how to incorporate the idea into actual design.

Question 2: Evaluation – no single best method

No matter how fuzzy the definition of usability is, it has been widely accepted that evaluating usability is a very important approach to make sure of the delivery of a piece of useful and usable product. The purpose of usability evaluation is to provide feedback to help remove faults and further improve design, to assess whether objectives are achieved and to monitor long term use of the product. The method of usability evaluation is a systematic procedure for collecting data in relation to end-users' interaction with a product. There are many different types of evaluation methods to be put in to use, but unfortunately there is never a best method that could fit all situations. Some of the methods are consistently referred to by most experts (Nielsen, 1993; Kirakowski, 1996; Rogers, *et al.*, 2011), while others are based on individual author's preference (Dix, *et al.*, 2004).

This thesis conducts an experiment to explore user's attitude towards different mapping products, where a mixture of techniques was used, including tutorial workshop, questionnaire, group discussion and observation, so as to stimulate users' participation and elicit their views. The major findings and relevant detailed discussion can be found in Section 5.2. It is important for a usability practitioner to choose appropriate method(s) for the product to be tested, as suggested by Reiterer and Oppermann (1993 cited in Fitzpatrick, 1998, p.5),

> *"…there is no single best evaluation method. All of the methods have some disadvantages, or consider only a limited number of the factors influencing an evaluation, but many of them contain useful ideas, or are very appropriate for the evaluation of a specific factor. What is needed is a combination of different evaluation methods for the different foci of an evaluation."*

This statement points out that the challenge for usability evaluation is to make sensible use of different methods. Such challenges are also echoed by a critical comment from Capra (2007) who concludes that formative usability evaluation is not a reliable process due to the

uncertainties caused by the evaluation method(s) used, the evaluator's effect such as experience and moderating styles, the number of types of users, the different views of evaluators on severity scales (Capra, 2007). It is clearly claimed that the reliability of usability testing as an approach can be questionable and thus designers have be very careful when making the decision of when, where and how to use it in the development. A further related point is made by Mendes (2011) who suggests that one should not forget that usability evaluation only changes products incrementally and it does not generate new products. These kinds of views on usability testing have created quite a critical tone regarding the sustainability of usability testing practices in the future. To evaluate usability can be both easy and difficult: it is easy because whichever method is chosen, it is always likely to discover some usability problems, from which further improvements will be guided; it is difficult at the same time as how to maximize the effect of evaluation, acquire the positive feedback and reflect correctly on the system or product design.

Question 3: Users – the imperfect human-being

To make users happy with a product is the reason for approaching and assessing usability, but how much has been known about such a group of people so called users? User, sometimes also called end-user, is simply one or a group of people who use a product. Most of UCD discussions emphasise the fact that the voices of users should be involved from the early stage of the design and development process (Shneiderman, 1998; Johnson, 1998; Wilson, 2000) and the associated communication and participation will thus become the key to successful UCD proceedings. However it is not that easy to centralize users and it is important to understand and respect the "imperfection" of users before getting them involved in the design.

Hudson (2008) presents a very interesting painting (Figure 3.9) in which he shows what a perfect user looks like in a designers' mind and according to his description, this user should have the visual acuity of an eagle, memory of an elephant, navigation skills of a bat, stamina of a camel and dexterity of a monkey. If all users were so perfect, there would be no need to worry about usability problems, but this cartoon is rather an ironic illustration that urges all system designers not to overlook human limitations and needs, many of which are still not fully known. It is further argued that all the known and unknown limitations stem from failings of visual perception, or sometimes called *blindness*, which include attentional blindness, change blindness and mud splash blindness (Hudson, 2008).

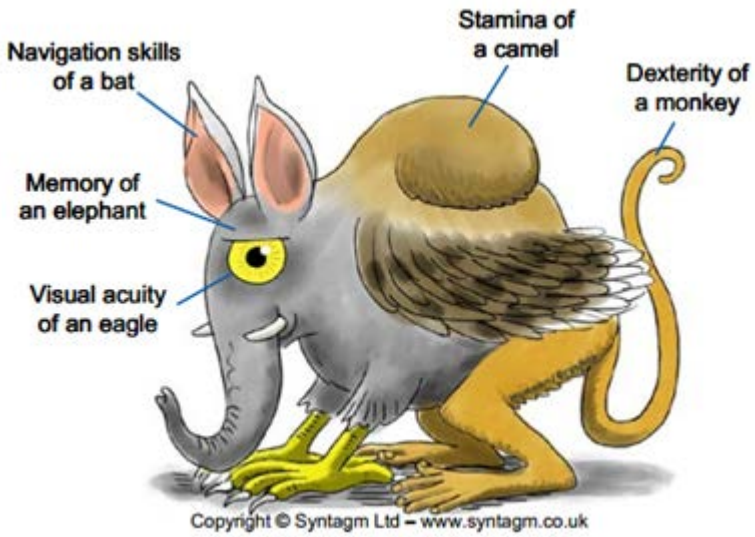


Figure 3.9 The Perfect User (Hudson, 2008)

Because GVIS deals with visual perception, particularly in a decision-making situation where large amounts of spatial dataset and domain knowledge are involved, the imperfection of users could pose great influences on the use of the product. For example, many people may find it quite difficult to master the use of the 3D virtual working environment due to their lack of computer skills and their unwillingness to do extra training on using a sophisticated system.

Building a user scenario as mentioned before (see Section 3.3.3) can be a good way to obtain an understanding of users, whereas it usually requires the interference of specialized usability experts, which can be difficult to facilitate in medium and small scale GVIS developments. An alternative approach is probably to test the user interface with as many potential end-users as possible so that more human limitations can be reflected and incorporated into the design.

Question 4: UCD – how to get users participated

Traditional instrumental system design is often criticized for its linear and low efficient process (Zemke and Rossett, 2002), which leads to the development of UCD, being increasingly popularized because of its idea of reflecting user expectations throughout the product development. However the unique social-technical nature of UCD makes it provide, rather than specific methods, general guidelines such as user participation, contextual inquiry and iterative design (Baek *et al.* 2008). How to facilitate such guidelines could vary a lot in practice depending on the context and content of the product.

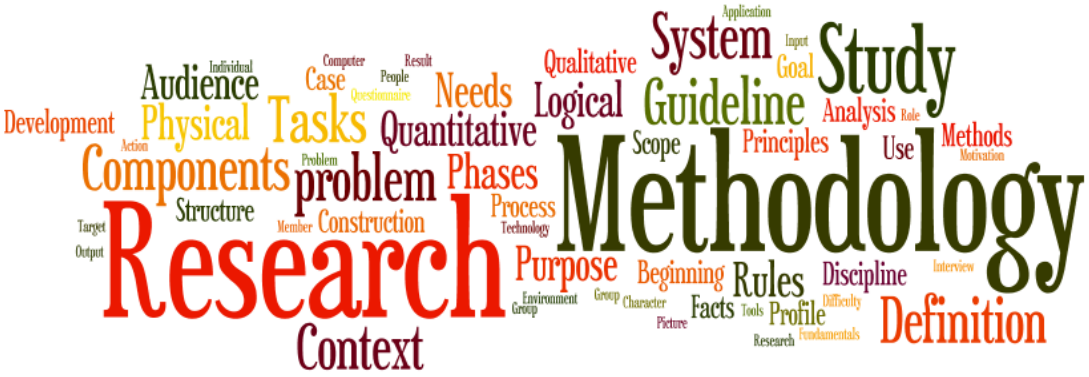
According to UCD, user participation is critically important in terms of providing useful input into the whole design process. Tom Erickson, usability engineer of Apple company, suggests four dimensions of participation: direct interaction with designer, long-term involvement in the design process, broad participation in the overall system being designed and maintaining a significant degree of control over design decisions (Kuhn, 1996). For a large commercial software development project, such as Mac OS or ArcGIS, facilitating such these different levels of participation is likely to be organised by specialized usability engineers, whereas for a medium or small size software development project, it tends to be “optional”. Any participation of potential users will help improve usability of the products, but to what extent

should users participate and how they are organised to do so still remains as a question. Furthermore, from a methodology point of view, questions such as who should participate, how to make sure that they represent the target user group, how to recruit them and how to record their feedbacks will eventually decide the scale and scope of users' participation.

Additionally, UCD encourages integrating as much users' participation as possible, but practically how much participation is enough? Luke *et al.* (2004) presents an observation of a participatory design where early brainstorming of users generated very high demands, which were not moderated by designers with any realistic time and costs requirement analysis and the consequence was those expectations turned into overall disappointment. It is commented that in this particular case, the designers and users were "*too participatory and too open*" which made the development lacking a clear evolving direction (Luke, *et al.*, 2004). As added by Letondal and Mackay (2004), a successful user participation is also decided by the maintaining of the balance by designers between "low responsibility" and "useful results".

3.7 Summary

This chapter links GVIS to the research focus on usability and UCD. It ends with some insights into some of the on-going concerns. These questions will be returned to in Chapter 5, in the context of enhancing usability in the design process of geovisualisation.



Chapter 4

Research Methodology

4.1 Introduction

This research used a three-stage methodology that involves desktop literature studies and experiments using various GVIS tools. Stage One is to establish a good conceptual framework, as explained in the previous two chapters. Stage Two proposes a unique solution to usability problems identified in the critiques of GVIS usability. It seeks to build a new operational and procedural framework for GVIS design, which will be presented in Chapter 5. The last stage described and discussed in Chapter 6 then presents two case studies that were conducted in Ireland and China respectively on the topic of flood mapping, in order to implement and assess the new design framework in a real-life GVIS context.

4.2 Research Focus Development

The sequence of reasoning that helped lead to the research question at the heart of this thesis is shown in Figure 4.1. The starting point was the review of GVIS origins and use, as outlined in Chapter 2 above. The critiques of GVIS usability encountered in this review led to the question of *how to make a useful GVIS application*. In order to adequately address this, a clear picture is needed of *what is meant by GVIS usability*. These two strands of thinking then merged

into the question of *how to facilitate usability enhancement in GVIS design*. Seeking answers to this question was then inspired by studies on UCD, thus the idea became "whether it is possible to develop a new GVIS design framework based on UCD that centralizes a user's involvement and aims to enhance usability of the output." This became the central question of all the follow-up discussions and it was developed formally into the research focus.

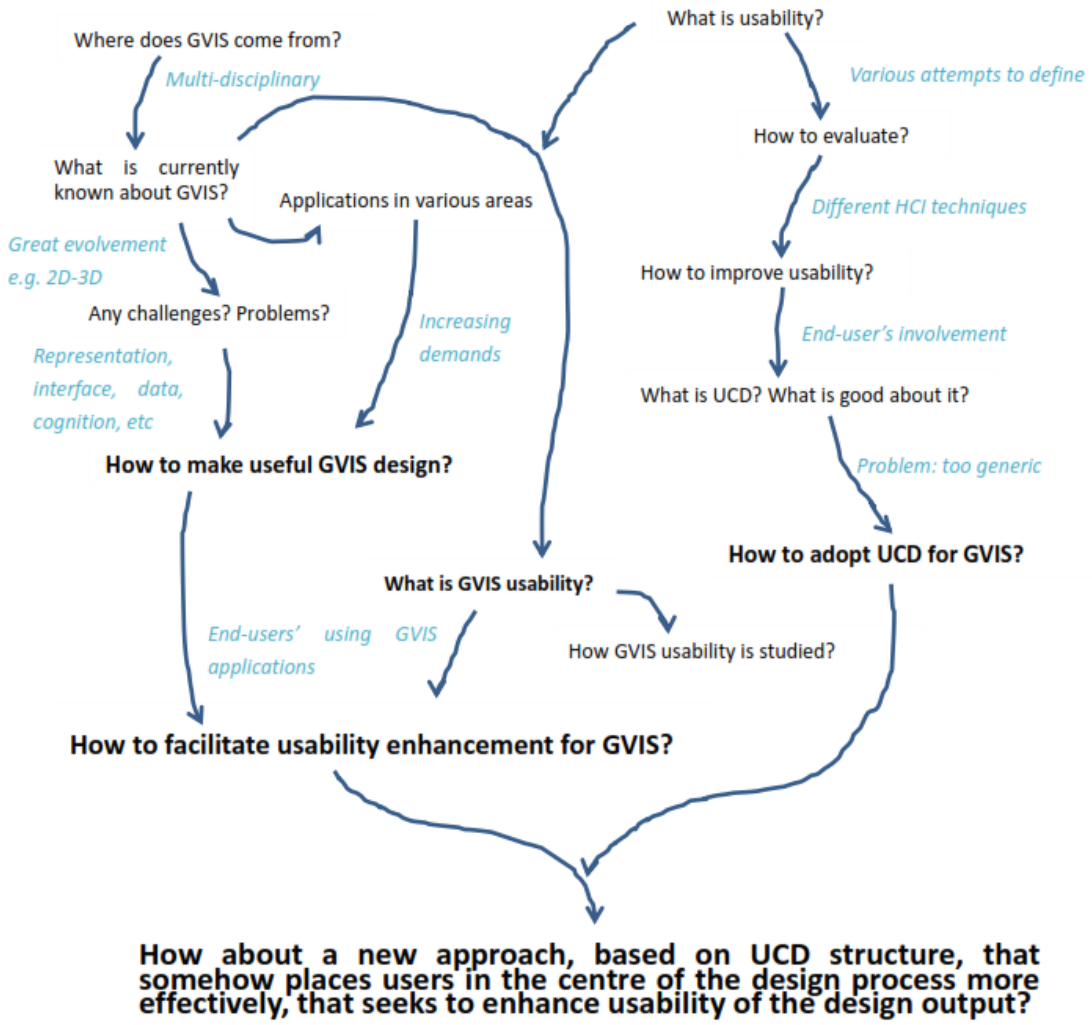


Figure 4.1 How the research focus is shaped up through literature studies

4.3 Survey Methodology

Marine and coastal flooding was chosen to provide the application context against which the question of GVIS usability could be explored and tested. This problem domain was

considered particularly relevant to the research for two main reasons. Firstly, due to global climate change and the projected future sea-level rise (SLR), many coastal communities around the world are under threat. There is a growing need to communicate the causes and likely impacts of inundation to a variety of decision-makers and other stakeholders. Given the topicality of the problem, this topic is also likely to draw more support for the research from the targeted survey participants. At the same time, coastal inundation is a good example of how to communicate complex spatial information via modern technology.

In order to pursue the research objectives, workshops were conducted in Ireland and in China, which mainly consisted of demonstration, questionnaire survey and open discussions. In the survey, participants were given a brief presentation to set the context of flood risk in Crosshaven (located in Cork Harbour, Ireland) (the presentation slides used at the workshops can be found at *Appendix 4: Workshop Presentation Ireland* and *Appendix 5: Workshop Presentation China*). This was followed by a demonstration of a range of GVIS tools. The participants were asked to complete a questionnaire that contained a number of questions regarding usability of those GVIS products. At the end of the workshop, participants were invited for an open discussion to exchange their views on those different GVIS products. In the two case studies, questionnaire was replaced with face-to-face interviews, where participants were asked to return their feedback after using the tools.

A mixture of questionnaire survey, interviews and open discussion was used in this study for the survey and case studies. Questions were set up with the focus on effectiveness, efficiency and satisfaction in relation to the mapping products presented. The participants were asked to deliver a timely reflection on the experience of actually viewing different types of GVIS

tools so that they did not simply draw a generic conclusion after trying all the products. Data retrieved from questionnaires became the major source of reference to develop a discussion on user characteristics. The designed questions also encouraged participants to view usability from different perspectives to make the participants more orientated with and engaged in the follow-up discussions. The open discussion session was set to provide participants with an easier environment to exchange their own views with other participants.

4.3.1 Selecting Survey Participants

Participants were carefully recruited from a range of fields or areas of application that potentially require the use of GVIS tools for work (Tobón, 2005). Therefore selected participants in the two study sites included professionals, government officials and scholars with a variety of interests and different levels of requirements with regard to using geographic data as well as presentation or analysis tools. Not all participants were technically expert in using GVIS tools, some came from those fields (e.g., planning, environment consultancy, coastal management) that utilise information provided by these tools. Therefore most of them had basic knowledge of cartography or GIS.

The workshop conducted in Ireland had a total participation of 19 people, whose profiles are shown in Table 4.1, while the Chinese workshop had 15 people (Table 4.2). Between them, the participants brought different levels of knowledge and experience with regard to GIS and GVIS to the data gathering process (Table 4.3).

Table 4.1 Status of participants from the Irish Group

User	Occupation	Interests or expertise
P1	University research assistant	Project administration
P2	University scientist	Climate adaptation
P3	University lecturer	Geography, coastal morphology
P4	County council project officer	Environment project
P5	Research institute scientist	Coastal management
P6	Naval service staff officer	Naval operations
P7	Coast heritage project officer	Heritage management
P8	Research institute scientist	Marine environment
P9	Coastal literacy officer	Community engagement
P10	Environment consultancy scientist	Biological conservation
P11	Regional authority engineer	Coastal engineering and planning
P12	University PhD student	Marine policies and strategies
P13	University climate researcher	Climate change and adaptation
P14	University lecturer/director	Cartography, GIS
P15	University research assistant	Planning, spatial analysis
P16	Environment management consultant	Community participation
P17	Research institute director	Fishery
P18	County council officer	Environment planning
P19	Project officer	Tourism development

Table 4.2 Status of participants from the Chinese Group

User	Occupation	Interests or expertise
P1	Director	Coastal territory administration
P2	Deputy director	Marine management information centre
P3	Engineer	Data management
P4	Officer	Coastal resource administration
P5	Deputy director	Coastal territory administration
P6	University lecturer	Oceanic remote sensing
P7	Research institute scientist	System development and maintenance
P8	Director	Oceanic administration
P9	Deputy director	Coastal environment monitoring
P10	Director	Marine law enforcement
P11	Engineer	Coastal environment monitoring
P12	Engineer	Marine and coastal planning
P13	Deputy director	Marine law enforcement
P14	Deputy director	Oceanic environment protection
P15	Engineer	Marine data management

Table 4.3 Background of participants

Items	Grades	Irish Group (number of people)	Chinese Group (number of people)
Experience of coast management	Lots	6	2
	Some	13	9
	None	0	4
Experience of GIS	Lots	5	3
	Some	12	10
	None	2	2
Needs for GI in work	Lots	14	11
	Some	5	4
	None	0	0
Experience of GVIS	Lots	4	2
	Some	9	12
	None	6	1

The two groups were geographically distant from each other. The majority of the participants did not merely work on coastal management, but on related jobs and thus had a certain amount of associated working experience. Their work involved either frequent or large amounts of geographic information processing and analysis. Although all participants came cross the concept of GIS and different kinds of GIS products, their job specification did not involve much in-depth use of the technologies and most of them did not have sufficient domain knowledge of GVIS. The above shows the way of selecting workshop participants in the first experiment. Users with slightly different profiles were engaged for the other two case studies as described in detail in Chapter 6. Nevertheless the basic idea and principle of selecting experiment participants remained the same.

4.3.2 Questionnaire Design and Analysis

In the first two experiments, the study needed to find a way to collect users' feedback on using different types of GVIS tools. Since the experiments were carried out in the form of workshops, which meant targeted users did not have to be approached individually, the selected

method had to be suitable for reaching a number of people at one time. A questionnaire approach was thus selected to be the primary method.

The aim of carrying out the questionnaire survey was to find out users' views towards different types of mapping products within the same application context in this case – coastal flooding. After viewing and experiencing the range of maps, the workshop participants were asked to fill in a questionnaire before moving to group discussions. The same workshop was conducted in two different places, thus the questionnaire was compiled in both English and Chinese language. The contents remained exactly the same in both versions. The English version was proof-read by three native language speakers including two university lecturers and one postgraduate student.

Inspired by the case study shown in Section 3.5.3, this thesis also focused on the three dimensions of usability suggested by ISO Standard 9241-11 (ISO, 1998), namely effectiveness, efficiency and user satisfaction. Because an open discussion was organised afterwards, all the questions were in closed format so that they would be easy and quick to fill in and also easy to code and analyse afterwards.

The full questionnaire applied can be found at *Appendix 1: Questionnaire*. Generally it can be divided into three sections. The first section simply asks for basic personal information, including organisation, job specification and occupation. This will help the survey analysis generate an overview of user groups. The second section is meant to collect respondents' views on SLR and flooding and their involvement in coast management and geographic information. This data can be useful in terms of helping direct a respondents' focus to the use of GVIS in coastal inundation, gaining an insight of participants' characters and linking the questionnaire to

the demonstration run beforehand. The following two examples show how the questions were presented.

Which of the following would you consider as important responses to sea level rise? (Choose more than one option if necessary)

- ☐ Implement sound adaptive strategies
- ☐ Raise public awareness
- ☐ More financial support from government and other sources
- ☐ Low carbon economy policy
- ☐ Scientific and informed use of coast and marine resources
- ☐ Employ new and advanced technology
- ☐ Improve coast defence engineering
- ☐ Other

_____

This question tried to introduce the core context of the test, which was the topic of potential sea-level rise as one consequence of climate change. A few widely addressed concerns were given as multiple choices and respondents were allowed to give extra comments in the blank space provided at the end of the question.

How long has been your involvement with…?

	>10 years	5-10 years	<5 years
marine and coastal management	☐	☐	☐
cartography	☐	☐	☐
geographic information systems	☐	☐	☐

This question tried to collect more background information about the workshop participants. Respondents needed to indicate their involvement (or experience) with the above three categories that might influence their attitudes towards the mapping products.

The first two sections of the questionnaire were completed by respondents before the presentation of maps in the third section (also the main body) of this questionnaire. Almost all the questions in this last section used a Likert Scale, which is one of the most widely used itemized scales (Jamieson, 2004). The respondents were asked to indicate their degree of

agreement to statements offered, by choosing one of the five response categories. The following example shows one of these questions.

Please indicate your level of agreement with the following statements

	Strongly agree	Agree	Neither	Disagree	Strongly disagree
The way that coastal inundation is presented is clear and understandable	☐	☐	☐	☐	☐

This question was set up to see whether these visualisations told what should be told, as a sound GVIS product is supposed to display the primary and interested information in a straightforward way.

The third section was the core part of the whole questionnaire, because all the questions were set to look into the effectiveness of, efficiency of and satisfaction with the visualisations presented to the workshop participants. The following example shows another question in this section.

To what extent are these geovisualizations visually attractive to you?

	Very attractive	Attractive	Neither	Unattractive	Very unattractive
Paper map	☐	☐	☐	☐	☐
2D	☐	☐	☐	☐	☐
3D	☐	☐	☐	☐	☐
Map animation	☐	☐	☐	☐	☐
Virtual reality	☐	☐	☐	☐	☐

The immediate benefit of introducing advanced rendering technologies and game engine is that GVIS tools are becoming more and more visually impressive. Users will be more willing to approach those visually appealing products, which is a correct reflection of people's way to perceive the world. This question asked respondents to choose their preference on the visual appearance of the different visualisations.

For basic questionnaire analysis, the numbers of answers to each question were

manually counted and sorted in a table, which can be found in *Appendix 2: Questionnaire Counts*. Microsoft Excel was used to convert this data into diagrams such as bar charts and pie charts. The diagrams were then explained together with the transcripts taken at open discussion session. The complete questionnaire analysis can be found in Section 5.2.

4.3.3 Interview and Open Discussion

This research also employed interview technique to support the findings of the questionnaire and to probe users' views on GVIS usability issues in greater depth. These interviews, and the open discussions that formed part of the workshop programme, added further useful data to this research.

Unstructured interviews were carried out, which means the questions posed were not specifically limited or set, so that the conversation could flow freely. Interviewees were encouraged to start with their reflection on viewing and using different tools.

In the Chinese part of the research (Section 7.2), interviews were used as the primary survey technique. A questionnaire was not employed because no opportunity was created to *get al*l the interviewees together. Instead individual interviews were conducted with project participants at the most convenient place for them, such as their offices and homes. Such interviews are found to be particularly helpful when explaining features of different visualisations, because many interviewees were not familiar with the concept of GVIS and the actual use of GVIS tools. It was much easier for questions asked during the survey to be answered promptly. Besides, interviewees were given plenty of time in a more intimate and relaxed environment during the face-to-face interview.

4. 4 Data and Software

Another important part of the research, undertaken prior to the workshops, was to produce the different visualisations to be demonstrated at the workshops. The data used for creating all the visualisations were provided by the corresponding research institutes and administrative bodies where experiments took place (Table 4.4).

Table 4.4 Major GIS data sources accessed in this research

Experiment One	
Data	*Source*
OSi Map	Ordnance Survey Ireland
Aerial photograph	Department of Geography, University College Cork
Digital Elevation Model (DEM)	Coastal and Marine Resources Centre (CMRC)
Digital Surface Model (DSM)	Coastal and Marine Resources Centre (CMRC)
Rainbath	William Lynn, Cork Institute of Technology
Experiment Two	
Data	*Source*
OSi Map	Ordnance Survey Ireland
Aerial photograph	Department of Geography, University College Cork South & East Cork Area Development (SECAD)
DEM	South & East Cork Area Development (SECAD)
DSM	South & East Cork Area Development (SECAD)
GIS database (Cork county)	Department of Geography, University College Cork
Experiment Three	
Data	*Source*
Planning chart	Zhushan Town Administrative Committee
DEM	Changzhou Mapping and Surveying Institute
Aerial photograph	Changzhou Mapping and Surveying Institute

To make use of the above GIS datasets and produce the various mapping products for the experiments, this research involves a number of different software platforms. The rest of this section describes what these platforms are and what they do for this thesis.

ArcGIS-version 9.2 (Environmental Systems Research Inc., 2007) was used in this research and was provided by the Department of Geography, University College Cork under an

educational license. In the experiments, ArcGIS was mainly used as a tool for processing data and creating 2D maps. For example, one of the maps in experiment one overlapped an orthophotograph with a created flood layer (Figure 4.2). The orthophoto was loaded and georeferenced to the Irish National Grid projection system in the software. The photo was then overlaid with a separate layer that had the elevation of simulated water level. More maps created in ArcMap are shown in Section 5.2 and 6.3.

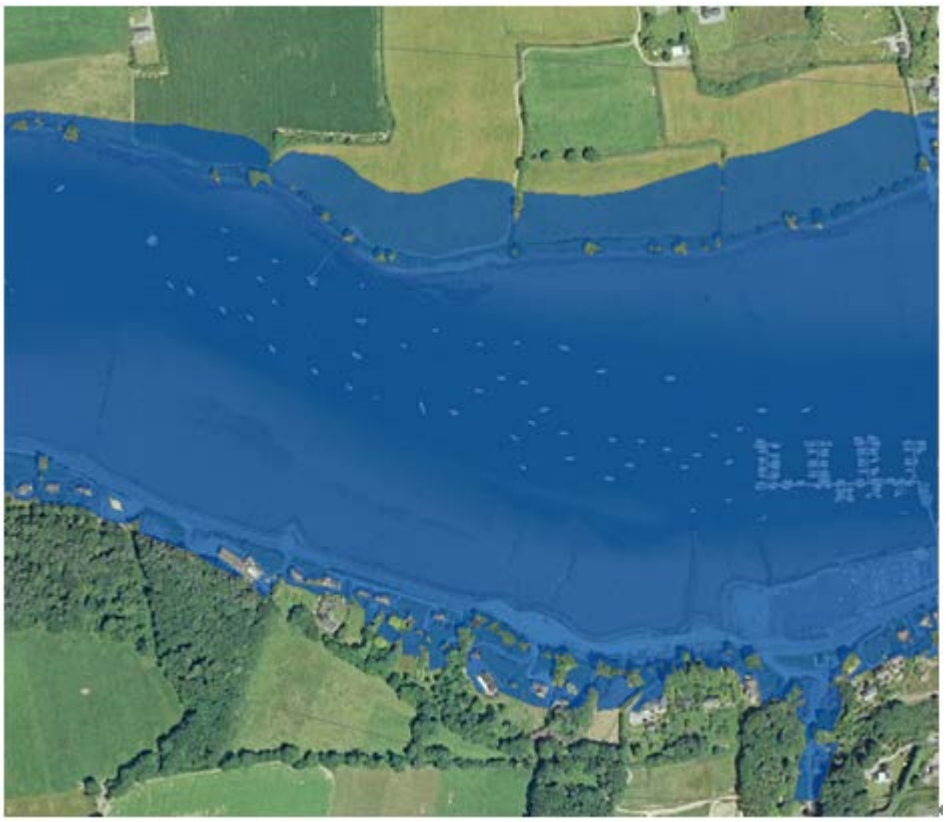


Figure 4.2 A flood map of part of Crosshaven estuary, Ireland, created using orthophoto in ArcMap

Another key software used in this research for creating 3D visualisation is ArcScene. Like ArcMap, ArcScene is originally a component of ArcGIS, but it is engineered to display GIS data in three dimensions. The software can overlay data layers in a 3D environment by reading height information from feature geometry, attributes and layer properties and layers can be handled

differently in the 3D view. Figure 4.3 shows a 3D scene of the same area containtin all the real-world features contained in the photography. Some extra features such as trees and houses were also added into the scene using the 3D models contained in ArcScene.

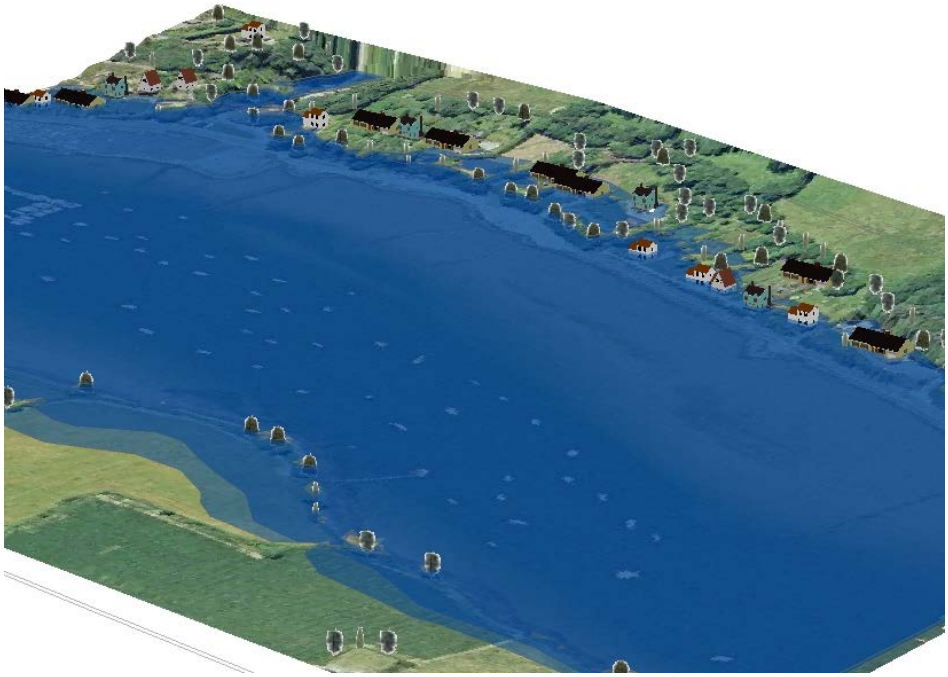


Figure 4.3 A 3D flood map of the same study area, created in ArcScene using DEM and orthophoto

ArcScene was selected in this research as the primary mapping platform because it is more specialised and powerful in handling GIS data than many commercial 3D rendering platforms. Additionally it was selected based on the consideration of making use of available software without causing extra expense by using or buying software. However ArcScene is not the best choice for creating photo-realistic 3D scenes due to its limited functionality on creating and editing customised high quality 3D models. Therefore this research employed Google SketchUp (now Trimble SketchUp) as a supplementary platform particularly for producing quality 3D models used in ArcScene.

In this study, SketchUp was used in two ways: on the one hand, it was used to design

new models for the important features contained in the 3D scene such as buildings because they are usually noted first by users; on the other, it was used to source pre-existing models in 3D Warehouse, which is a collection of 3D models created and uploaded by other users, in order to find appropriate 3D models for some of the features such as trees and street lamps. In terms of producing models in SketchUp, in order to enhance reality of the models, photograph captured on site were used as textures when rendering the models (Figure 4.4). The models were then added to the 3D surface in ArcScene as external symbols.

Figure 4.4 Creating 3D models in SketchUp using photographs captured on site

4.5 Discussion of Research Methodology

This research was built around a series of experiments that focused on coastal inundation and the information needs of decision-makers and other stakeholders who need to respond to the threats posed by this.

One problem encountered was that numbers of people who participated in the workshops was, in each case, too small to provide definitive data from which to draw universal conclusions. The participation levels were sufficient, however, to provide useful initial results,

from which suggestions can be made for further, more targeted and wide-ranging research in the future.

The profiles of the participants could likewise have usefully been expanded. For the Irish case, 19 users were approached, all of whom were representatives for a same project in Ireland from partnership institutes across the Europe. For the Chinese case, all the 15 users were government officials from the Oceanic and Fishery Bureau of Nantong city. The profiles made a reasonable representation of professional end-users from environmental and coastal management areas with a well-balanced knowledge of the design and use of GIS and GVIS. However, due to time and budget constraints, this research failed to approach a wider range of audience. For a case study aiming to investigate users' different views on GVIS tools, the more different categories of users approached the better for reaching an in-depth understanding of the issue. One potential solution to this problem might be to conduct the survey online, by means of a dedicated website. While the mapping tools used in the research are all capable of publishing output to the web, such an approach was considered impractical for the research reported on here, because of restrictions of time and other resources.

A small number of questions applied in the survey turned out to be confusing and not well understood by interviewees. For instance, one question asked whether using specific GVIS tools could significantly reduce "mental efforts". Originally this question was set to ask whether GVIS helps reduce the amount of work required for accomplishing tasks compared to traditional approaches. The words used-"mental efforts" was a direct translation from the Chinese questionnaire and it was considered strange by a number of participants at the workshop in Ireland. This suggests that precise wording of a question is critical when it is about to reach

audience from different language or cultural setting. Solution to this problem is to facilitate pilot surveys with small audience groups.

Besides, the questionnaire had a few questions, particularly at its beginning section, surrounding the topic of climate change and SLR. The primary focus of the questionnaire was to let users explore of usability of different GVIS tools, whereas setting up such questions only diverted the attention of the audience away from the focus. In the future, these questions will be replaced with ones contain critical views on usability and UCD.

4.6 Summary

This section presents an overview of how the research was built and developed. Section 4.2 describes the evolvement of research focus and explains how the central research question was brought forward. Section 4.3 explains the general methodology implemented for the surveys conducted in Ireland and in China. Section 4.4 introduces the major GVIS datasets employed and how they were assembled scientifically to create the visualisations on different GVIS platforms. The last section gives a critical reflection of the applied methodology and specifically identifies the major problems involved in the surveys.

Section 2

Developing the Conceptual Framework

Chapter 5

Reflecting User Requirements: Subject-Technology Matching

5.1 Introduction

The conceptual and operational challenges that GVIS currently faces were outlined in Chapter 2. The need for advanced representative technologies to assist in solving complex and dynamic problems was outlined and it was emphasised that resolving these challenges requires inputs from both the geographic (end-users) and visualisation communities. A clear message is conveyed that future GVIS products are meant to be more pictorial, straightforward, immersive, interactive, convenient and more user-friendly so as to facilitate the transforming of geospatial data to information and then to knowledge. It was stressed that the way a usable and useful GVIS application is designed may be more important than the actual end product itself. Previous discussions have shown that GVIS usability is uniquely featured due to user cognitive function, which is closely linked with various human factors such as preference, experience, domain knowledge and even computer skills. Efforts solely devoted to technological innovation are not enough to provide a sustainable solution. This prompts the question of whether a new approach based on UCD structure can be developed that places users in the centre of the design process more effectively thereby enhancing the usability of the design output?

This chapter addresses this question. The chapter starts with discussion of a user survey, conducted as part of this research, which provide insights of the diversity of user requirements and brings about the question of how to incorporate their requirements more effectively. This question is answered by the next section through proposing the concept of Subject-Technology Matching (STM), which offers a new approach of interpreting and reflecting user requirements.

5.2 Understanding User Requirements

Understanding of user requirements and expectations should be the starting point for designing a GVIS application, but obtaining the required information may be problematic. For this research, surveys were conducted in Ireland and in China that looked closely into users' attitude towards usability issues of GVIS tools. The methodology employed for these surveys was outlined in the previous chapter. The GVIS products presented at the workshops included a standard topographic (Ordnance Survey Ireland) map, a 2D flooding scenario, a 3D flooding scenario, an animated flooding scenario and a VR flooding simulation. Each of the products depicted the same geographical area (part of the Crosshaven estuary in Cork Harbour, Ireland). These visualisations are shown in Figure 5.1 to 5.5 inclusive, while Table 5.1 offers a summary of the main features of these different products.

Table 5.1 Main features of mapping products presented at workshop

Products	Features (strengths and weaknesses)
OSi Map	Traditional 1:25000 paper map showing basic topographic features such as contour lines, roads, rivers, etc. Flood zones were marked simply with lines in colors (Figure 5.1). **Strengths:** Easy to use, no computer skills needed. Easy to carry along, very light. **Weaknesses:** Very limited information. Not interactive. Texts to be hard to read.
2D flood mapping	Screen-based visualisation produced in ArcMap. Orthoimagery overlapped with flood layers (Figure 5.2). **Strengths:** High-resolution image shows details on the earth surface in reality. Basic interaction (e.g., zoom in/out). **Weaknesses:** Fixed viewing angle not to be changed. Requiring specific software platform (i.e. ArcMap).
3D flood mapping	Screen-based visualisation produced in ArcScene. Landscape created by overlapping DEM and orthoimagery. Trees and buildings symbolized with 3D models (Figure 5.3). **Strengths:** 3D viewing environment with enhanced reality. Enhanced interaction (e.g., rotation) **Weaknesses:** Not enough realism of 3D models. Requires specific software platform (i.e. ArcScene).
Animated flood mapping	Screen-based animation composed by a series of static flood maps. Created in ArcScene using DSM and orthoimagey (Figure 5.4). **Strengths:** Motion picture showing the change of water level. **Weaknesses:** Video format cannot be changed or edited. Not interactive.
Rainbath VR simulator	A customised SketchUp software which allows users to create a virtual flood scenario for Cork city centre (Figure 5.5). **Strengths:** Fully immersive and realistic viewing environment. High-level interaction, creating unique 3D models. **Weaknesses:** Requiring specific software platform (i.e. SketchUp). Intensive 3D rendering work requires powerful compuer hardware.

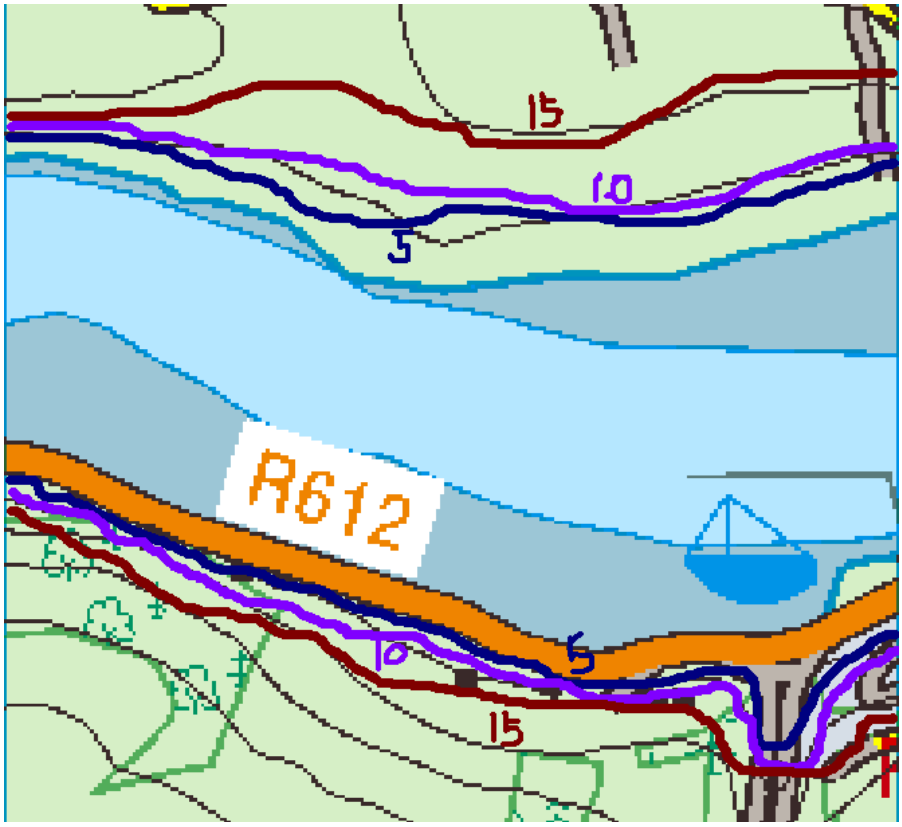


Figure 5.1 Extract of a traditional 1:25000 OSi map with added coloured lines to show flooded area under different conditions of sea-level rise

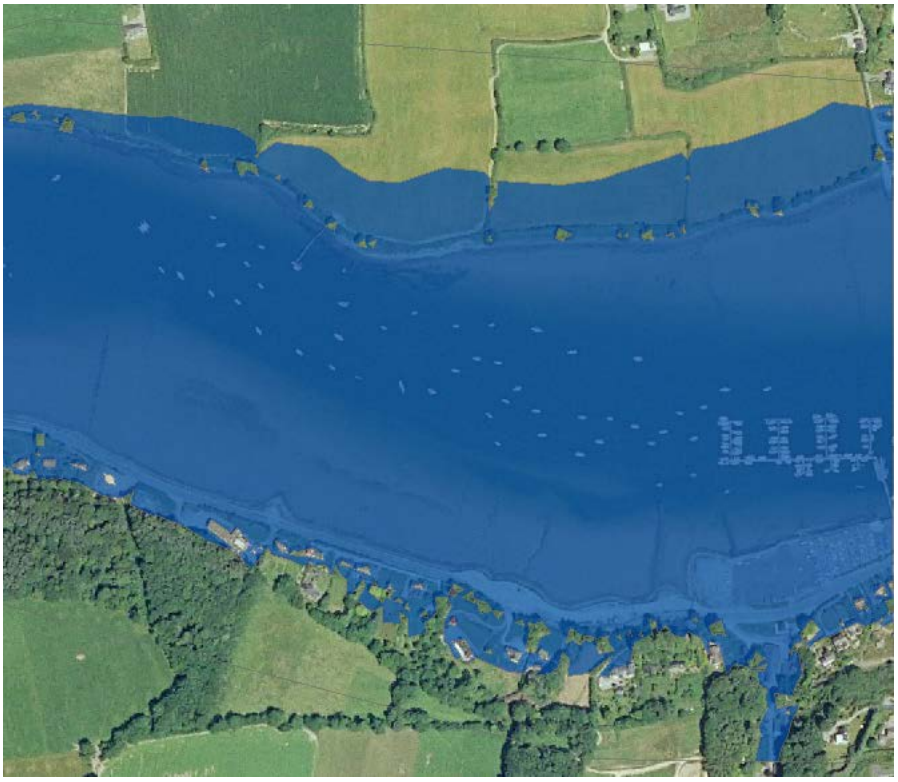


Figure 5.2 Mashup of 2m aerial photograph with simulated water layer

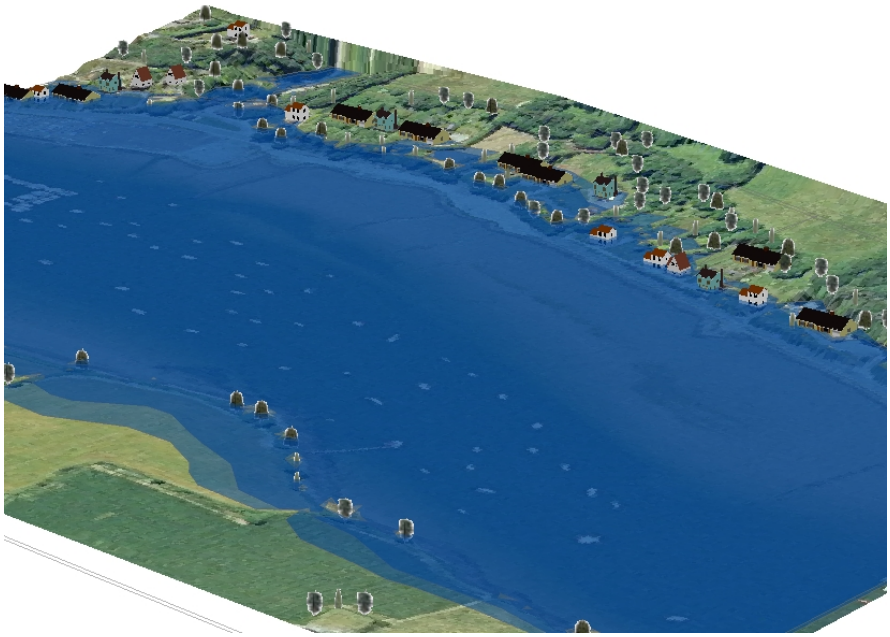


Figure 5.3 3D landscape modelling (DEM+3D models) with simulated water layer

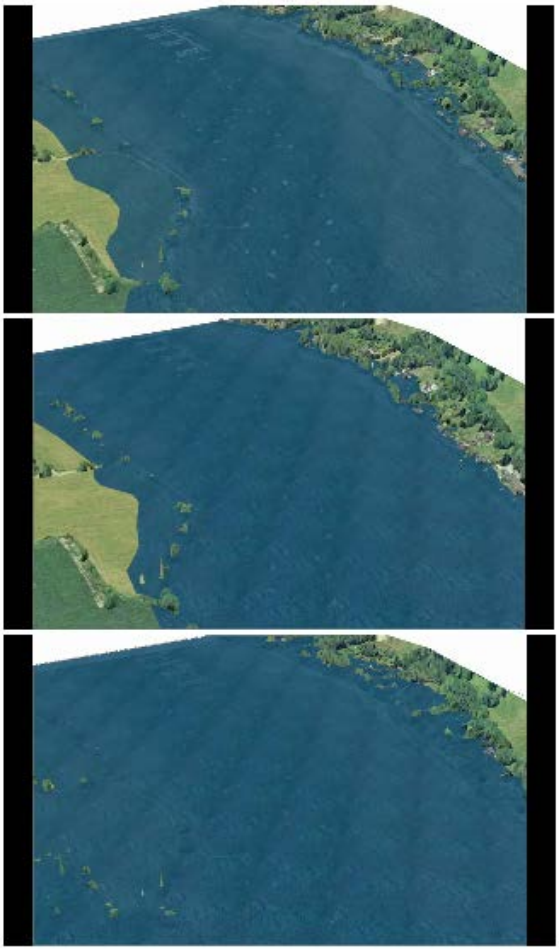


Figure 5.4 Animated mapping of mashup of DSM and aerial photograph

Figure 5.5 Rainbath virtual reality software for urban flooding (Courtesy of William Lynn, 2010)

Workshop participants were asked to complete a questionnaire, whose major findings will be shown in the rest of this section, including the results of each question (see *Appendix 3: Questionnaire Analysis* for all diagrams) and an overall view of the analysis.

The result of Question 1 (see Appendix 3) shows that all the visualisations displayed, no matter they are 2D map or virtual reality, convey the flood scenario in a correct way. Almost all the respondents give their opinion "*Agree*" and "*Strongly Agree*" based on their own experience. Only one participant selects "*Neither*" and explains later in the discussion session as,

> *"I can see at my first glance that it is a flooding scenario with a clear display of the land and water, but there should be some sort of text or label sign to show where the exact location is. I understand we are told where the location is orally before the presentation, but I'm too old to remember. There are so many parts of the coastline that might look exactly the same."*

This statement poses a spatial orientation question against coastal applications. Compared with urban environment, coastal environment provides even less reference for users to recognize the surrounding. Such problem can be critical in large scale visualisation-assisted

coast management systems.

In Question 2 (see Appendix 3) Less than half of the people in both of the two groups agree with the scenario visualised. One response on this was,

> *"Yes I believe the situation will go like this if the sea-level keeps going up", or "It is likely that the case speaks for itself if [the site was] hit by a storm…sea-level rise would not make it happen like this solely."*

However, a certain number of respondents chose "*Neither*". Suggested by their working contexts, they are not fully involved in coast management or vulnerability management and presumably they do not feel themselves in a position to make a judgment on the correctness of the scenario. Those respondents who vote on "*Disagree*" and "*Strongly Disagree*" are the experts in coastal management and they are quite familiar with SLR issues. One comment states,

> *"while the sea surface is supposed to rise to such height and half of the houses down in the water, you are talking about a [sea-level] rise of around 10 metres high…this is not going to happen."*

It is all agreed that the visualisations give a clear predictive description of

> *"…what we would see in the future if [the current sea-level rise] is further escalated [by climate change]. It is worthwhile to help decision makers to make preparations. The only thing is [here in China] that most of our coastline is protected by sea wall which is reinforced each year and they never really need to be worried too much. It is unnecessary to make a fuss over what may not happen in the future."*

Two different situations are presented by responses from the two groups for Question 3 (see Appendix 3). Most of the CG participants (11/15) agree with this statement. Two of the group raise a different view and one of them states,

> *"I'm in charge of [the section of] fishery supervision with few chances of using [these types of] visualisation technology. I use a computer everyday only for routine tasks such as checking emails and reading news. It would not be possible for me to sit down and learn to operate a system like this."*

Regarding the IG reflection, six people express their disagreement with this statement and another five people chose "*Not sure*". Taking into account the diverse background of all participants, it can be anticipated that on the one hand, GVIS is complicated due to its

integration of GIS, cartography and computer graphics, etc. and their associated analytical functions. Most of the domain-specific GVIS systems require certain knowledge and operating skills to bring the product into effect, which might become an issue for users without professional trainings and which might also be the case with the respondents. On the other hand, GVIS is the use of spatial representations or maps to depict these data. It creates visual display facilitating users' thinking and problem solving and embodies cognitive, experiential and perceptual components. With vivid depiction, GVIS helps users save mental efforts in the cognitive process of visual thinking.

Responses to Question 4 (see Appendix 3) form a sharp contrast. Most of the IG participants (15/19) are not sure whether using GVIS will help save the cost of decision making, while most of the CG participants (12/15) believe it does work. Such contrast suggests an interesting fact that the Irish audience is very cautious about cost-effectiveness of implementing new technologies, whereas most of the Chinese audience do not worry about it at all. The reasons behind such contrast are teased out by two comments from the CG. One respondent states that,

> *"In China things are usually what we called 'administration-driven' instead of 'requirement-driven', which is why any technology system we have here is huge [in size] and all-inclusive [for functions]. Usually a fine-looking system with high efficiency would receive greater attention."*

And another respondent echos,

> *"We are different from western countries, where a project could spend up to one year or longer time in conducting feasibility evaluation before creating and adopting a new system. Here when designing systems, we take more into consideration the satisfaction of our authorities than the system itself. If the head of a department is happy enough about the system, there should be no problem of implementing it. "*

Such statements help clarify that it is the different administrative system in China that makes Chinese decision makers far less concerned about costs involved in developing and

implementing advanced technologies, which could make usability a particular problem in China. It also proves that, as mentioned at the beginning of this section, different social and cultural environments could also affect a user's view on usability.

For Question 5 (see Appendix 3), apparently all the respondents agree that GVIS is critical in communicating geographical information such as climate change, which suggests the overwhelming popularity of GVIS application. However one respondent raises an issues that,

> *"There are many web-based platforms that issue useful geo-information with a focus on different areas to the whole public, but the amount of visits is very low. They are still not accepted by the public. The reason is partly because the interface is not friendly enough, but more importantly people are still not aware enough of geo-information and its usefulness. To ensure the quality of communication, we need to make geo-information more approachable to the public."*

This suggests that although GVIS application such as online mapping can be accessed from everywhere, it is still seen not widely accessed. People use online mapping service mostly for navigation purpose, or simply their interests in exploring the world. Successful domain-specific GVIS tools (e.g., flood mapping) are still not known enough by the general public.

Results of Question 6 (see Appendix 3) show that 2D and 3D mapping products are primary choices in both groups as they are the most widely used forms of presentation in current cartographic and GIS applications. Apparently most participants (17/19 in the IG and 13/15 in the CG) believe that spatial analysis based on 3D data will be the future trend when more and more data are collected and stored in 3D form. While the IG respondents find paper maps still work, most of the respondents of the CG (11/15) think a paper map is getting less effective. For example a respondent states,

> *"…now we can't live without a computer and [we can't] work without a computer. Traditional paper map has already been left behind and replaced by modern technologies, not even to mention to be used in complex analysis."*

For Question 7 (see Appendix 3), Irish participants are generally optimistic and active in response to this question, where 8 out of 19 of them believe that new technologies such as animation and VR will certainly be "*Very effective*" on the general public. One participant states,

> *"Advanced visualisations such as VR will allow people to view detailed features like lawns, roads, buildings, which will be easily recognizable for local people. This will assist them to accept the quality of the information [you show them]."*

Another participant states,

"I think 3D is more straightforward, vivid, [and people] will be more willing to see."

Some participants believe that paper maps and 2D mapping will be ineffective in future communication with general public as an interesting comment goes,

> *"Human beings are 'visual' animals as we believe what we see, right? People love to see 3D and they love to link it with real world, but obviously you can't do it with a paper [map]."*

Still some participants believe paper maps are in good use. One respondent argues,

> *"There are [a lot of the] old generation who used to live without computers for most of their life. They probably never saw computers before, but they all know paper maps. A simple map works even better, so why not?"*

This argument is further echoed by CG responses, one of which states,

> *"If you look at the map of northern Jiangsu, there're not many towns next to the sea. Those who live closely to the sea are local farmers working on shellfish culture. What we do mostly is approaching to their farms and talk with them, sometimes we explain on paper maps, but never our laptops."*

Responses to Question 8 (see Appendix 3) from the IG are interestingly average. Paper map, 2D, 3D and map animation are equally preferred, while only 3D is slightly higher rated than other three. At the same time, performance of VR are not really satisfying as only seven people choose "*Effective*" or above, while four people chose "*Ineffective*". This suggests that the latest technology is surprisingly not appreciated by everybody. Looking at the CG on the other hand, 3D and animation are increasingly becoming the decision maker's favourite, while paper map and 2D are not so preferable, but still remaining at a reasonably good level. Over half of the CG

participants (11/15) don't see a clear future of VR. One of them states,

> *"Decision makers would be familiar with OSi map with simple mash-up and [such mapping] also clearly defines the land-use and land boundaries on the map affected by flooding."*

Another participant points out that,

> *"The accuracy of GVIS data is critically important to us decision makers. But it doesn't mean that we [always] need LIDAR or high-resolution remote sensing imagery. It is also too expensive to ask for LIDAR for the whole of our coastline."*

It is also stated that,

> *"In 2006 while we worked with Environment Protection Administration on Taihu Lake Cyanobacteria Incident, we kept provincial governor informed with a daily status report. 3D models were used to show the evolvement of the incident, together with comprehensive detailed statistical diagrams and text analysis. Three days later the governor still asked why we couldn't just show a simple graph depicting the change of the affected area of the lake."*

The results of Question 9 (see Appendix 3) are quite the same for both two groups. Most people (13/19 and 10/15 separately) still find paper map and 2D mapping relatively easy to use. Those people who are more used to a computer working environment also prefer 3D mapping given that more information is provided in a 3D setting. Taking into account the comments from previous questions, it is not difficult to find that many people are still used to working with 2D products. One CG participant states,

> *"I used to be a cartographer before taking the current position and we worked with paper maps for over twenty years. I know the whole world is entering the era of 3D, but I always think paper map is the most straightforward type [of maps]."*

This statement points out the fact that a lot of the users are more used to 2D environments and they find that 3D tools lead to certain level of usage difficulties. In this particular case of mapping flood, 2D map does provide a better overview of the flooding status and being static make users need not to worry about any interaction with the software. Therefore it is probably still too early to say whether 2D will be replaced by 3D in the future. How to present an easier-to-use environment and make users more comfortable remains a

challenge for 3D tools.

Results of Question 10 (see Appendix 3) present a quite similar response comes from both groups. Paper map, 2D and 3D are still the most preferred products regarding time-consuming of usage, while no votes are given to either animation or VR. Apparently people are not fully convinced by the performance of the latter two techniques. For example, animation is essentially a video that can be played and there is nothing else to do except repeatedly playing it in order to view the contained information. With regard to VR, users spend most of the time on changing angels and zooming in/out in order to find the information they are about to find. Participants from both groups states that,

"We *have to keep either going back to check the instructions or asking other people for help. For example, I spent roughly the same time on getting used to working with this tool at the beginning as on finishing the rest of the tasks. "*

Results of Question 11 (see Appendix 3) suggest visual effect is the winning factor of 3D tools compared with other 2D products. 3D certainly provides a more realistic expression of the scenario, while virtual reality technologies provide a more immersive navigation and observation experience. At the same time, map animation draws a lot of attention because of its dynamic presentation of information which is particularly significant in this case of coastal inundation simulation. People would be more comfortable to see the flooding simulation as an actual image just as what might be really happening – water gradually going up and inundating the nearby places going over the geographic objects in sight. One comment regarding this is,

> *"The animation leaves me a deep impression as it is straightforward and easy to understand. It can help the authority make prompts decision for action."*

Results of Question 12 (see Appendix 3) are very mingled as shown by the diagram.

Most of the votes go to 2D and 3D, while comparatively speaking a lot more people firmly believe that 3D is the best tool for them to use. This reflects sharply from some of the previous findings that the more likely trend is the in-depth use of 3D but with the essential support of 2D. One Irish respondent stated,

> *"The 3D effects are quite useful in delineating the scenarios of the risks and impacts of flooding, but a lot of information is still concealed or unseen and not as easy to capture due to the effects."*

"*Ineffective*" votes mostly go to paper map and virtual reality which are interestingly the least and the most advanced types of visualisation. In both cases there are quite a few people (10/19 and 9/15 separately) who are uncertain about their experience with virtual reality technologies. This can be related to some of the concerns about virtual reality implicated by previous questions and results.

A major issue to be investigated through the survey was whether users' understanding and perception of flooding scenario will be improved when display is upgraded from two-dimensional to three-dimensional. One of the research aims to unveil the usability concerns behind the technology use. The concerns were addressed via a comparative study of replies from two groups based on the participants' personal empirical experience. In order to show a clear image of the usability investigation, these results were revisited and gathered altogether with a systematic comb. The approach adopted was quite simple – the numbers of votes that each visualisation obtained with Questions 6 to Question 12 inclusive were counted. The 1st rank represented the greatest number of votes obtained and the 5th rank represented the least number of votes obtained and they were summarised in Table 5.2. Figure 5.6 offers a more visual display of the summary by displaying the data in a plotting diagram.

Table 5.2 Rankings gained by different visualisations in answering Questions 6-12

Questions	Ranking				
	1	2	3	4	5
Q6 How effective … used for analytical works?	3D	Ani.*	2D	VR*	Paper*
Q7 How effective … used for communication with public?	Ani.	VR	3D	Paper	2D
Q8 How effective … used for general decision making?	3D	Ani.	2D	Paper	VR
Q9 Which one … is the easiest to use?	Paper	2D	3D	Ani.	VR
Q10 Which one … cost the least time to finish all tasks?	2D	3D	Paper	Ani.	VR
Q11 To what extent … visually attractive to you?	Ani	VR	3D	2D	Paper
Q12 How satisfied … to work with these visualisations?	3D	Ani.	VR	2D	Paper

***Ani. for *Map animation*, VR for *Virtual reality* and Paper for *Paper map* in the survey**

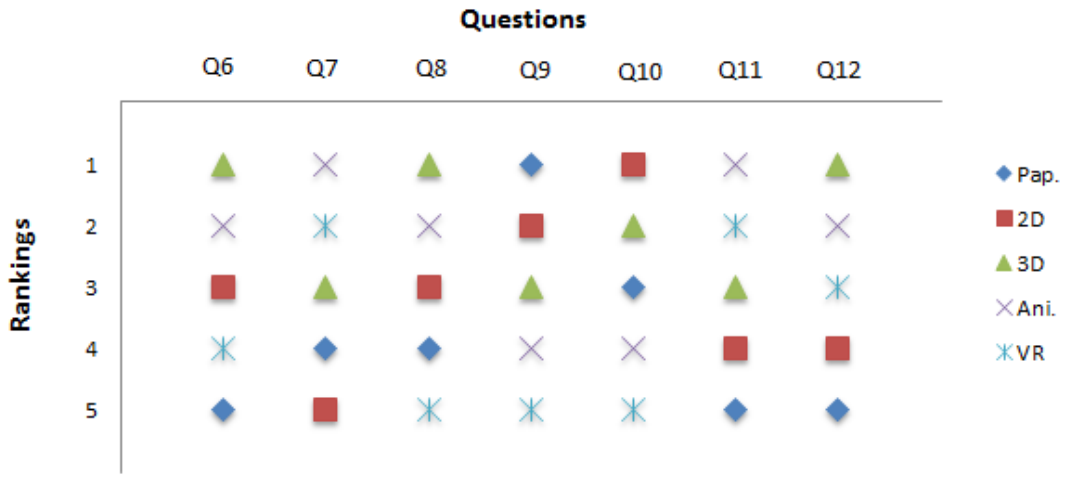


Figure 5.6 Rankings of preferences for alternative visualisation types

Figure 5.6 delivers an interesting message: there was no single "winner" in this "match" among these different visualisations and there were a lot of ups and downs in their performance. For example, the virtual reality visualisation represents the latest immersive visualisation technology but delivered a poor performance in most of the questions. The best overall performance came from the 3D visualisation which remained top three for all the questions. At the same time, traditional visualisations still showed their advantages on some aspects such as ease of use and time consumption. In this sense, the results show that the latest visual technologies do not necessarily always mean the best performance. It is thereby crucial to adjust the use of visualisation tools according to specific user groups and user needs.

The questions disclosed are not confined to this study, or to the specific two groups of users, or to the specific GVIS products presented in the workshops, as data exploration tasks are usually very broad and hard to define and evaluation of usability in achieving these tasks is quite a challenge (Andrienko and Andrienko, 2006). Nevertheless, the above analysis triggers several thoughts in relation to the usability of GVIS design:

1) It is important to look beyond immediate "sexiness" of technologies.

It is noted that the take-up of new technologies can be driven both by society requirements ("pull" factors) and by technology feeding itself ("push" factors). The most common driving force is that the users (or customers) have the idea of cutting the cost of a system in application, or improving its service and asking for a new product design occurs to meet the increasing requirement (Gould and Lewis, 1985; Dumas and Redish, 1993; Shneiderman, 1998; Dumas, 2007; Wassink, *et al.*, 2009). It can also be the case that an existing system is too difficult to use and users wish to replace it with a simpler and easier product. Another driving force is the attempt of testing a new piece of technology in a specific application area and it is usually because the technology has the advantage to create a new possibility for the current product or the potential to open a market for a new product (Gould, 1998; Shneiderman, 1998; Dumas, 2007; Nivala, *et al.*, 2007). Both reasons lead to the continuous and phenomenal adoption of new technologies. Nowadays the computerised and virtualised world seen on screens is becoming visually more "sexy" thanks to new rendering and display technologies applied. However, it should be noticed that visual presentation is only one of the four fundamental functions of GVIS (see Figure 2.17) and it is not sensible to overlook the other three functions particularly for the applications that are attempted to go to professional decision-makers. Being "sexy" and "useful" should be carefully balanced and structured in order to deliver a sound GVIS design. This can be reflected by some of the comments made by participants at the workshops. For example, one participant said,

> *"I like the [map] animation because it is very straightforward, [and it] looks perfectly showing the actual motion of tide going up. The last simulation gives a 'real' layout of the city centre and it just looks amazing. However both of them seem to probably work well in particular areas and I wonder if they're ready enough to provide more useful*

analysing tools? I mean it's just from my own experience that we use two dimensional maps in most of areas and we are happy enough with them."

Another participant stated,

"Current GIS tools development asks for an interaction between users and developers from [selecting the appropriate] platform, data structure, interface [design] to presentation. A logical way is to think about us users first rather than a new [software] platform or data structure."

This is a voice for technology development and a call for technology improvement as well. Andrienko and Andrienko (2006) point out that many data analysts only allow users to make discoveries and generate hypotheses, whereas users also expect to verify these discoveries and hypotheses with the tools. Many ill-designed tools put most effort on leveraging the visual exploration without offering essential and appropriate confirmatory techniques, such as linking attributes data query and outputting statistics. It is thereby suspected that the overall poor performance of VR at the workshop was due to its lack of convincing potential of providing analytical functions, which made participants found it difficult to see the strength of decision-making support apart from the advanced interactive interface.

2) A better understanding of users is needed more than ever.

In traditional cartographic mapping, understanding the customers (or end-users) is considered as the way to provide end-users with a map that works effectively for the tasks that the map is aimed at (Harley and Woodward, 1987; Taylor, 1991; Liebenberg and Demhardt, 2012). Researchers in recent GVIS development are usually dedicated to designing generic tools and techniques rather than addressing specific users, which is often described by people as "re-invent others' wills" (Slocum, *et al.*, 2001; Kraak and Ormeling, 2003). Earlier sections of this thesis stated that established principles and approaches of user-centred design will not be fully applied to this domain due to the exploratory nature of GVIS (see Section 2.2.5). Tools required

for investigating one specific aspect of a geographic event can be varied and relate to the intrinsically complex nature of data exploration and there is no single visualisation that is capable of showing the whole, which is the reason Fuhrman *et al.* (2005) urge designers not to focus at the general user level but identify different domain users so as to orientate the system development correctly.

In order to deliver a comprehensive understanding of users, this study argues that one should consider at least three aspects:

Firstly, identify domain and non-domain user groups. Domain users hold the necessary contextual knowledge as well as technology-use experience of a specific area, thus they are the direct targeted audience. From a usability point of view, a domain-specified application includes specific features, which may be difficult to understand by non-domain users. However the involvement of non-domain users in the evaluation is considered as a way to gauge the level of acceptance of the product. The attitude towards usability could be quite different between domain and non-domain users. One of the workshop participants, who had many years' GIS development experience, stated that,

> *"…visualisation opens up a way to display the data and is deeply rooted in technical platform and data structure. I heard that some people are researching how to use better-designed symbols for mapping, [which sounds more like] arts instead of technology. Because it is arts, there can hardly be any principles [about what to do]."*

The above was an interesting observation from a software development technician who was convinced that the fundamental way (and probably the most practical way) to improve usability is the improvement on programme functionality and data structure. However, such views neglect the fact that the technical elements of a design are usually beyond the end-users' scope of knowledge and doing so may eventually lead to the misplacement of developers the

centre of design process.

Secondly, identify the usage situation. Designers should realise that a system developed can possibly be used in a real-world situation that is unfamiliar to them, whereas the end-users usually have a clear idea of the potential application of the product. For example, one participant at the workshop said,

> *"For each of these [mapping products], I can actually picture the proper situation where this tool is exactly needed or workable in the effective way. For example the map animation is quite good in showing the Odd Tide at our area."*

The word *Odd Tide* refers to an unusual episodic tide-level rising that frequently happens in summer times on southern Jiangsu coastal mud flat that caused accidental death of local shellfish farmers. An "Odd Tide" monitoring network funded by the central government is being established in Nantong city. By referring to this issue, the participant linked animated GVIS tool to his domain knowledge and opened the door for one potential invaluable application area. In this sense, the end-users' empirical and field experience may help GVIS design find the suitable usage with the appropriate audience.

Thirdly, take into account the demographic factors of users. It was found in the survey that users' preference towards GVIS product was closely linked with their individual features including age group, educational and training background, occupation and computer literacy. These demographic factors of users can be easily neglected in the actual design process. Designers should be aware that users' individual differences such as cognitive capacities, socio-demographic profile, individual knowledge base will decide the way they use a product (Slocum *et al.*, 2001; 2005). A number of workshop participants expressed their concern about using sophisticated technologies such as virtual environment simulator. For example, one said,

> *"I like the way that VR works, and you can add detailed buildings, trees and cars. But I*

just find it so difficult to remember which buttons should be clicked [to do that]. I have seen people at city planning department [using the similar system] to depict a new building in the planned construction site and see the [change of] skyline, but those are young people who know more about computer [technologies].”

The survey showed that quite a few users tend to avoid using sophisticated systems and instead, they will ask designated technical personnel to operate the system. Take the immersive VR tool presented at the workshops as an example, the adoption of gaming engine made system operation more “enjoyable” than before, but it inevitably challenged users for a higher level of computer skills. How to alleviate the complexities involved in using the product becomes a significant challenge for designers and the likely solution is to deliver a thorough and well-established user analysis for the design, which yet has not been investigated by GVIS practitioners.

3) Users’ improved understanding of the design process is equally critical.

Most of the mapping product developments nowadays are built on a platform of past practice (Nivala, *et al.*, 2007). The assumption behind this is that by doing so, most of the obvious usability problems can be easily avoided. Modern technologies allow a user interface composed with numbers of modules and it is easy to make changes to modules whenever necessary. Therefore it is possibly more important for developers to consider whether or not the data is up-to-date, accurate enough and easily delivered to users. It is often presumed that users would be concerned more about the first prototype based on which they could give very specific feedback. One reflection from the survey was,

“The companies we selected to work with are those who have a good reputation in the area and adequate experience on similar projects” and “we usually set up a schedule [for them] to come up with a prototype. It is indeed easier for us to give comments based on something that is there.”

Users also expressed their concern about the quality of the product, for example, one

participant stated,

> *"Yes we do like to know how the application is realised. Personally I don't know any of those terminologies used in GIS or 3D things, but we have a technician at the department [who will be] responsible for [things like] database management and system maintenance. If the company has previous experience creating a system, for example, for neighbour city, I still hope to see if they can make something differently for us."*

The question still remains in what way users can know more about the design and development process. While relevant studies suggest it is important for designers to facilitate good understanding of user requirements (Slocum, *et al.*, 2001; Fuhrmann, *et al.*, 2005; Lloyd, *et al.*, 2007), we believe that it is equally important to establish an effective communication mechanism from the beginning for end-users to know keep track of the product evolvement.

5.3 Subject-Technology Matching

5.3.1 Definition of STM

Subject-Technology Matching is the new method proposed by this research looking for a better solution of understanding user requirements and reflecting them in the design process. *Subject* (S) and *technology* (T) are the coupled elements of this new term. In this research *subject* is defined as the specific items are formed by geovisualisation experts via classifying and layering user requirements in terms of issue, data, technique and application. Subject is therefore not any pre-existing item, but output of user requirement analysis by GVIS experts. It can be understood as the type of key information that has strong technological indications and represents user expectations on the design. In this sense, user requirements will need to be transformed into subjects before being used to assist the design. In the above definition, *classifying* and *layering* refer to the type of interpretation that involves horizontal and vertical separation and extraction of a specific theme. The horizontal is called classifying and the vertical

is called layering. Such interpretation is meant to acquire as much key information as possible and sort them out in a scientific manner. Figure 5.7 is an illustration of such interpretation with SLR issue as an example. As shown in the picture, layering of the theme can be considered as a process of asking four questions.

What do users expect to do is the first question which confirms the theme of a GVIS application. Sea-level rise (SLR), in this case, is a complicated geographical event that can possibly lead to a number of different consequences and can be further separated. Horizontally sub-themes such as flooding, erosion, saline intrusion can thus be set up accordingly. One specific GVIS application is usually designed to serve one specific task or in other words, focuses on one of these sub-themes. Whatever a task is, it is important to understand it from the perspective of understanding its umbrella theme which is associated with knowledge that can be critical for tool design. Therefore this question is to clarify the themes of a GVIS application and associate them with specific domain knowledge.

The second layering question is what kind of data is needed, which confirms the data used for building the application. There are many different types of data that can be used for creating GVIS tools and these data can be classified into such as spatial and attribute data, thematic and non-thematic data, referenced and non-referenced data. The classifications do not label a dataset according to its specific application area. Knowledge and expertise of those who are familiar with GVIS data use thus can be quite helpful. This means not any software patch or toolkit but a knowledge warehouse of understanding the data that can (or should) be used as well as the approaches to collect, store, manage and use them.

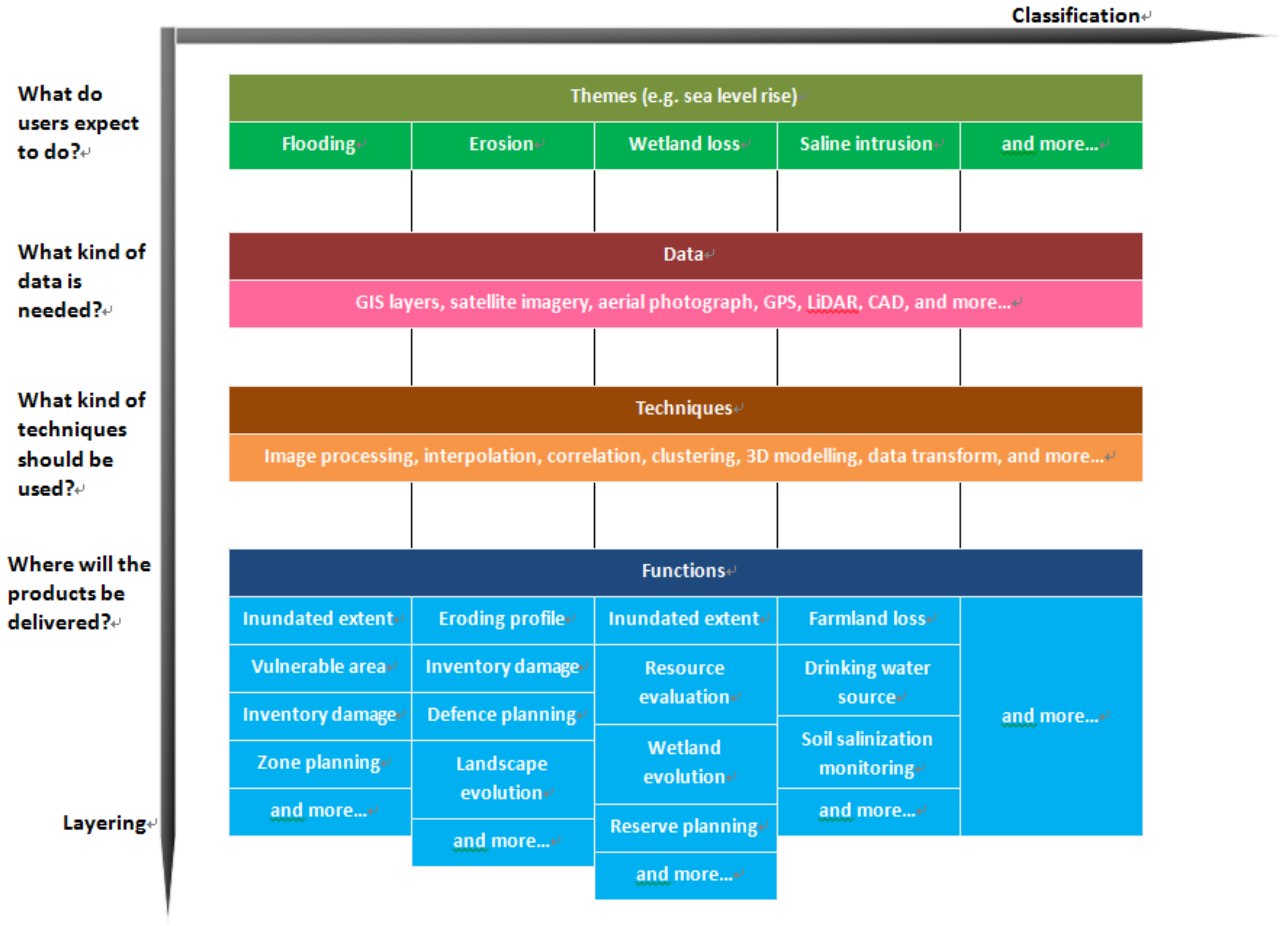


Figure 5.7 Classification and layering to retrieve subjects

The next layering question is what kind of techniques should be employed which confirms available techniques for a design. Techniques can be referred to data acquisition and preparation methods such as image processing and surface interpolation, vast range of geo-processing techniques such as buffering or feature overlay, or output technologies such as static thematic mapping or map animation. Similarly this relies on the knowledge inputs of those who know well about technology use of GVIS and this means the establishment of a knowledge warehouse of potentially available technologies. The above illustration does not associate horizontal classification of GVIS technologies to sub-themes because usually a theme is likely to be achieved by a mixture of several technologies.

The last layering question to ask is Where will the products be delivered, confirming targeted application fields of the visualisations to be created, which are closely related to the design of the functionalities. For instance, in the above illustration, visualising coastal erosion can serve the purposes of displaying shoreline retreat, creating eroding profile or symbolizing inventory damage, simulating coastal landscape evolution as well as assisting coastal defence planning. Each of these purposes indicates and determines certain functionalities that a GVIS tool should deliver and they should be clearly identified before carrying out the design. Again the establishement of such a warehouse of application fields will greatly help experts to find out the problems and their corresponding solutions.

Having explained the above four questions, it is apparent that the core idea of this layering work is not to simply transcribe the records or tidy up the texts, but to interpret user requirements from a GVIS knowledge perspective which will be explained later in this chapter. The aim is to gain a better understanding of users' demands, which will not always be promptly

or explicitly stated in textual or verbal user requirements, particularly when users have limited knowledge of the GVIS technologies involved. Classifying and layering tend to establish a useful knowledge base of themes, datasets, technologies and applications. To have such knowledge and experience usually requires designers to have a good and wide understanding of a large number of relevant application cases, or best practices, from similar GVIS projects. The whole process of extracting and proposing specific subjects is thus quite open and very much dependent on designers' knowledge level. Some examples of STM will be shown later in this chapter.

The other element *technology*, which has been mentioned when explaining *subject*, is easy to understand and can be explained described as those technical measures and processing approaches that are used in GVIS design. For instance, an online map service such as Google Map allows users to search for information about an object at one specific location, or Point of Interest (POT) and this function needs be realised by the rapid spatial – attribute query performed in the spatial database behind the interface. Technically each function needs to be realised by one piece of technology or a series of techniques. Either term *technology* or *technique* can be used when referring to the applying of certain technology (or technique) for corresponding subject.

The last element of STM is *matching*. STM is the process of matching subject and appropriate technology and generating instructive working scripts, which means STM is a two-part working process. For each proposed subject, there needs to be a corresponding technical solution. Instead of using *linking* or *connecting*, this research uses *matching* to highlight the fact that it should be ensured that one technique is the optimal choice compared with others and

optimal choice means that main elements of usability should be delivered. The output of such matching is a tabulated summary of STM which contains three columns of contents – subjects, technologies and matching remarks.

Apparently there is no computer-aided automation of retrieving subjects and matching them with techniques and the output of STM completely relies on experts' knowledge and experience in relating to the application area and generally the way of doing STM can be described as the following.

> *"Aiming at one theme, designers need to collect and summarise current common (and popular) geovisualisation technologies on this particular theme through extensively reviewing and analysing relevant cases. Based on the expert knowledge, acquired user requirements are represented by a list of to-be-achieved subjects. For each subject, experts propose one technology respectively and match the two. All these subjects, technologies and their matching relations are recorded and displayed in a table with support annotations."*

From a developer's perspective, the process of finding a technical solution happens during the design and development anyway. The problem of insufficient coordination and communication of traditional development framework is because, no matter how straightforward or unnecessary such processes seem to be, they are not communicated promptly and users either do not know or cannot understand them. This is why a sensible method is needed to let users know how the GVIS is designed and developed in a more sensible and effective way. In addition, using STM is to bring together adequate knowledge from designers to secure a quality understanding of user requirements, which if often neglected by designers.

The context of a project, the available dataset, the individual knowledge and expertise of three parties will lead to the creation of unique STM documents. Technically it is still possible for different scripts to share some same STM items. For those GVIS applications that fall into a

same domain, many of the items can possibly be the same or similar enough to be applied in subsequent GVIS design projects. Table 5.3 gives a STM template taking the example of creating static coastal inundation visualisation. In the table, HM refers to High-level Matching, which means the suggested technology is likely to be the best solution for the subject, while NM refers to Normal-level Matching and it means that the suggested technology is limited or optional.

Table 5.3 Potential STMs involved in static coastal inundation visualisation

Subject (classification and layering of user requirement)	Technology (techniques recommended by GVIS experts for the subject)	Matching (expected performance)
Terrain surface/landscape (pictorial, immersive)	High-resolution orthoimagery	HM
	High-resolution DEM	HM
	Coast bathmetry	NM
	High-resolution DSM	NM
Exploratory --navigation (interactive)	Panning	HM
	Zooming	HM
	Rotation	HM
	Multiple views	HM
Large scale scene	Scene segmentation	HM
Realism --3D view --walkthrough (pictorial, immersive)	3D objects--buildings, plants, vehicles, etc	HM
	Level of details (LOD)	NM
	Rendering to texture (RTT)	NM
	CG texture--all objects and water	HM
	Real world texture	NM
	Symbology--colour theme--textual label	HM
	Highlighting	HM
	Real-time lightening--shade--water reflection	NM
Spatial analysis --attribute data --raster and vector analysis --map output (interactive)	2D, 3D Query	HM
	Point of interest (POI)	HM
	Statistical results (histogram, pie chart, scatterplot, etc)	HM
	Mapping tools (density, choropleth, etc)	NM
Temporal sequence	Time series output--change of inundated areas	HM
Ease of use (convenient, user-friendly)	Interface layout	HM
	Artistic design (buttons, toolbars, etc)	NM
Platform (convenient)	GIS-based --open source or commercial software	HM

This example lists those STM items that might be involved in a static coastal inundation visualisation project. The length of this list is subject to the functions to be delivered by the proposed product. 3D or VR environments, for instance, require more sophisticated exploratory navigation functions, thus the corresponding STMs will be extended. There is always room for additional STMs if the proposed GVIS product is going to employ advanced and sophisticated technologies and the length of the list is going to be longer. However, STM does not always guarantee the final output, thus proposed matching might not be achieved in actual prototyping due to all types of technical or non-technical constraints in the actual project.

Table 5.4 lists several extra STMs that possibly will be added when creating an advanced and dynamic coastal inundation visualisation in addition to Table 5.3 and a lot of the techniques used in static visualisation are often used in dynamic visualisation as well. Many of the basic items listed in this flooding-focused STM document, may also appear in other relevant applications, such as erosion, wetland loss, etc. In this sample document, most of the matching pairs are marked as “HM”, which are believed to be essential for the design. For instance, high-resolution DEM is believed to be the primary option for landscape reconstruction. In case of only low-resolution DEM is available in the actual development process, this matching will be updated and downgraded to “NM”. This means the visual quality of the landscape will be reduced and the reduced precision will affect further analysis, which might cause the consequent dropping of user satisfaction. Some “NM” items in the list are suggested as optional and they often serve the purpose of enhancing certain aspects of the product.

Table 5.4 Extra potential STMs for dynamic coastal inundation visualisation

Subject (Summary, classification and layering of user requirement)	Technology (techniques selected by the subject)	Matching (circumstance of matching and performance)
Exploratory --navigation (interactive)	Routing --travel-through, fly-by	HM
Realism --3D view --walkthrough (pictorial, immersive)	Objects in motion --moving vehicles --swinging plants	HM
	Water modeling --running/flowing effects	HM
Temporal sequence	Animation --change of water level --change of illumination	HM
Platform	Gaming engine or other simulation environment	HM

5.3.2 STM Examples

It can be summarised that the implementation of STM relies on the analysis of user requirements based on their knowledge of GVIS practices in relating to the specific topic. Previous sections also suggest that the output of STM is a table-form of working scripts, in which those key technical targets involved in the project are clearly stated and matched with suggested GVIS techniques. This section showcases four examples of STM from projects that focus mainly on flooding and erosion visualisation. It has to be noted that these projects were undertaken by other scholars and for purpose independent of the present research. They do not involve any elements of STM and are presented here simply to demonstrate what a STM document might look like.

Yangtze River flood monitoring

The first example comes from a project that applies 3D GVIS technologies for scientific river basin management for Yangtze River Jingjiang section (Zhan, *et al.*, 2011). GIS technologies

are introduced to provide a novel solution for water level monitoring and river basin management systems. High resolution base data are acquired from aerial and land based digital photogrammetric survey and a 3D working environment is built by employing ArcEngine, ArcSDE and Oracle 9i. This simulator aims to provide an immersive display of the landscape with a particular focus on historical architects in the area, which are considered highly vulnerable to the flooding threat (Figure 5.8).

Figure 5.8 3D walkthrough in the virtual Jinjiang city (upper) and POI query of protected architects in the system (lower) (Source: Zhan, *et al.*, 2011)

Aerial photography is used to display the background of the targeted area, while 3D models are created for key landscape features including those significant architects. Several spatial analytical tools are provided in this system, such as the interactive 2D/3D spatial query of ground features. Table 5.5 presents major STMs involved in the design of this simulator. Because the background aerial photograph is overlaid with 3D models without being rendered, thus they do not match very well in the scene, which affect the overall level of realism of the visualisation and that's why some items are rated NM in the table.

Table 5.5 STMs of the 3D Yangtze River flood monitoring project

Subject (summary ,classification and layering of user requirement)	Technology (techniques selected by the subject)	Matching (circumstance of matching and performance)
3D landscape visualisation	High resolution DEM, Orthoimage overlay	NM
Large scale scenes	Scene segmentation (DB-Group-Object-Face-Subface)	HM
Sense of reality	Mip-Map texture mapping	NM
	3D models	NM
Real-time walkthrough	ArcScene-based environment	HM
	LOD (level of details)	HM
	Seamless scene change	HM
GIS analysis (area and volume calculation, topology, cross and vertical section of buildings)	2D/3D POI query	HM
	3D feature editing	HM
Functionality (flood dynamic management) --real-time water level simulation --routing model and forecasting --flood discharge area --emergency plan	-Extended functions	Not stated

Beach morphology change analysis

The second example comes from a project conducted by Mitasova *et al.* (2003) that investigates coast erosion as part of beach morphology change, which is another event closely associated with SLR. Based on the observation of the change of beach morphology over a certain period of time, both the spatial and temporal features (extent and rate) are visualised. High-resolution LIDAR dataset is used to display the coastline and the beach, while RTK-GPS data were collected at a number of points across the coast to record the retreat of the coastline. All the data and analytical functions are integrated in GRASS GIS platform (Figure 5.9).

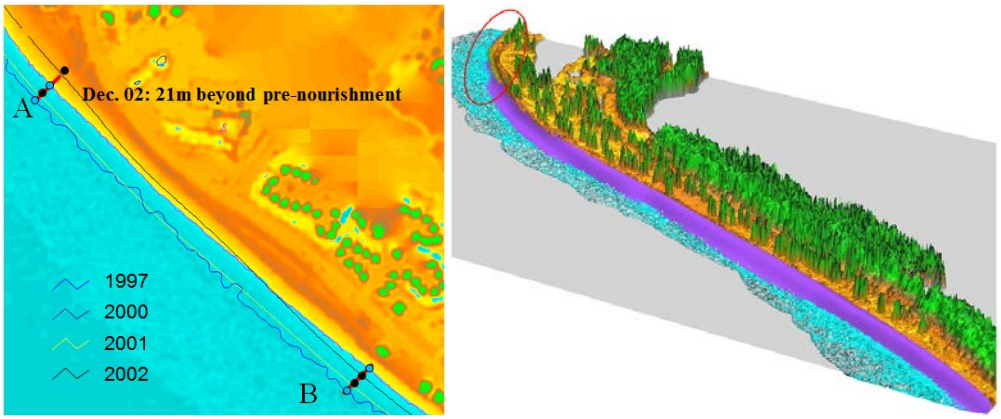


Figure 5.9 2D visualisation of shoreline change (upper) and 3D shoreline change after nourishment (lower) on Bald Head Island, NC (Source: Mitasova, *et al.*, 2003)

The use of LIDAR data provides unique image of 3D coastal topography evolution at a reasonably high resolution sufficient for identifying features such as water body, shoreline, the land and coastal vegetation. As the primary task is to show the change of shoreline, the system does not involve any extra 3D modeling or rendering of the ground features. This is probably based on the consideration of reducing possibly distracting detail, allowing the user to focus on the "bigger picture" overview. The system provides GIS-based analytical functions that allow users to quantify observed changes such as elevation, shoreline, volume, slope, etc. Key STM

items are summarised in Table 5.6.

Table 5.6 STMs of the coastal morphology change analysis project

Subject (summary ,classification and layering of user requirement)	Technology (techniques selected by the subject)	Matching (circumstance of matching and performance)
Topological survey -- bathmetry -- beach topography	--LiDAR data --RTK-GPS data (10cm vertical resolution) --Interferometric sonar sounding	***HM***
3D terrain visualisation	·-RST approach to extract DEM from LiDAR ·-Color theme highlighting landscape	***HM***
Numerical modelling -- surface differences -- elevation differences	·Raster data analysis ·3D cutting plane ·Beach profile separation	***HM***
Temporal sequence	·LiDAR data 1997-2000 ·Masks created to extract representing points	***HM***
System flexibility and implementation	·GRASS GIS platform	***HM***
Functionality ·Beach morphology management -- coast erosion monitoring -- sediment loss monitoring -- coast refurbishment engineering	·Application extensions	***HM***

Flood disaster on the Columbia River

Traditional static maps have been recognized as insufficient when being applied to display phenomena that involve temporal changes. When probing into those dynamic and complex problems, a common solution is to create a time series of static images. This can be further animated to help interpret a changing event such as flood disaster. In this example, Gessel (2007) creates a 3D cartographic animation based on ArcGIS 3D Analyst (Figure 5.10). Colour themed TIN model (generated with DEM) is used as the background highlighting the topology of the river valley. The flooding event is overlaid as a separate data layer.

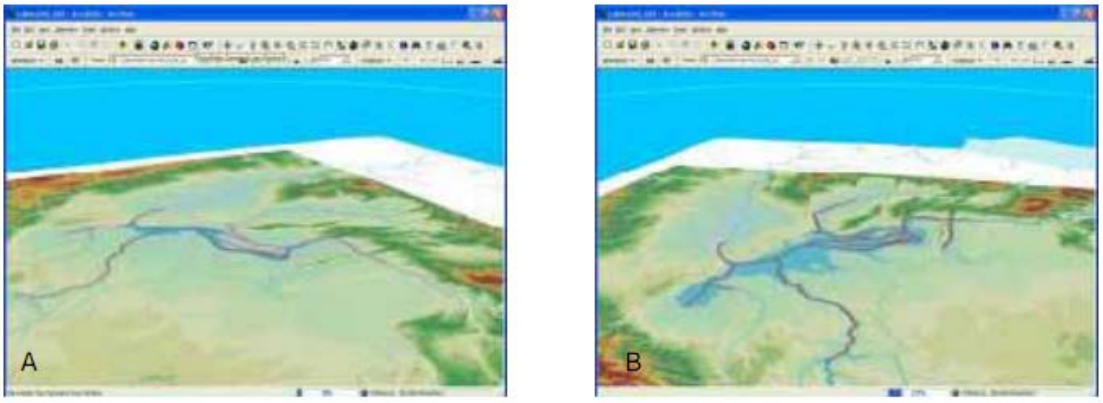


Figure 5.10 Flood Path indication by the system (Source: Gessel, 2007)

The output of this GVIS tool is a video file of an animated flooding event, users can see the development of flooded areas along the river. Although strictly speaking videos are not typical mapping products, they provide a straightforward and easy-to-understand overview of the situation for non-expert users. Table 5.7 summarises the major STM items involved in the design.

5.3.3 Future: STM Template Set

It is possible for two STM documents to have similar contents if two projects have the similar themes and applications, but in practice each GVIS application has its own specific problems to be solved and it is unlikely that a generic STM document could be applied to each different occasion. To make the use of STM more sustainable, a STM template set is proposed as part of the research findings. A STM template set can be understood as a well organised collection of STM documents that are inherited from previous projects and documents, and that are categorised according to the themes.

Table 5.7 STMs of flood disaster animation project

Subject (summary, classification and layering of user requirement)	Technology (techniques selected by the subject)	Matching (circumstance of matching and performance)
3D landscape visualisation	--DEMs-GTOPO30, USGS 1:250000 DEMs, National Elevation Data Set and USGS 10m DEMs -- Orthoimage – MrSID format, 1m resolution	HM
Sense of reality -- Vegetation cover	-- Orthoimagery interpretation and classification -- Coloring	NM
Visual mapping -- Datasets requirement -- Environment setting -- Animation setting	Create narrative summary and visualisation scripts -- group layer animation -- View scroll (camera move) -- animations combination --change of water level --flow path (with arrow) --change of illumination, background color and transparency	HM
Software flexibility	ArcGIS 9.2, ArcGlobe	NM
Functionality Hazard presentation system --Flood routing simulation --Historic flood database (video-based)	-- Customised extensions -- video collection (in .avi format)	HM

The term “template” suggests that STM documents used in previous GVIS designs can be modified and re-used as templates for other subsequent projects with similar theme. The afore-mentioned classifying and layering approach used for retrieving subjects encourages a set of STM documents and template sets to be built up according to their respective themes. The number of documents contained in the collection and the quality of the documents will be critically important to the functionality of the set. In this case, the construction of the template set can begin with a relatively small collection of documents looking at one specific domain. A number of STM templates within the same domain will form a small domain focused template

set and a few small sets across relevant domains will make a larger set, thus the template set can be upgraded and expanded in such way. For example, STM document created for coastal flooding, erosion, wetland loss, etc. can be pulled together to establish a *coastal disaster GVIS STM template set* and if other documents, such as coastal inventory, landscape, ecological conservation, fishery and tourism, were also added, the original set can be expanded to a larger theme. In order to help enhance usability of a GVIS design and development, the STM template set should have the following properties and characteristics:

- *Reusable*. Each template can be fully or partially used to instruct subsequent design activities. All the templates contained in the base use the same simplified and standardized format so as to ensure quick retrieval and easy deployment.
- *Extendable*. Each template supports further editing when applied to a specific area. Designers are allowed to update a template with verified and technically feasible content. The base becomes increasing useful when more templates are stored.
- *Flexible*. Either single template or a combination of relevant templates can be used to advice the design. Templates across multiple disciplines can also work together to provide tailored solutions.

The advantages of employing such a template set include:

- *Save manpower involved in the development*. By consulting the templates, it will be possible for a relatively small team to deliver a quality GVIS design.
- *Overall cost-saving*. Making use of templates will help propose a well-structured design and a sensible view towards employing new and expensive technologies. It also helps make the best out of available resources thus avoiding unnecessary cost

- *Save time spent on design*. To reuse design templates can make developers quickly run into the right track of sourcing required data and technologies as well as adjusingt the design to specific changes. Therefore the whole project schedule can be significantly reduced.

STM is derived from user requirements through experts' interpretation and ultimately it is a type of expert knowledge and the role of STM in a design process is similar to the role of a case in case-based reasoning (CBR, see *Appendix 6: Case-based Reasoning System*) in AI research area. In this sense, each STM document is a case of GVIS solution to a specific problem and the template set is a container that hosts all different cases that represent knowledge of tackling various problems. To retrieve, reuse, revise and retain STM document drives the life cycle of a template set (Figure 5.11). It should be noted that the whole operation of STM and STM template set construction is based on subjective work of the experts in terms of interpreting user requirements using their own knowledge. Therefore STM template set cannot be simply considered as a kind of knowledge base, it cannot be simply considered as an expert system in AI engineering, because it does not have an inference engine or similar mechanism.

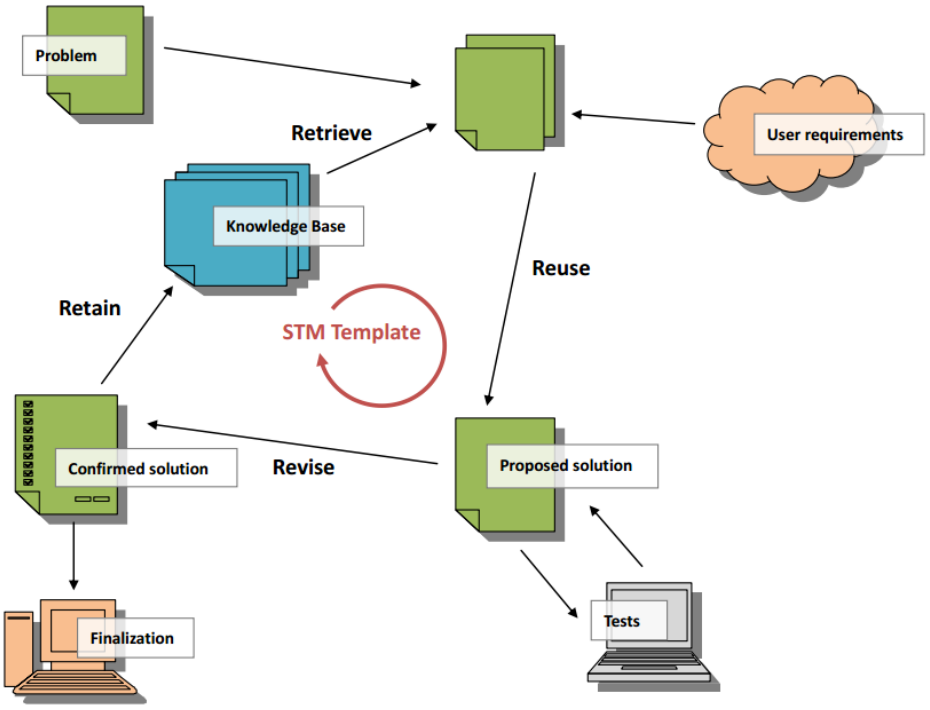


Figure 5.11 The STM template set cycle

5.4 Summary

This chapter presents the results of workshop survey, which showcase the diversity as well as complexity of user requirements that will potentially affect a GVIS design. In order to gain a better understanding of user requirements, this chapter brings forward the first key original concept of this research: Subject-Technology Matching (STM). The detailed structure of STM is explained together with examples derived from previous projects. The key role of STM will be seen from the new design framework discussed in the next Chapter.

Chapter 6

Usability-enhanced Coordination Design

6.1 Introduction

As teased out in previous chapters, there have been quite a few discussions about usability issues across a range of disciplines. In the area of GVIS, arguments have also been made repeatedly through the work of many scholars (MacEachren and Kraak, 2001; Slocum, *et al.*, 2001; Sheppard, 2001, 2005; Bishop and Rohrmann, 2003; Fuhrmann, *et al.*, 2005; Andrienko, 2006) (see Chapter 3), which deliver a clear message that usability needs to be incorporated in the design process and the design of a GVIS product should be established upon a good understanding of user requirements. It should be clear that ultimately users judge the usability of GVIS applications and users should be put in the centre of a GVIS design process with sufficient interaction and communication with the developers. Their requirements need to be promptly elicited and understood by the designers. At the same time, as shown by the survey, user requirements can be hard to capture and reflect in the design without sufficient support of domain knowledge and expertise.

Although a new approach like STM can be a good solution to a better facilitation of user requirements, STM alone is insufficient to improve usability engineering in a GVIS design. Thus,

a major conclusion of the current research is that the concept of STM must be extended, and incorporated into a more comprehensive framework that will centralize users and facilitate their requirements more effectively. It has been shown that GVIS is characterised by its cognitive nature and the significance of GVIS tools is to augment users' spatial interpretation and perception and help users discover and understand patterns out of complex geographical events. Due to such a cognitive nature, GVIS is meant to facilitate the process of transforming geo-data to geo-information and geo-information to geo-knowledge. In this sense, there are three essential principles that become the basis of bringing forward a new GVIS design framework, i.e. that of Usability Enhanced Coordination Design (UECD).

The first principle is **the requirement of focusing on user cognition**. GVIS is associated with cognition and communication (DiBiase, 1990; Taylor, 1991b; DiDiase, *et al.*, 1992; MacEachren, *et al.*, 2004; MacEachren, 2005) and the objective of a GVIS application is to enhance user's understanding of a geographical problem. It asks for strengthening and deepening cognitive functionality of visualisation at all key stages of interpreting and communicating a geographical process. The focus on enlarging cognition capacity of GVIS tools has already become a growing field of GVIS studies and many recent practices investigated in this paper (section 3.2) have shown that improved data and information visualisation methods are applied for the purpose of enhancing spatial cognition. As mentioned in section 2.5.2, future GVIS is expected to be more pictorial, more straightforward, more immersive, more interactive, more convenient and more user friendly in order to meet the cognition requirements.

The second principle is **the requirement of focusing on usability**. To meet the requirements addressed above, the functionality and performance of GVIS tools need to be

indicated and measured scientifically. Usability is a critical indication of the designed functionalities (enabled by certain techniques) according to user requirements, but it is a uniquely intuitive and complex performance indicator of GVIS and it is complex because there is no established and agreed way to measure it. In ISO 9241-11 (ISO, 1998), usability is defined according to three parameters: effectiveness, efficiency and satisfaction. They are three distinct aspects, which are considered as essential elements of user-centred design. While effectiveness and efficiency are specific components with a clear definition, user's satisfaction is a broader term closely related to the user's subjective opinion about products. It is usually measured as complex attributes or environments depending on the application domain. The realization of usability-focused counts on effectively identifying target users and their characteristics; defining user requirements and understanding their expectations; and prompting the communication and involvement of stakeholders in research and development process.

The third principle is **the requirement of coordinating design process and enhancing user involvement**. An effective and sustainable design approach should always avoid one-way, purely technology-driven development with blindness and low efficiency. UCD is a methodology widely used to guide information system design focusing on understanding the needs and requirements of users. To improve usability requires a two-way communication and interaction between users and developers and this kind of communication should carry out along the whole process of development. The two key elements highlighted in this principle are *coordinating* and *enhancing*, which claim the importance of making users as much involved as possible in the design process and setting up a coordinated work flow.

6.2 Structure of UECD

Usability-Enhanced Coordination Design (UECD) is an original idea, as well as one of the main “products”, brought forward as part of this research. The proposal of this new design framework is meant to fill in the gap of insufficient usability integration in current GVIS design. The framework is drawn on the above STM approach and it aims to make a GVIS design process focus on usability from the beginning to the end so that output design can be as useful as possible to meet users’ specific requirements.

The conceptual model of UECD can be described as “three-party and five-phase” (see Figure 6.1;Table 6.1). In this model, the whole design includes five major phases: data collection, user requirement collection, STM, prototyping and usability testing and this process involves the participation of three parties: users, GVIS experts and developers, among which the later two make up the design team.

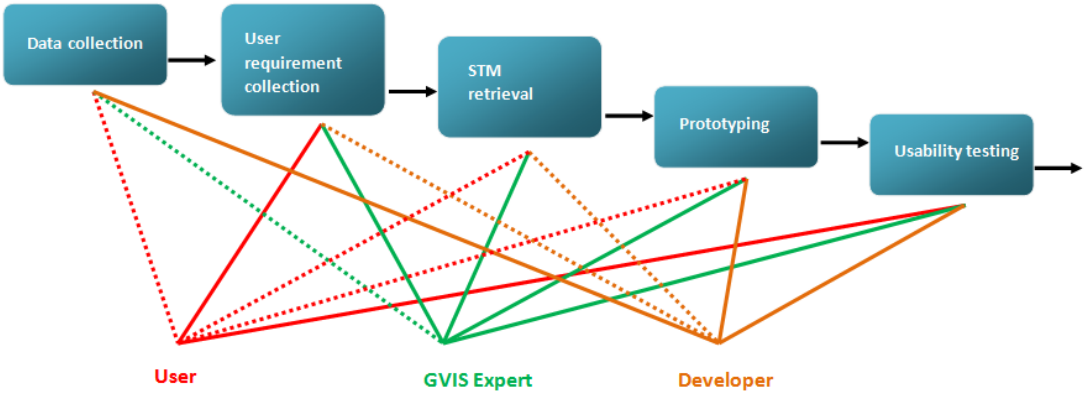


Figure 6.1 UECD conceptual model. The lines connecting the phases indicate the involvement of the parties within the specific phases. Solid lines manifest a strong involvement, while dash lines indicate a relatively less strong involvement

Table 6.1 Components of UECD model

Component	Definition
User	A user is an agent, either human or product or service, that uses a product or service. In the context of computer science, a user is also called end user, which refers to the ultimate operator of a piece of software, but it is also a concept in software engineering, referring to an abstraction of that group of end users (i.e. the expected user or target user).
GVIS expert	A GVIS expert is a person who holds the domain knowledge, expertise and experience of GIS or GVIS. This person can be a researcher from an academic institute or a GIS or GVIS practitioner from relevant domains. It is better to involve two or more such experts as a team in the design.
Developer	A software developer is a person concerned with facets of the software development process. Compared with a "programmer", a "developer" would be involved in wider aspects of the software process such as design, product definition, cost-benefit analysis, etc. There are usually several developers in a design team.
Data collection	Data collection refers to the search for available dataset to be used in a development process. Datasets can be sourced from both users and other data vendors such as Ordnance Survey Ireland (OSI), Geological Survey of Ireland (GSI) and Environment Protection Agency (EPA) or even developers. In many cases, data will also be collected on field.
User requirement collection	An important and difficult step of designing a software product is determining what the users actually expect it to do. User Requirement collection is the stage that the expectation and needs of users are sounded out through certain interactive ways by developers and then noted and transcribed into certain forms of records.
STM	STM is an abbreviation for Subject – Technology Matching, which refers to the process that GVIS experts classify user requirements into scientifically described subjects and find the best (most appropriate) technologies accordingly for the subjects. This is a completely new concept brought up by UECD framework
Prototyping	In a broader sense the term development usually includes all that is involved between the conception of the desired product through to the final manifestation of the product, ideally in a planned and structured process. Here it simply refers to all the works involved in design, structure and produce the GVIS tool.
Usability Testing (including regular testing)	Testing is an investigation conducted to provide stakeholders with information about the quality of the product under test. In software engineering, testing usually includes, but not limited to, executing product with the intention of spotting "bugs". Usability test is the general concept of a testing mechanism used in any product manufacture. It aims to make a product user-friendly and productive, for users to use and more demand-oriented (or user oriented) rather than supply-oriented. A usability test usually means letting potential users go through a series of tasks using the given product.

Phase One – Data Collection

Data is always important for a GVIS project and data availability is usually the first thing to be investigated by the design team, thus the priority of this beginning phase is to gain access to the potential data sources that are available for the project. The data can be sourced at the development team's side or users' side and the data can be free or purchased depending on requirements. In UECD, data collection is marked as the first phase because a clear idea of data availability enables the design team to come up with appropriate technical solutions for specific targets (or *subjects* in STM). This phase is connected with all the three parties because they can all be possible hosts of useful data, where the solid line connecting developers claims that they are mainly responsible for data collection. Data collection is of course not a single phase at the beginning of the design and it can be a continuous work throughout the process when new tasks ask for additional data.

Phase Two – User requirement collection

Rogers *et al.* (2011) define a requirement as "*a statement about an intended product that specifies what it should do and how it should perform*." A better understanding of users and their expectations and requirements determines the success of a design. UCD emphasises the significance of user-centred concept and this phase is where users' involvement starts. The organisation of such involvement is the key to a successful user-centred process. There are many different ways for the design team to approach users, such as face-to-face meetings, telephone calls or email contacts, which are all useful methods for collecting requirements. The collected requirements need to be carefully transcribed and interpreted afterwards so as to yield usable information for GVIS design and put it on the right track. *Developer* is connected with this phase

by a dash line in the above picture because UECD believes that *GVIS expert* will deliver a better performance when primarily conducting the work of this phase.

Phase Three – STM

This is the core element of UECD, the major work of which is to generate STM documents for instructing the follow-up prototyping. STM is mainly performed by GVIS experts, where they extract those key subjects out of user requirements available and list these subjects as the technical objectives to be addressed in the prototype. The domain knowledge and expertise possessed by GVIS experts enable them to work out the appropriate solutions for these objectives. This document will help developers to more efficiently construct a viable prototype. Although STM documents are made and retrieved by GVIS experts, they are still in the need of being confirmed and validated by developers, which is why the dash lines connect them as well in the diagram.

Phase Four – Prototyping

Prototyping is the stage where developers come up with the proposed GVIS tools. In UECD, prototyping follows the instruction of the STM document and prototyping is the process of validating STM scripts since the features expected by users still need to be validated by GVIS experts and developers in terms of project constraints such as access to specific dataset, software platforms or techniques. Prototyping is also the stage where all data are brought together and technically assembled by developers. During this course, GVIS need to work with developers to make sure designed functions can reflect users' needs.

Phase Five – Usability test

Developers often conduct a series of tests (referred to as “debugging” in software engineering) after prototyping to capture technical flaws. Usability testing is different from common tests as it investigates user experience of the proposed product in terms of aspects such as, effectiveness, efficiency and satisfaction. The test can be quite open, which means testers could employ different indices to evaluate product features. In a UECD framework, GVIS experts and developers jointly conduct the test and invite the participation of potential end-users. All the feedback gained from the tests will be sent back to the design process to help improve the design, thus it is a phase that requires full involvement of all the three parties.

The basic structure of UECD was shown in Figure 5.12 which highlights the overall flow of the framework from a project management perspective, whereas from a slightly different angle, Figure 5.13 gives a more detailed supplementary illustration of the activities involved in the process. It shows the flow of user requirement acquisition, the creation and use of STM scripts and how user needs are incorporated in the iterative design.

UCD suggests that the design should be an iterative and cyclical process so that tests can be conducted repeatedly. Gould *et al.* (1991) state the four key points of user centred design as follows:

- **Early focus on users**. Product designers should try to understand users’ needs as early as possible in the design process.
- **Integrated design**. All aspects of the design should evolve together from the start. Internal design of the product should tailor to the needs of users.
- **Early and continual testing**. The rule is simple: the design only works if end-users

decide its works. Therefore the only feasible design approach is to incorporate usability testing throughout the process so that users are given chances to deliver feedback on the design before its final release.

- **Iterative design**. Small problems can accumulate and turn to big problems. Designers and developers need to revise the design iteratively throughout the rounds of testing.

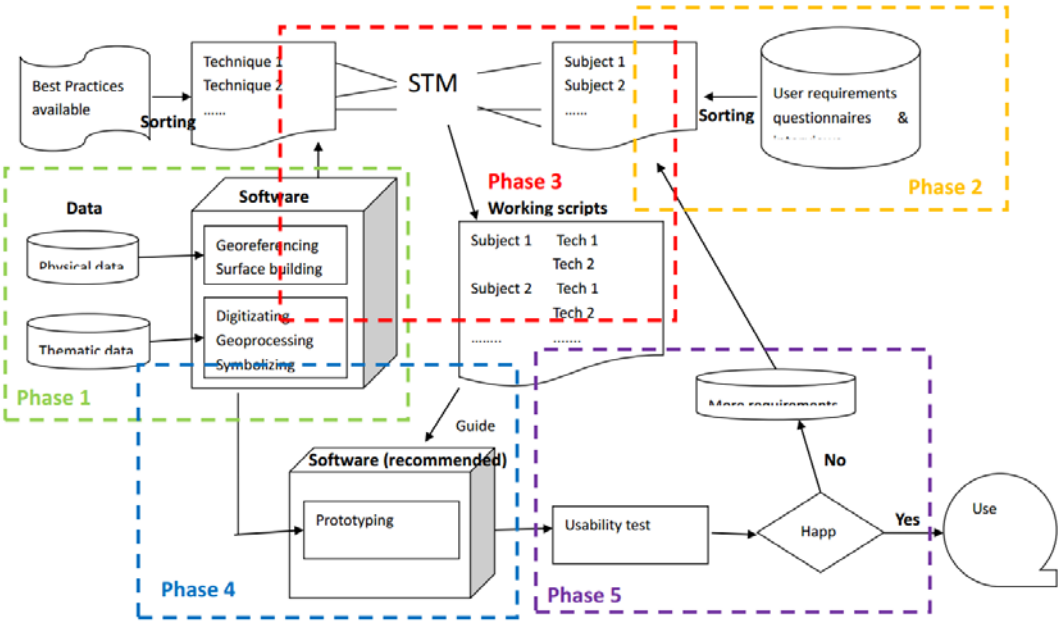


Figure 6.2 The major activities involved in a UECD framework

It has to be noted that the UECD model is separate from the actual product development. Its role is to highlight the different roles and connections of the three parties that are participating in a GVIS product development. The concept of "three-party and five-phase" can be blended into a waterfall, spiral or hybrid development model (Boehm, 1984; Boehm, 1988; Paula Filho, 2006; see *Appendix 7: Waterfall or Spiral Development Model?*) depending on the actual organisation of the whole project.

6.3 Coordinated Workflow

From a system design perspective, requirement analysis is the mainstay of a user-centred approach creating products that appeal to users and meet their needs at the closest level. It provides precise descriptions of the content, functionality and quality demanded by prospective users. The advantages of a successful user requirement collection can help identify potential user populations, find out what they expect from the product and learn how they will accomplish their tasks with it. A sound GVIS tool should stand out based on a good understanding of user requirements. Through mediation and interpretation by GVIS experts, user requirements can be more straightforward for developers to blend into tool design. There are various existing ways of conducting surveys to gather user requirements depending on the specific research context and the context of target users and a summary is given in Table 6.2 stating the concept of these methods as well as their benefits and drawbacks.

Table 6.2 Main methods of collecting user requirements

Method/Technique	Description	Benefit	Drawback
Scenarios/User cases/Persons	Detailed realistic examples of how users may carry out their tasks in a specified context with the future platform	Personas can bring their user needs to life	Scenarios may raise expectations too much. Personas may over simplify the population
User Surveys	A set of written questions to a sample population of users. Surveys can help determine needs, current work practices and attitudes to the new system ideas	Relatively quick method of determining preferences of large user groups/allows statistical analysis	Does not capture in depth comments and may not permit follow-up
Focus Groups	This technique brings together a cross-section of users/stakeholders in discussion group format. A useful method for requirements elicitation	Allows rapid abstinence of a wide variety of user views	Recruitment effort to assemble groups. Dominant participants may influence group disproportionately
Interviewing	A series of fixed questions (about needs or requirements) with scope for the end user to expand on his/her response	Interviews allow quick elicitations of ideas and concepts	Possible different opinions from different users
Existing Systems/Competitor Analysis	Comparison of expected product with existing systems	Effective in identifying current problems, possible new features and acceptance criteria	May lead to including too many new functions or make system too similar to a competitor's

Figure 6.3 presents the workflow for collecting user requirements through a workshop-based approach. The structure is fully interactive, adaptive, and works particularly well for reaching several users at one time. The primary goal of the workshop is to let users check GVIS examples and encourage them to voice their preferences for the one(s) to be developed. From preliminary experience of this research, the focus of the demonstration workshop should be made different from the original project focus, so as to prevent participants from forming misconceptions that the project will produce a GVIS tool that is either very different or nearly the same as the one demonstrated. An easy way is to present the users with a selection of example GVIS products, based on a simple dataset relevant either for the same target area (subsection) or a different but comparable location.

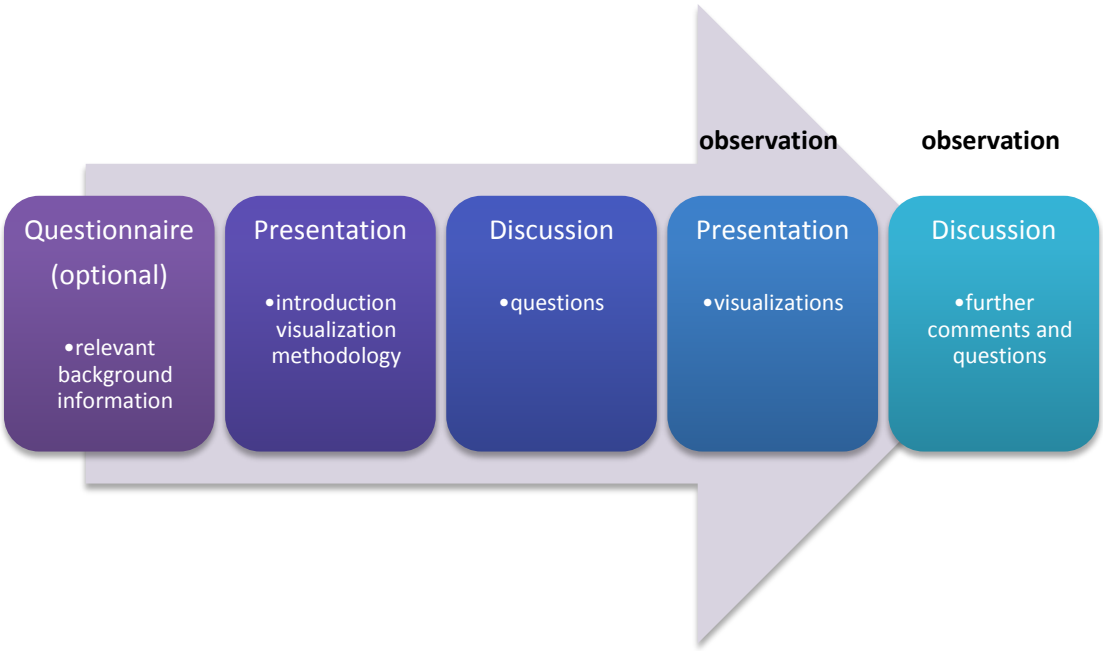


Figure 6.3 Example of organisation of a workshop for gathering user requirements

Another key phase of development is to produce STM working scripts. Since the STM task is one to be accomplished largely by GVIS experts, based on their knowledge and experience, it involves no computer-aided automation. The first part of STM is the transcription

of notes and records by GV experts which is similar to a data transcription method known as "*conversation analysis"* for qualitative research (Silverman, 2001). When trascribing, GVIS experts analyse all transcription and pick up key statements that have technology implications. Such key statements usually suggest the expectation on certain aspects of the product and it is important for GVIS experts to make such expectations known and understood by designers.

The follow-up phase is usability testing, which is like a quality control system set up for evaluating the acceptance of the proposed GVIS tool before it reaches the final users. It is generally accepted that a usability test helps make the product user-friendly, productive, easy to use and demand-oriented rather than supply-oriented (Quaye-Ballard, 2003). Zhang and Adipat (2005) outlined a generic framework for testing usability of a mobile application, which lays out four key phases: testing method, tools used, selecting what to measure and data collection approaches. Woronuk (2008) adopted this framework for a study of investigating the usability of 3D visualisation in the case of fire incident command. For a better correspondence to UECD, this study suggests adopting a modified version of the framework as shown in Figure 6.4.

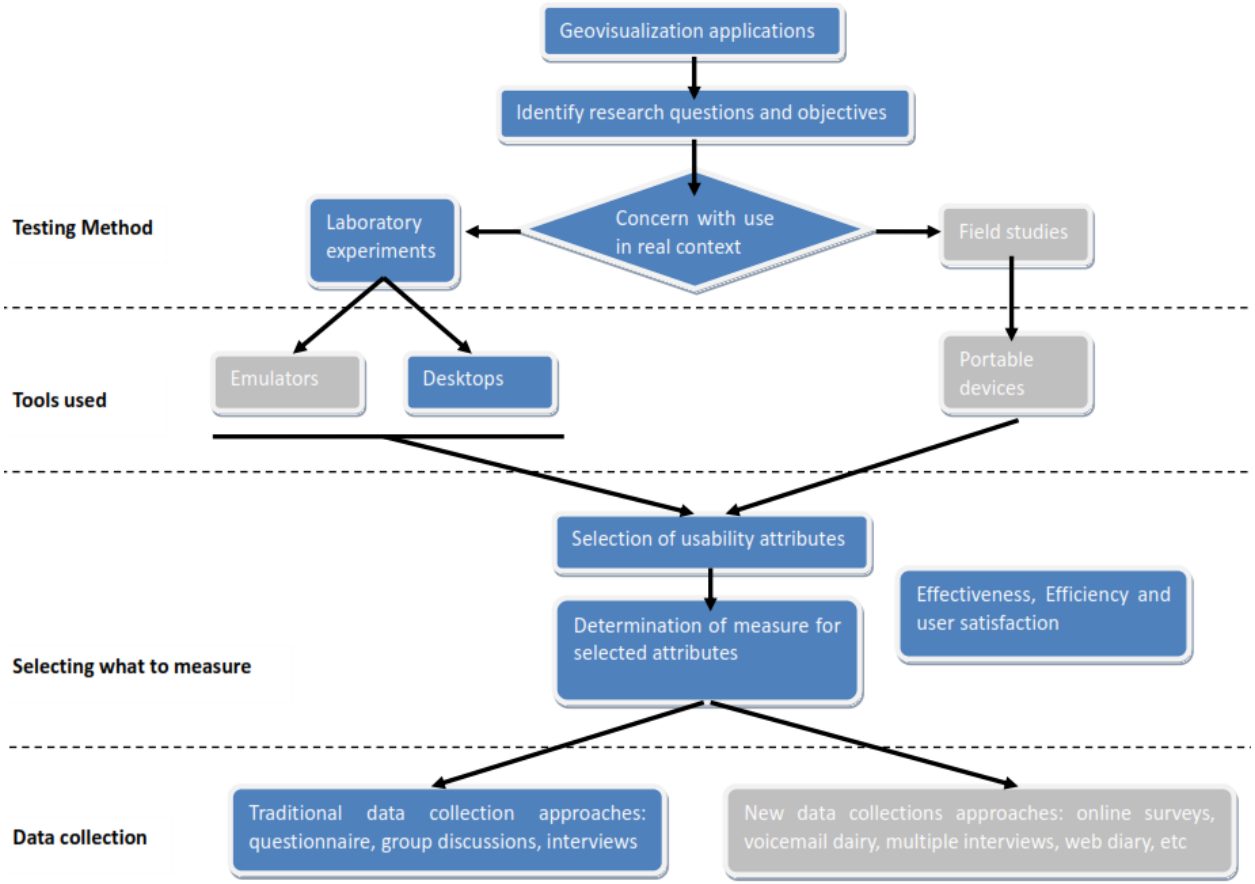


Figure 6.4 Usability test framework (modified after Zhang and Adipat, 2005)

The setting up of a usability test is slightly different in content from the workshop used for establishing user requirements. Figure 6.5 shows a sample framework that contains five sessions. Session one is a quick induction presentation that contains project context and information about the operating platform of the tool. The next session is simply to offer participants the opportunity of raising prompt questions. Session three is the main practical platform where participants need to go through several tasks using the GVIS tool provided. GVIS experts and developers are expected to get ready and provide prompt assistance when needed. In Session four participants are asked to fill in a questionnaire that aims at collecting users' feedback on working with the tool. The last session sets up the discussion where participants can further exchange views and experiences.

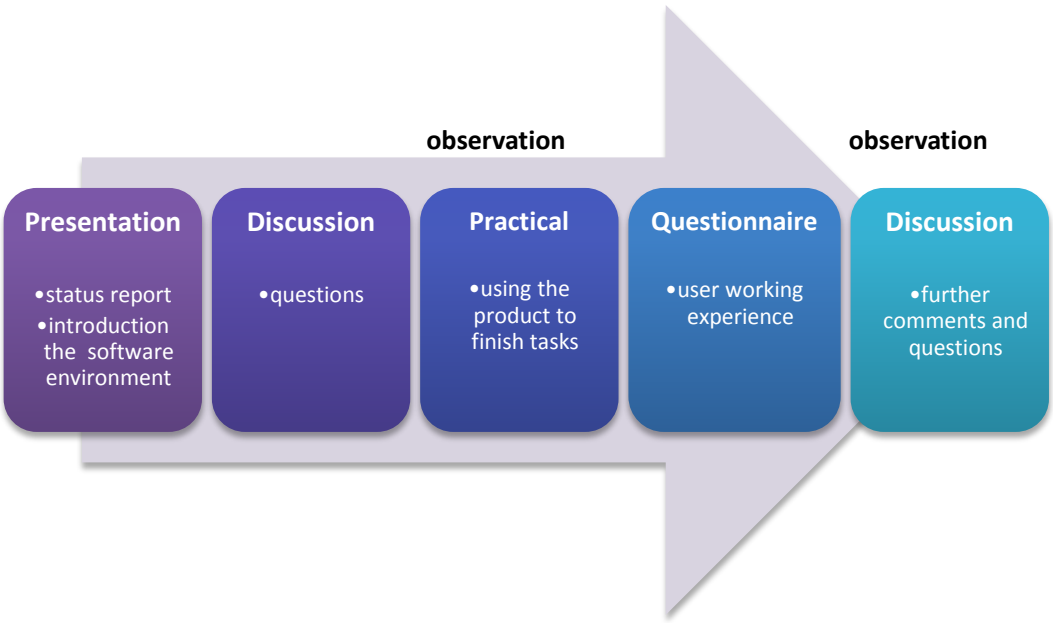


Figure 6.5 Example of organisation of usability test

Questionnaires used for testing interactive computer software user interface can be adopted in UECD usability testing (Root and Draper, 1983; Chin, *et al.*, 1988; Davis, 1989; Nielsen, 1993; Lewis, 1995; Perlman, 1997; Lund, 2001). An in-depth discussion of these

commonly used methods is given by Tullis and Albert (2008). A good example of such a questionnaire is the Software Usability Measurement Inventory (SUMI) proposed by the Human Factors Research Group (HFRG), University College Cork[2]. In order to receive more focused feedback, questionnaires need to be customised according to the specific features of a project. Questionnaires and notes taken at the workshop will be further investigated by GVIS experts and developers and useful information will be treated as new requirements and used to update the original STM scripts. If certain features of the prototype cannot meet users' expectation, they can be traced back to the scripts, where experts can explain and propose amended or alternative solutions. If users' feedback suggests the need for extra features or functions, they will also be reflected in the updated scripts, whereas the feasibility of added features will need to be verified carefully by the developers and experts.

Figure 6.6 illustrates the spiral model for such usability test, where the cycle starts from usability test and goes through user requirement (interpretation), STM to prototype and enters the next usability test. The use of spiral methodology is limited due to the time and budget allowance and it may be difficult for tests to be organised in the form of above workshop as proposed above. Another major difficulty is to recruit the same participators repeatedly whereas their availability may not be guaranteed. A solution is then to employ small-size and different types of supplementary methods other than workshops, for example on an individual basis, before and after the primary test. In a worst case where a workshop like suggested above cannot be organised at all, all types of interviews with users can be very helpful.

[2] HFRG is led by Dr. Jurek Kirakowski and his colleagues based at University College Cork. It has existed since 1984 and is a recognized research and consultancy grouping specialized in usability engineering. More details can be found from http://www.ucc.ie/hfrg/index.html

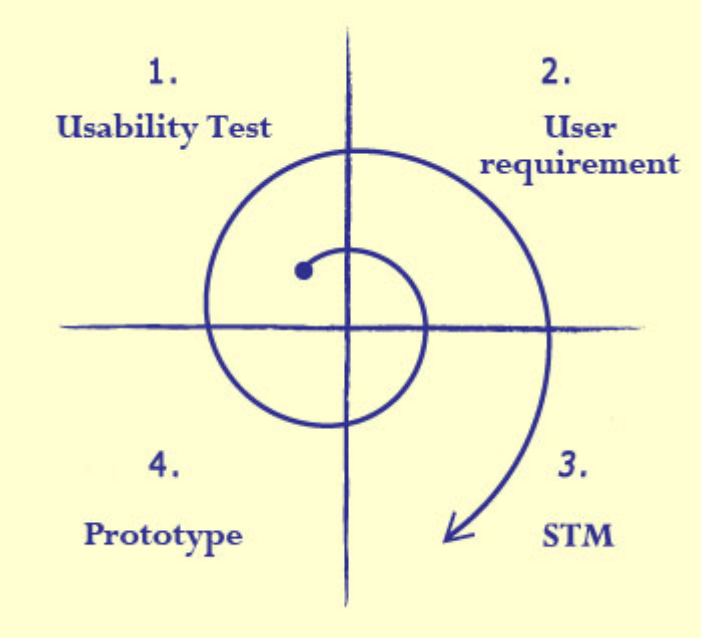


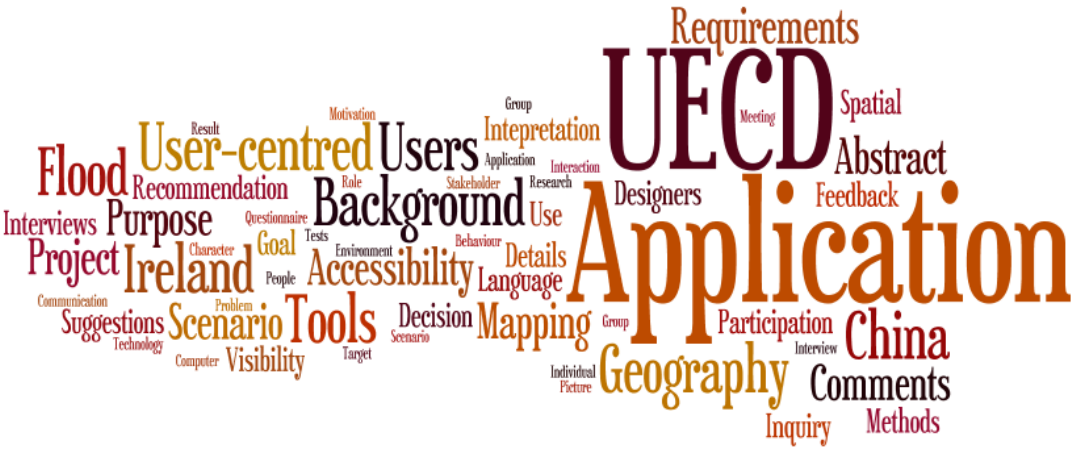
Figure 6.6 A spiral mode of usability test

6.4 Summary

This chapter brings forward the original UECD design framework as a possible answer to the increasing usability concerns in GVIS. The structure of UECD is explained in details. The extended and coordinated GVIS workflow that arises from the introduction of UECD is discussed The validity and utility of the concepts introduced in this chapter will be tested and demonstrated in the next chapter, by reference to case studies and potential application.

Section 3

Case Studies and Potential Application



Chapter 7

Usability-Enhanced Coordination Design and Potential Application

7.1 Introduction

This chapter intends to demonstrate the potential of employing UECD to instruct a GVIS design process in a real context. Two independent projects are conducted in this research. The town of Whitegate, Cork Harbour, Ireland (see Figure 7.1) is the first target site. A 3D mapping tool is created using ArcGIS and ArcScene to show the likely coastal inundation scenario of the town in the context of future SLR (IPCC, 2001, 2007, 2013; Dunne, *et al.*, 2008). The second project looks at Zhushan Town, which is located in southeast Jiangsu province in China. A 3D GVIS platform is created to support flood risk analysis decision making. Section 7.2 and 7.3 describe and discuss each of the two projects in detail.

7.2 Case Study 1: Cork Harbour Flood Risk Mapping (Ireland)

7.2.1 Context

Ireland has over 7,400 km coastline surrounded by extensive water territory and 900,000 km^2 marine resources in the North Atlantic Ocean (Marine Institute, 2005). Due to global climate change, sea temperature and sea-level around Ireland have been rising yearly in

recent decades. Satellite measurements suggest a rapid warming rate of 0.6-0.7°C per decade since the 1980s (Dunne, *et al.*, 2008). Early studies suggested that the relative sea level for Ireland is rising around 1mm/yr on average but with significant regional variations (Carter, *et al.*, 1989; Devoy, 1990, 1995, 2000a). It was estimated that SLR around the coast of Ireland would be at 17-31cm over the next 30 years, and the overall rise between 1990 and 2030 would be 30cm (Department of Environment, Heritage and Local Government, 2001; Royal Irish Academy, 2002). More recent assessment reports published by Intergovernmental Panel on Climate Change (IPCC) suggest a rate of rise of 3.2mm/yr for 1993-2010 and 3.7mm/yr for 2007-2013 (IPCC, 2001; 2007; 2013). It is estimated that net regional sea-level change near Ireland between 1986-2005 and 2081-2100 will be around 40-50cm (IPCC, 2013).

The greatest impact of coastal flooding would be strikingly evident in the urbanised east coast and in the three major coastal cities, Dublin, Cork and Galway. Many studies have been undertaken in terms of SLR impact and vulnerability for Ireland (Carter, 1991; National Coastal Erosion Committee, 1992; Environment Service of Northern Ireland, 1995; Sweeney, 1997; Halcrow Group Ltd., 2008). Early analyses by Rotmans *et al.* (1994) place Ireland in a low vulnerability category to SLR in the whole of Europe, which is supported by later assessment data (Parry, 2000). Scholars suggest that no further reclamation of estuary land should be conducted in eastern Ireland, and no buildings or developments should be planned within 100 metres of soft shoreline (Royal Irish Academy, 2002; Sweeney, 2008). There have been very few published discussions on flooding threat in Cork Harbour (Figure 7.1). A recent investigation is performed by McGrath *et al.* (2003) presenting an illustration of flooding in Cork City centre in an assumed SLR scenario.

Figure 7.1 Irish study site – Whitegate, Cork Harbour, Ireland (Source: Google Map)

Some of the previous flood event records can be consulted via the OPW National Flood Hazard Mapping tool and the recorded events are mainly due to high tides and wave action in extreme weather patterns (Table 7.1). Generally speaking flood happens more frequently at the west side of the harbour and among those places at the east side of the harbour, Whitegate is the only one that was badly flooded before. The overview of recorded flood shown by Figure 7.2 reflects the vulnerability of the area to the impacts of future SLR.

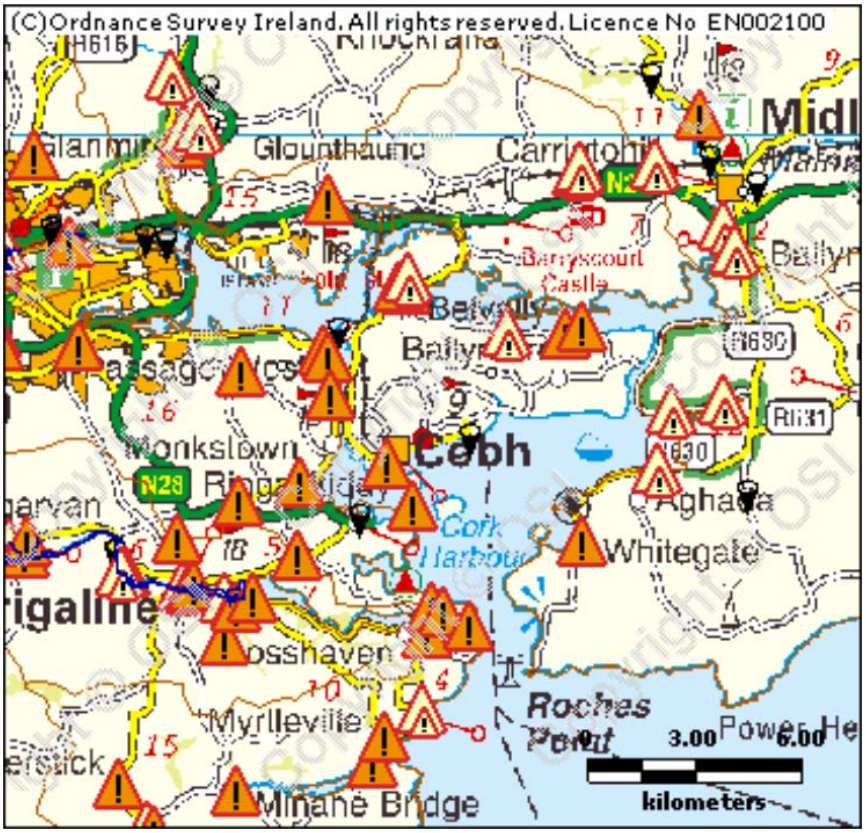


Figure 7.2 All flood events within 2.5km of the harbour. The triangles represent the places that have recorded floods over the history. The orange ones show single flood events and the yellow ones show repeated flood events. (Source: OPW, 2011)

Table 7.1 Recorded flood events in/near Crossheaven and Whitegate, Cork

Location	Description
Currabinny pier	Coastal flooding.
Carrigaline Walk in the Owenboy Estuary	Walk was flooded due to high tide levels in estuary.
Myrtleville	Coastal flooding due to high tides and extreme wave action.
Fountainstown Strand	Coastal flooding due to high tides and extreme wave action. Car park flooded and road adjacent to strand blocked by a mixture of debris and flood water
The point Crossheaven	Coastal flooding from high tide and extreme wave action. Property damage, boundary wall collapsed
Graball Bay	Coastal flooding from high tide and extreme wave action.
Ringabella coastal flooding	High tide and extreme wave action. Some minor subsidence and flood damage.
Robert's Cove	Coastal flooding due to high tides and extreme wave action.
R630 at Whitegate	Very infrequent.
Rostellan Road	Extreme tides and wind direction. Occurs infrequently.
Ballycotton pier	Flooded due to tides and waves but also on regular basis – recurring flood.

Extra flood observation can be obtained from community groups such as CHASE (Cork Harbour Alliance for a Safe Environment) which was set up in October 2001 with the aim of preventing a waste incinerator being established in the area. A number of flooding events are published on the CHASE website, including cases in 2009 and 2010, which are not covered by the official database. This research conducted several field trips to towns in the harbour area including Cobh, Ringaskiddy, Carrigaline and Whitegate (Figure 7.3) and the objective was to collect views of people from local communities on flooding issues. Photographs taken during the trips are used later as visual references when creating visualisation of the target site.

Figure 7.3 Whitegate in southeast side of Cork Harbour (Source: photograph by author, 2010)

7.2.2 Objectives

A flood mapping system carrying modern visualisation technologies should be employed for Cork Harbour to provide an optimised way of communicating flood risk and control information for decision makers and local communities. This study intends to:

- Test the functionality of UECD and its coordinated workflow led by GVIS experts and discover spaces for further improvement. Examine the process of generating

STM scripts from user requirements making the scripts guide the design and investigate users' acceptance of the design.

- Create a novel presentation platform displaying the scenario of flooding for Whitegate under the context of future SLR. Lay down a solid foundation for the establishment of a more sophisticated flood visualisation system for the harbour in the future;
- Make use of available GVIS platforms, datasets and visualisation techniques to provide targeted functions according to user requirements;

7.2.3 Working Phases

This case study aimed to propose a new way of visualising inundation impacts due to SLR and communicating the issues with local stakeholders. Such a tool was meant to be deployed and used by professionals, thus a range of potential users were targeted, which included environmental planners working at government bodies, scientists from environmental agencies and students from universities. The GVIS team consisted of one GIS practitioner from the Geography Department of the University College Cork and one domain expert specialized in coast environment studies from Coastal and Marine Resource Centre. Two postgraduate students from the University majored in GIS with sufficient knowledge of GIS application programming were organised as the design team.

Phase One: Investigating available datasets

The first task for the design team was to look into currently available datasets for creating the inundation mapping system. In order to minimise the cost, the possibility of accessing free data from various sources was investigated by the team first. Through research

connections with various institutes, the team secured a number of relevant GIS datasets (Table 7.2). For example, the Geography Department of University College Cork shared a 20-meter resolution Digital Elevation Model (DEM) of the whole county. A GIS database that contains a number of thematic layers such as transportation, tourism, land-use, water resource, natural reservations and civil facilities for the whole Cork County was also provided by the Department. A high-resolution data pack was shared by South & East Cork Area Development (SECAD) and this data pack was originally used for monitoring the severe erosion of the East Cork coastline. The pack contains LIDAR point cloud, RGB orthoimagery, 2m Digital Terrain Model (DTM) and 2m Digital Surface Model (DSM) for the whole southeast part of the country's coastline stretching from Whitegate to Youghal.

The above list provides an insight of the types of data that are usually involved in a typical GVIS project. In order to create a realistic 3D visualisation, this study also employed the LIDAR point cloud to render high-resolution 3D landscape.

Table 7.2 Major datasets collected for Cork inundation mapping system

Item	Content
GIS Spatial database (Cork County)	A total of 24 layers. Each layer is stored as a spread sheet in a geodatabase. The themes include: amenities, antiquity, barony, boundaries, buildings, coastal, counties, duchas, fire_res, forestry, index, islands, land_feat, military, powerlines, relief, services, tour_syms, townlands, transport, ulster, urban_areas, water and extent.
OSi map (Cork City and Harbour)	OS1206, OS1406, OS1606 1:25000 OSi print-off map in TIFF format
Aerial imagery (Cork Harbour)	200_cork_harbour Single image in JFIF format 3 Bands (Red, Green and Blue) Year 2000
Aerial imagery (cork Harbour)	O6290-A~O6584-D A total of 220 image files in ECW format 3 Bands (Red, Green and Blue) Year 2005
Aerial imagery (Southeast Cork coastline)	W8161~W9968, X0063~X0970 A total of 80 image files in TIFF format 3 Bands (Red, Green and Blue) Year 2006
Point cloud (Southeast Cork coastline)	W8162~W9968 , X0063~X0970 A total of 78 point cloud files in ESRI Shapefile format Average 50,000 points contained in each file
DEM (Cork County)	dem_cork 20-meter resolution
DTM (Southeast Cork coastline)	w86dtm, x06dtm 2-meter resolution
DSM (Southeast Cork coastline)	w86dsm, x06dsm 2-meter resolution

Phase Two: Collecting user requirements

The study tried to approach a wide range of potential end-users and to make sure the audience can be representative enough of local communities. Due to budget constraints, no

extra survey workshops were organised, instead the data collected in previous workshops were used because the two studies had the same central topic. However, a few supplementary face-to-face interviews were organised and the profiles of the interviewees are shown in Table 7.3. Most of the interviewees had no former experience in GVIS profession, and they represented the residents that lived in Cork Harbour area. Brief introduction about GVIS was first given to the interviewees, followed by a presentation about the Crosshaven visualisation study (see *Appendix 4: Workshop Presentation Ireland*). The presentation included explanation of how the different visualisations were produced. Participants were then asked to share their preferences on the types of GVIS tools they would like to see and to use.

Table 7.3 Profiles of the face-to-face interview participants

User	Occupation	Background
P1	University lecturer	Cultural studies
P2	County Council engineer	City planning
P3	University PhD student	History
P4	Restaurant owner	Live in Carrigaline
P5	University academic assistant	Administration
P6	City Council official	Business and Enterprise
P7	City Council engineer	Waste management
P8	Former County Council engineer	Environment planning
P9	School Principal	Education
P10	Shop owner	Live in Cobh
P11	Landlord	Live in Douglas

Phase Three: Subject Technology Matching

Key statements from interviewees were recorded in notes. Table 7.4 listed a few examples of these types of statements from interviews with above participants.

Table 7.4 Statement samples with technology implication

Statements from users	Technology implication	Subjects
"…accuracy is very important to decision makers, while for some other users low resolution images would be ok"	This user wants the information presented as accurate as possible likely for analysis purpose. This can be done through either reducing the level of generalization or using high resolution data source such as LIDAR and aerial photograph	High resolution landscape/object modelling
"…flat maps are more practical [for our work]…three dimensional [visualisation] for the whole coastline sounds economically not sensible"	This user is happy with using 2D mapping concerning his work context and he also believes that 3D is not practical for small scale. This is related to the data storage and management as well as processing and rendering load	2D thematic mapping (for small scale)
"…I like to see buildings with more details rather than boring blocks"	This user believes that details bring realism to the models which makes the working experience more exciting. The details are realised through creating more accurate models and realistic textures.	Requirement on reality
"…the money spent on collecting those high resolution data and creating very detailed 3D models…"	This user concerns are more about the project budget both regarding the cost of data collection and the cost of GVIS production. It requires the development to make use of free or low cost dataset and software.	Select suitable software platform (e.g., open source)

It is stated before that STM scripts can be adopted by subsequent design. The Yangtze River flood monitoring simulation presented in Section 5.3 is a good case of putting together RS imagery, DEM, 3D models and spatial database in a 3D walkthrough environment, which provides useful "template" to the design of the Whitegate flood mapping. The STM scripts of Yangtze River flooding monitoring simulation was re-used with modification based on the specific context of the data and platform use of this study. Table 7.5 shows the final STM document generated by the design team.

Table 7.5 STM template for Whitegate Inundation Mapping

Subject (classification and layering of user requirement)	Technology (techniques recommended by GVIS experts for the subject)	Matching (expected performance)
Landscape (Display in 3D environment)	2m DEM --high-resolution --retrieved from LIDAR dataset	HM
	2m orthoimagery --high-resolution --referenced	HM
Realism (Create key geographic objects to make the place recognizable)	3D models --Google SketchUp (buildings, cars) --ArcGIS (road lamp)	HM
	CG texture --water, grass	HM
	Symbology --2D and 3D	NM
	Highlighting --layer transparency	HM
Navigation (Interactive)	Pan, zoom, rotate --ArcScene like	HM
	Fly-by --3D linear route editing	NM
Spatial analysis	Measurement --distance, height	HM
Platform	ArcScene-based environment	HM
Application --Cork Harbour SLR visualisation tool	Large scene processing --DEM generation --Image merging Intensive 3D modelling and processing --Handling huge amount of 3D models --Rendering load, navigation experience --Performance of ArcScene	

Phase Four: Development

STM document above suggested that the ideal output design was a 3D mapping environment providing basic viewing and analytical functions. The design team chose to build the application again with ArcGIS because a full access to ArcGIS was provided by the university Besides, ArcGIS is the mainstream GIS software used currently in public sectors in Ireland including government departments, environment agencies and research institutes.

Creation of the actual visualisation started from high-resolution landscape modelling.

Through raster data clipping and georeferencing in ArcMap, the DEM and aerial photograph portion for Whitegate were segmented from the original dataset (Figure 7.4). GIS data of all main ground features were captured through digitisation from the aerial imagery and saved as GIS layers in a spatial database created in ArcGIS (Figure 7.5). The aerial imagery also made up the basic 3D terrain surface in ArcScene (Figure 7.6). Some of the ground objects (e.g., road lamps, grasslands) were symbolised using the pre-existing 3D models contained in ArcGIS with reference to the field photograph (Figure 7.7a, 7.7b). Other objects (e.g., buildings, cars) were created by using textures from dedicated computer graphics resource website. The water layer was created in ArcMap as a flat layer and then exported to ArcScene and elevated to pre-defined heights. The position of this layer changed when the height was given a different value, thus users could see the change of the flood plain in different scenarios.

Figure 7.4 DEM and aerial photograph for Whitegate extracted from original data. The grey scale (black-white) indicates the change of elevation. The aerial photograph provides a high-resolution bird's view of the ground features such as roads, buildings, trees and fields.

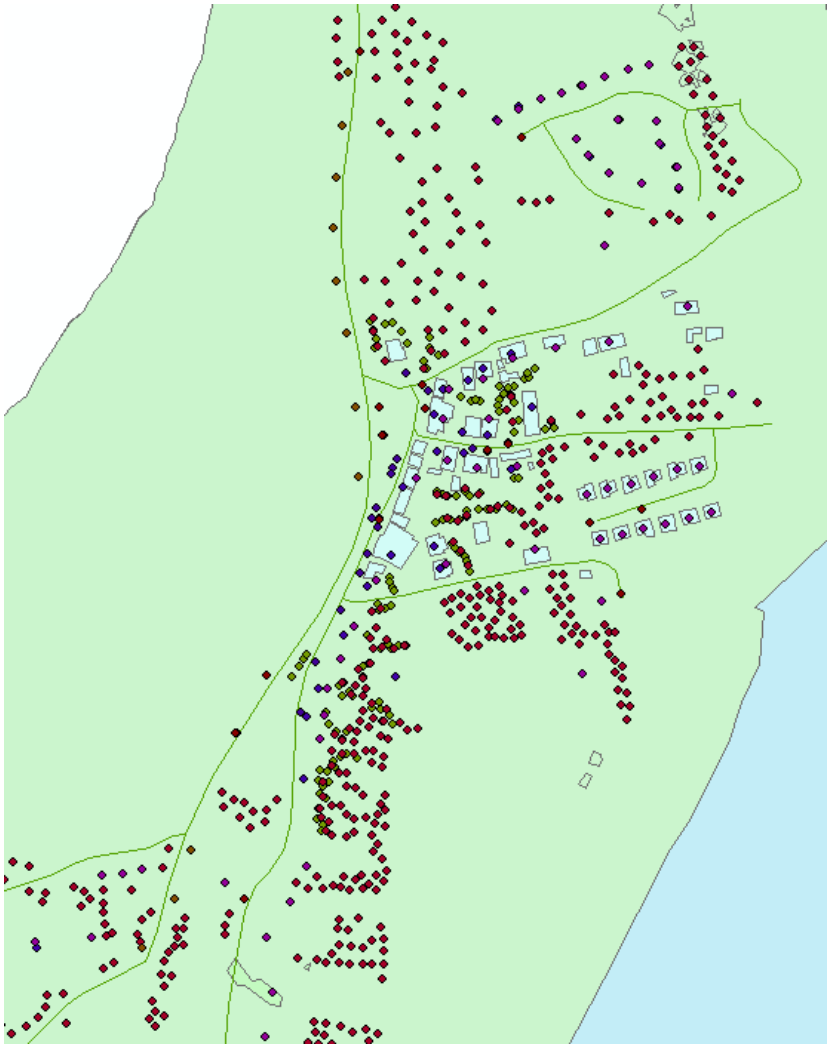


Figure 7.5 Data capture based on aerial imagery. Emerald lines are the central lines of roads. The rectangles are major houses in the town. Purple circles are street lamps, blue circles are vehicles and other brown and red circles are trees.

Figure 7.6 Mashup of the high-resolution DEM and the aerial imagery of the site. The aerial imagery is elevated using the height information contained in the DEM.

Considering the budget control and flexibility of the tool in the future, Google SketchUp 8 was taken onboard to collaboratively work with ArcGIS. All the basic building models were downloaded from 3D Warehouse with the reference to real ground features in the photograph. The downloaded models were further edited and rendered with textures extracted from the field photograph (Figure 7.8a, 7.8b) and then sent back to ArcScene for symbolisation. When all the 3D models were put in the scene, some fine adjustments, such as positions, angles and illumination, were made so as to make them blend in and fit the background landscape.

Figure 7.7a One of the road lamps in Whitegate (Source: photograph by author, 2011)

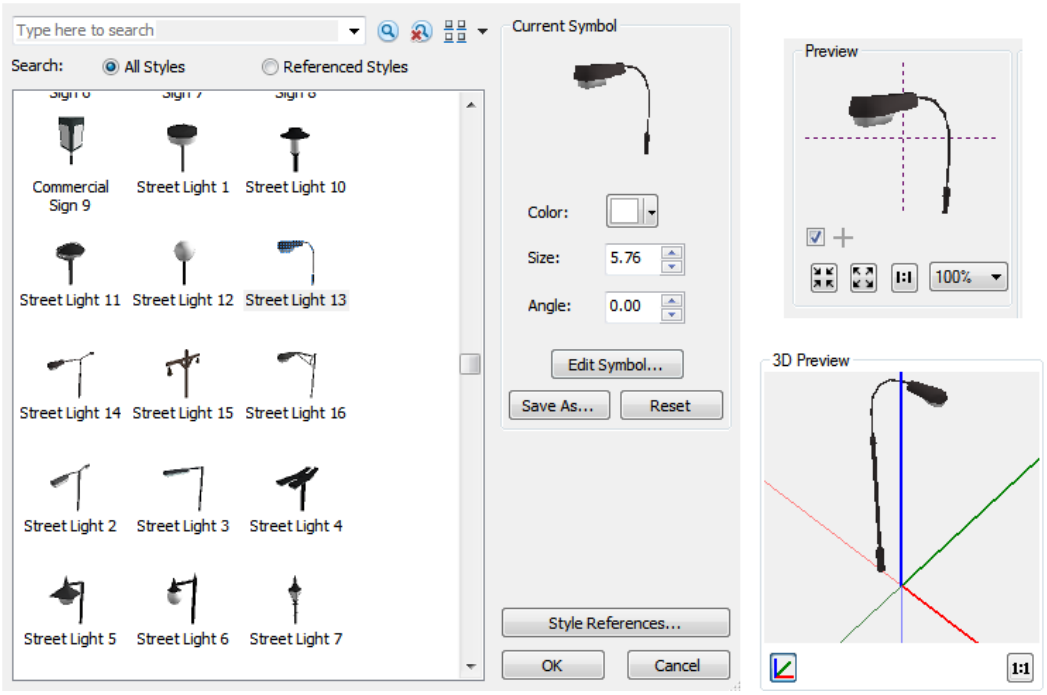


Figure 7.7b Collection of 3D road lamp models in ArcGIS (Source: ESRI, 2011)

Figure 7.8a Residential building examples in Whitegate (Source: photograph by author, 2011)

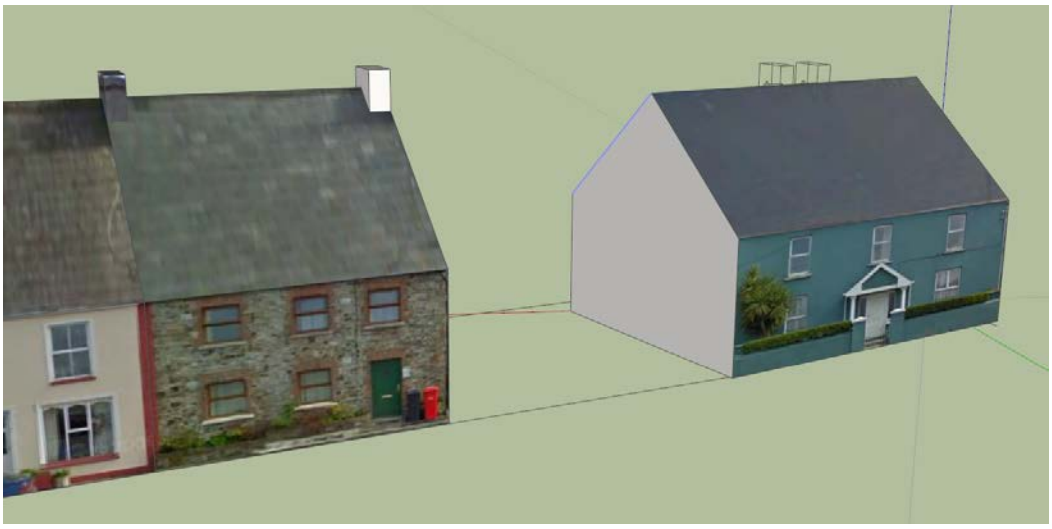


Figure 7.8b 3D building model creation in Google SketchUp 8. The texture is derived from the field photograph.

The final output of the above work was an ArcScene-based 3D visualisation environment that employed photo-realistic landscape modelling using LIDAR data and aerial imagery, as well as detailed 3D models created Google SketchUp. The tool displayed the likely inundation scenarios in Whitegate and its nearby lands due to increasing SLR (Figure 7.9). It provided an immersive and interactive viewing environment, with which users could walk

through the scene freely and investigate the inundation and affected ground features from different angles (Figure 7.10a; 7.10b). Attributes of the features were made interactively consultable using the designated 3D navigation tools in ArcScene. Users could change layer features to change water level and see the different flooding scenarios (Figure 7.11). Besides, users could perform a number of different 3D editing and analysis (e.g., creating fly-by animation) with the spatial and 3D analyst extensions provided in ArcGIS.

Figure 7.9 3D coastal inundation mapping for Whitegate (face south). The screen snapshot shows the scenario where the main roads in the town are flooded. The buildings next to the roads were all affected.

Figure 7.10a Zoom in to see details of objects in Whitegate flood mapping (face south-east). This screen snapshot shows the details of the 3D buildings and the transparency effect of water in the scene.

Figure 7.10b 'Walk though' the scene and view from different angles (face east). This screen snapshot shows the details of tree features in the scene as well as the transparency effect of tree leaves and water.

Figure 7.11 Spatial distance measurement. This screen snapshot shows the 3D length measurement function provided in ArcScene.

Phase Five: Usability test

The first part of usability test was conducted during a workshop that was conducted for the purpose with a group of mature students at University College Cork. These students were all taking an Adult Education (part-time) course in GIS at the University, and come from various professional backgrounds from within the private and public sectors. As suggested by the course coordinator, students from the course were invited to volunteer to take part in the exercise, and those who came forward took on the role of end-users. In order to make it worth the volunteers' while, the excise was combined with a one-hour laboratory tutorial that taught participants how to create their own visualisations, similar to those used in the test. Each workshop participant received a tutorial hand-out (see *Appendix 8: Hand-out for HDip GIS Tutorial*) which provides step-by-step guidance on how to create a map that is similar to the Whitegate flood mapping by working with ArcGIS, ArcScene and Google SketchUp. Students

were given a small fraction of the original data (i.e. DEM, aerial imagery) and they were asked to follow the guidance and work through the whole 3D GVIS creation process including generating layers, capturing features from digitisation, generating models in Google SketchUp, symbolising features in ArcScene and customising the interface. The hand-out also set up several questions associated with the use of the map and participants needed to find answers by using the map they produced themselves (Table 7.6). Participants could ask for help from test organisers and the course coordinator whenever they ran into difficulties. When the hand-out was finished, all participants were invited to a discussion where they raised more questions about making and using the maps. A few extra maps were also displayed at the discussion showing other types of flood mapping techniques (Figure 7.12; 7.13; 7.14).

Table 7.6 Questions to be answered by workshop participants

Please find out the answers with the visualisation provided.
How many different types of vehicles are there in the scene?
Among all the buildings displayed, can you find one with a Guinness poster?
What is the height of the road lamp? Can you measure it?
At SLR 2, can you tell the height of coastal embankment?
At SLR 3, how many houses will be affected by flooding based on the pointed context?
At SLR 4, how many cars will be immersed in flooding?

In addition to this workshop, the research also organised supplementary tests in the form of individual interviews. Each interview was similar to a small scale tutorial, where the interviewee went through the hand-out to gain a sense of building 3D GVIS with ArcScene. The Whitegate flood mapping tool was presented at the end of the interview and interviewees were asked to comment critically on the actual usage of the tool, based on which the interview was extended further to a discussion of GVIS usability.

Figure 7.12 Quick mashup of 1:4000 Bing Map. This screen snapshot shows a basic topographic map overlapped with a blue color layer to show the flooded zone.

Figure 7.13 Mashup of 1m aerial photograph and road layer. The blue layer (water) is made transparent in order to display the features in the aerial imagery. The orange and white lines are roads across the town.

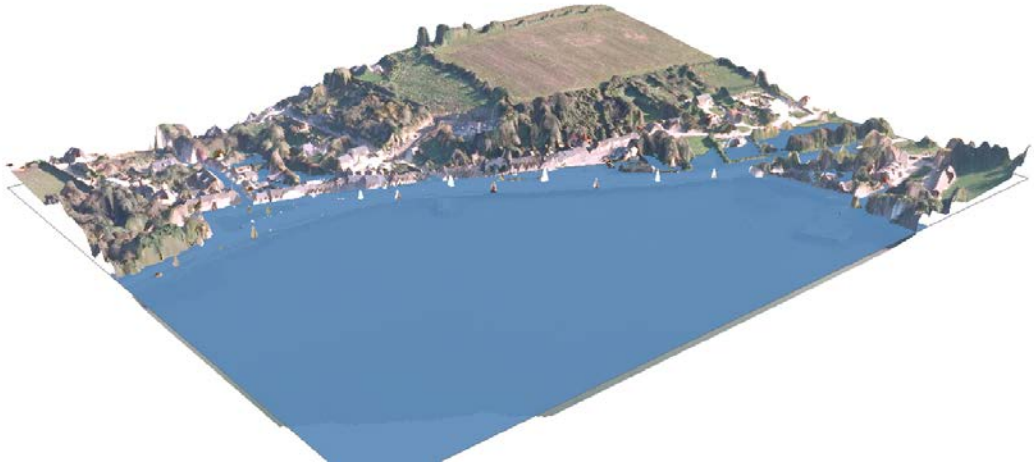


Figure 7.14 Map animation using DSM and aerial photograph. The aerial photograph is elevated using the height attributes contained in the DSM. The animation is created by displaying/fading a number of water layers (with different heights).

Taking the feedback received from all workshops and interviews, this GVIS tool achieved three major goals. Firstly, it displayed the likely flooding scenario of Whitegate due to likely SLR as a result of future climate change. It selected a typical target site which suffered from frequent flooding particularly in extreme weather conditions. The created mapping tool delivered a clear delineation of the main ground features of this area. Secondly, this tool showed an example of leveraging overall realism of flood mapping by employing photo-realistic 3D models of ground features working across different GVIS platforms such as ArcScene and Google Sketchup. Thirdly, with an immersive and interactive platform, it demonstrated a useful vehicle of communicating flood risk information. Users were allowed to explore the scenario more interactively (e.g., shifting viewpoints, zooming in/out, changing water levels), thus the amount of information that could be conveyed by the GVIS tool was significantly increased. Besides the overall navigation functions provided offered a similar interface of a web-based map service, which made the tool much easier to be accepted by end-users.

The tests also helped unfold several existing problems of the tool. *The first problem was how to further improve realism in the visualisations*. Feedback suggested that there was still considerable room for enhancing overall realism. For example, the rendered 3D ground features did not blend in well enough with the background landscape which was a high-resolution DTM and the position of some models could not match correctly the terrain surface when zooming into detail. Users also would like to see more details of the scene, such as foot paths, flowers, road signs and bulletin boards. Some users suggested that virtual figures of human-beings could be added as well.

The second problem was the lack of textual information displayed. If the scale of this visualised scene was further enlarged with more 3D featured added, it could be increasingly difficult to identify specific objects solely based on the rendered models. Without feature attributes clearly labelled in the 3D viewing environment, users might run into difficulties of finding the target information they were interested in.

The third problem was the need to simplify and customise the interface. Currently the tool was operated within ArcScene, whose original interface involved a number of toolbars serving different editing and analytical tasks. This could make a user, whom had no formal experience or training of using ArcScene, find considerably hard to operate the application. The need for improvements to the interface was strongly indicated in responses received from the project team.

Therefore in the original STM document, GVIS experts changed the STM item from *Use of ArcScene as the platform* into *A secondary development platform based on ArcEngine*, which means the tool should be made stand-alone providing only the specific functions required for

exploring the scene. This instructed the designers to separate the tool from ArcScene and develop into an independent tool temporarily called MiniArcScene (Figure 7.15). The interface of this new tool (Figure 7.16) looks like a highly simplified version of ArcScene's and it contains presentation functions (e.g., data input, layer selection, navigation) as well as spatial analytical functions (e.g., measuring tools, POI identifier).

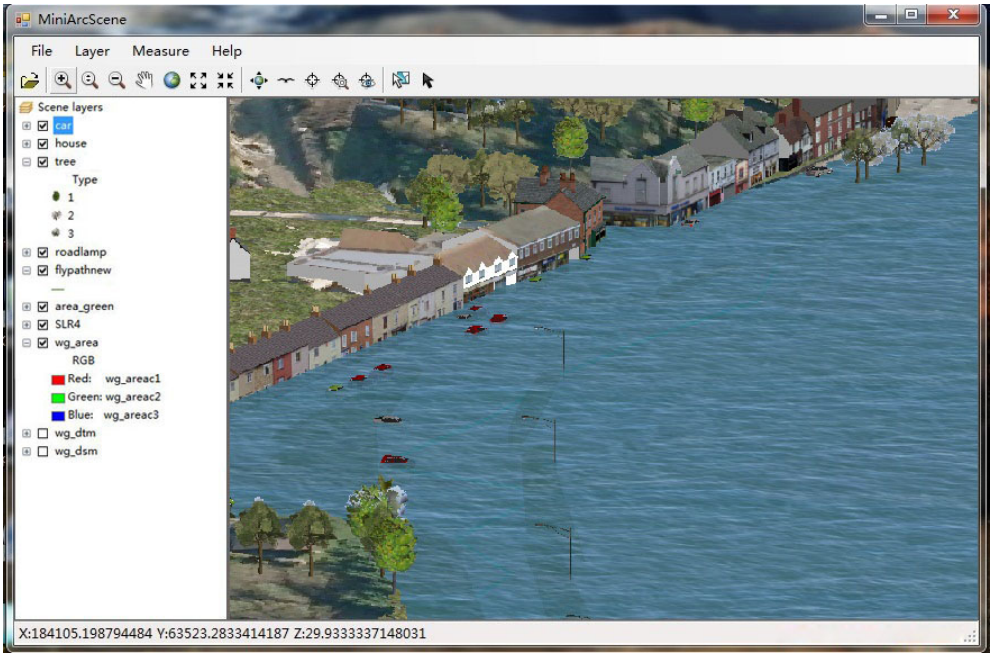


Figure 7.15 The interface of MiniArcScene. Toolbars are located in the top section of the interface. Table of Contents section is on the left and the display area is on the right. The bottom section of the interface is information display bar.

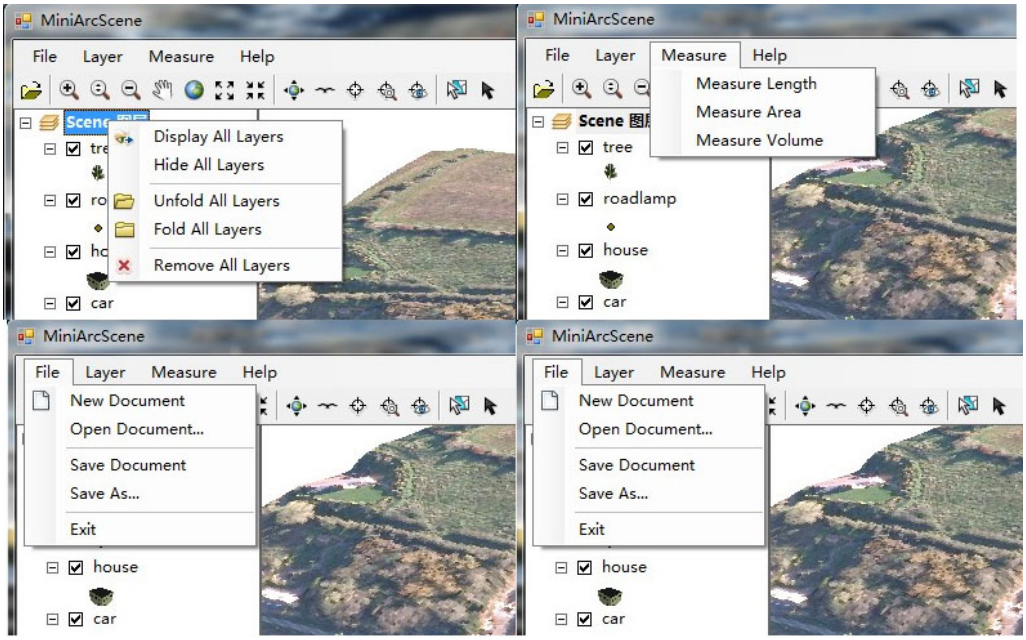


Figure 7.16 Basic functions included in MiniArcScene. The application allows users to perform basic operation on layers (e.g., display, hide) and on document (e.g., open, save). It also provides some basic spatial analysis functions such as length and area measurement.

7.2.4 Conclusion

The Whitegate flood mapping project was an empirical experiment conducted with the purpose of testing UECD framework. The project worked across different platforms, including ArcGIS, ArcScene and Google SketchUp and presented a GVIS tool that incorporated some of the latest 3D GVIS techniques. It provided users with an immersive and interactive viewing environment, where they could use a range of spatial analytical including data input and output, attribute query, spatial measuring and model editing.

The overall acceptance of the GVIS tool by case study participants showed the confidence of UECD as an effective and sustainable design approach for GVIS products. However the case study also helped identify the problems of the proposed theoretical elements in practice. For instance, some interviewees expressed their difficulties of trying to understand the items contained in a STM document, in particular referred to the technical terminology used.

This was mainly due to lack of sufficient knowledge about GVIS, GIS or computer technology in general. But if the terminology use became an problem for the effective understanding and receiving of STM by certain end-users, improvements would be needed to present STM items using more simple and descriptive terms without making the document tediously long or less instructive for designers.

7.3 Case Study 2: Zhushan Town Flood Risk Visualisation (China)

7.3.1 Context

Taihu Lake is located in the southern Yangtze River Delta encompassed by three cities – Suzhou, Wuxi and Changzhou. It is the largest lake in Jiangsu Province linked to the East China Sea and the second largest freshwater lake in the country. The lake is crescent shaped, encircled by a 405km long shoreline, covering 2338.1km^2 of water territory with an average water depth of 1.89m (Lin, 2002). Taihu Lake is the major component of the Yangtze River Delta stream network and the key to local agriculture irrigation and water transport. It is also very well-known for abundant fishery resources, and the surrounding region is one of the most developed places in China.

In the 2007 Boao International Tourism Forum, Taihu Lake was promoted as a "National Tourism Business Card", particularly because of the "Changzhou Taihu Lake Tourist Resort Development Project". The 39.6km^2 consists of a series of tourist spots including Taihu Lake Square, JoyLand Theme Park, Chinese Filial Piety Garden, Taihu Manor, Zhushan Town and the National Dragon Boat Training Centre. Among all these spots, the only waterfront place is the new 600,000m^2 Zhushan Town (Figure 7.17). This newly planned tourist area, containing hotels, holiday apartments, shops, barbecue zones, fishing ports and waterfront walks, is designed to

be the primary holiday destination for people living in nearby provinces. The 1st phase of resort development was finished and opened to the public in 2009. The 2nd phase of development started in 2011, whose core project - Zhushan Town International Conference Centre is planned to be finished by the end of 2013.

Figure 7.17 The location of Taihu Lake and Zhushan Town (Source: Google Map). Taihu Lake is located at southeast of China surrounded by Jiangsu, Zhejiang and Anhui provinces and it is one of the largest fresh water lakes in the country.

Taihu Lake has a long recorded history of frequent flooding since the Ming Dynasty. All the flood events are caused by the intensive rainfall in June and July every year known by people living in Yangtze River Delta region as the “Mei” (mouldy season) because everything goes mouldy fairly easily in such damp weather. Local people worry about the “Mei” because it means a long period of rainfall which usually leads to flood of Taihu Lake and its associated streams across the region. According to official records, the last severe flood of Taihu Lake happened in 1999 when the “Mei” lasted 43 days (June 7th - July 20th), which led to a mean rainfall of 1187.3mm (Wu, 2000). The water level of Taihu Lake rose rapidly from the beginning

of June and reached the warning level (3.5m) within 10 days, then its peak of 5.08m on July 8th, and remained at a quite high level until October 3rd (Wu, 2000). The consequent terrible flood lasted 116 days and caused severe destruction to nearby cities and towns with an estimated total social-economic loss of 1.64 billion USD (Lin, 2002).

7.3.2 Objectives

This project intends to employ the latest visualisation technologies to provide advanced flood mapping to support the flood risk management and associated emergency response and coordination functions to be extended in the future. Generally this case study intends to reach the following tasks:

- To further test the practicality and functionality of UECD as a generic approach and coordinated workflow in a different geographic setting (in comparison with Whitegate flood mapping project).
- To create flood simulation for the central part of Zhushan Town presenting the likely scenario in an extreme rainfall season and use appropriate technologies to enhance the visual effects.
- To equip the mapping tool with GIS spatial analysis functions to provide reliable scientific solutions and decision-making support.
- To ensure the flexibility of the platform with a structure that can be further extended to meet increasing requirements.
- To build a user-friendly interface and reduce the complexity of operating the system.

7.3.3 Working Phases

The Zhushan Town Administrative Committee (ZTAC) is the target user group of this GVIS application. This committee supervised the city Tourist Administration Bureau, looks after all matters in Zhushan Town and works closely with the Municipal Administration Bureau managing all the existing facilities and infrastructure as well as future development projects. The project is facilitated by the Changzhou Surveying and Mapping Institute (the Institute). The GVIS team is composed by three GIS scientists including one from the Institute and two guest experts from Changzhou University and Jiangxi Normal University separately. A team of six programmers is organised by the Institute and they are the designers in charge of system design, programming and modelling.

Phase One: Investigating available datasets

Since February 2007, the Institute started data infrastructure preparation for digital city management of Changzhou. By the end of 2011, the Institute had established a comprehensive GVIS database for the city's 220km^2 land territory, and the database contains the latest aerial photography, DEMs and GIS layers. This database, with full access secured by the Institute, became the fundamental and quality data source for building the visualisation[3]. The main three types of data used in the design were 1:1000 topographic maps in digital formats, 1:2000 high-resolution RS imagery and 2.5m resolution DEM of the site.

Phase Two: Gathering user requirements

A formal project meeting with four officials from ZTAC was hosted at the Institute in the end of February, 2012 after initial preparation of the project. A brief introduction was given by

[3] Due to data confidentiality policies in China for geographic data, unfortunately details of the data used for this project are not allowed to be displayed by any means in this paper.

the officials about the two-phase development plan of the town including the key construction projects. The director of the Institute and chief engineers reviewed the latest successful GVIS/GIS projects completed by the Institute and presented the initial findings from the design team's field trip to Zhushan Town. The design team gave a demonstration of a recent municipal facilities management GIS system built by the Institute, which was awarded Third Prize of Provincial Excellent Surveying Project. The Whitegate Flood Mapping project was also introduced at the meeting to show one possible type of GVIS tool that can be produced. The chief engineer emphasised the Institute's strength on producing photo-realistic 3D models for urban geographic objects. A preliminary discussion took place between the two sides regarding general project schedule and periodic reports at key stages of the design process.

A field trip to Zhushan Town was organised by the design team afterward with the purpose of interviewing ZTAC office for a better understanding of the target site and taking photography for the primary ground features such as all buildings that are to be visualised in 3D. The team walked around the town afterwards, while ZTAC official explained the the concerns of potential flooding in "Mei" and relevant flood control strategies applied by ZTAC. The designers took photograph from different angels for major residential buildings built in the town, and these photographs are used as visual references when making the textiles and rendering their 3D models (Figure 7.18).

Figure 7.18 Villas on sale all finished in 1st phase development of the town (Source: photograph by author, 2012). The field photograph were used as visual references for the 3D model rendering later on in the study

Interviews were conducted when the two officials brought the team to the archive room and showed us all construction plans, and architectural drawings from the two-phase development (Figure 7.19). Officials specifically introduced the largest project of the second phase - the new International Conference Centre that is located at the south edge of the town next to the piers. Such water front location gave the conference centre an extraordinary view of

the Taihu Lake (Figure 7.20), but it also made the building totally exposed to the threat of flooding. The conference centre could be flooded immediately once the water level rose beyond the warning level in a rainy season.

Figure 7.19 Consult construction and landscape plans at ZTAC (Source: photograph by author, 2012). Some of the drawings were used later on when 3D models were created in Autodesk 3D MAX.

Figure 7.20 Zhushan Town (1st phase) viewed from Taihu (face northeast) (Source: photograph by author, 2012). This picture shows that the buildings are built next to the lake and they are vulnerable to potential flooding in a rainy season.

Through informal discussions, ZTAC officials seemed to have little knowledge or experience with GVIS applications, which made them enthusiastic about the photo-realistic 3D immersive display environment demonstrated at the introductory meeting. The Whitegate 3D flood mapping (See Section 7.2) was shown as a sample of the type of GVIS tool that is to be produced, and the ZTAC officials were asked to give critically reviews, where four major problems were raised:

- The geographic scale of Whitegate and Zhushan Town is different, which means the amount of information to be visualised in the two cases will be different. Zhushan Town is much larger, and the numbers of ground features (e.g. buildings, trees) to be displayed in 3D will be multiplied. The quality of the visualisation handling the 3D models is a big challenge.
- Details of the 3D models in Whitegate case are not sound enough, and the overall visual display needs substantial improvement. The officials suspect that the quality is constrained by the capacity of the GVIS software employed (i.e. ArcScene), which is hopefully to be solved by making use of more professional GVIS platform and 3D rendering packages.
- The officials feel that the interface of Whitegate GVIS tool is slightly dull and confusing in terms of the toolbars, buttons, icons and the overall artistic design, which suggests that menus, toolbars and buttons should be re-designed to ensure a more comfortable using experience.
- Viewing the 3D scene was not smooth due to the rendering load of the system.

Apparently users looked more into visual elements such as interface, details and rendering than other aspects of the tool. When asked why the model details or more realism would be important for flooding display, a typical response was,

> *"This is based on three types of demands. The first one is the demand of superiors' decision-making, for which the system needs to explicitly show the attractiveness of the place and the problems; (the second) one is for the demand of current use and a full 3D environment makes the (focus of) planning move from one single project to the spatial pattern of the area; the last one is to show how the system is moving into a more scientific and advanced future."*

Phase Three: Subject Technology Matching

The GVIS experts soon ran into a difficulty because the interviewed user group from ZTAC was very small and they did not provide much useful information because of their lack of knowledge or experience with mapping products and GIS. Some valuable hints could be captured when they were commenting on the drawbacks of the Whitegate case. Therefore STM document used in the Whitegate case study, which had already included many user reflections collected in Ireland, was re-used again as an initial plan for this project. Table 7.7 gives the STM scripts that were used for prototyping.

Table 7.7 STM template for Zhushan Town Flood Simulation

Subject (classification and layering of user requirement)	Technology (techniques recommended by GVIS experts for the subject)	Matching (expected performance)
landscape	2m DEM --high-resolution	HM
	2m orthoimagery --high-resolution	HM
Realism	3D models --AutoCAD and 3ds MAX (buildings, trees)	HM
	CG texture --water	HM
	Real world texture --building	HM
	Symbology --2D and 3D	NM
	Highlighting --layer transparency	HM
	Object RTT in 3ds MAX	HM
Navigation	Pan, zoom, rotate --Google Earth like	HM
	Animation --output as .avi format	HM
Spatial analysis	Measurement --distance, height, volume, profile --tools extendable	HM
Platform	Uniscope --specialized 3D GVIS platform	HM
	Web-based structure	HM

The most important part of the project was detailed 3D landscape modelling. The terrain surface can be created through rendering DEM directly in the platform (Figure 7.21). A large amount of time was spent on creating 3D models for the buildings. The two dimension coordinates (surface location) of the building was decided based on a topographic map, so each building was matched to a real world reference system. The heights of the object components were acquired from aerial photogrammetry data. Details of the buildings were also rectified according to the architectural drawings shared by ZTAC officials. The primary textures were

extracted from field photographs. If certain textures from photos could not meet the quality standard, they were imported from external resources and processed by developers. The actual model creation was conducted using Autodesk 3ds MAX® which is one of the most professional 3D modelling and rendering software in market. Buildings were placed according to their relative locations in the scene. Rapid duplication and automation helped setting up structures and draping textures for those same buildings in the scene. Each building was however coded uniquely and assigned with its own attributes (Figure 7.22). Preliminary models were outputted and placed on the terrain surface to give an overall adjustment of all the geographic objects which appeared before further rendering works. In order to reduce the system rendering load and speed up the scene navigation, all the models went back to 3ds MAX for “texture baking”, or rendering to textures (RTT), which allows the creation of texture maps based on an object’s appearance in the rendered scene (Figure 7.23).

Figure 7.21 Basic terrain surface created by DEM (face north). This screen snapshot shows the elevated aerial photograph with support of high-resolution DEM. All the ground features are clearly viewed in this scene.

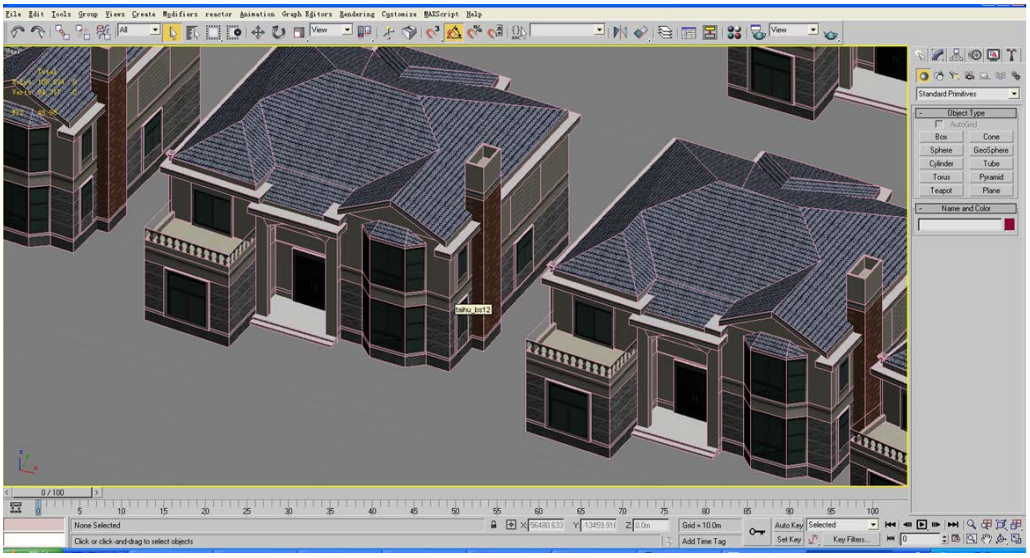


Figure 7.22 Creating 3D building models in Autodesk 3ds MAX environment. This screen snapshot shows the 3D villas, with reference to the field photograph, are being created in detail before further rendering.

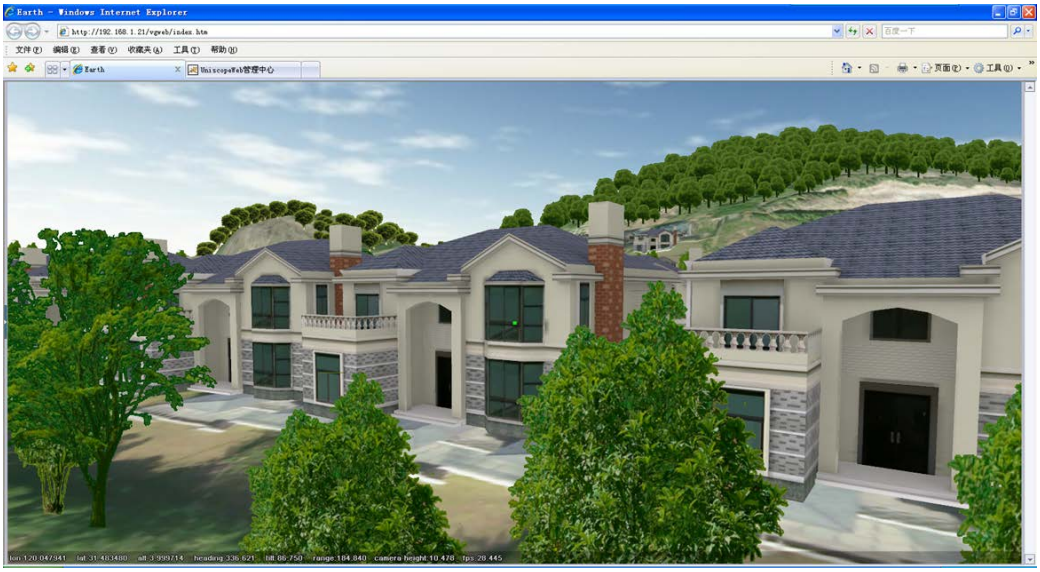


Figure 7.23 3D building after "texture baking" (face north). This screen snapshot shows the photo-realistic detailed models created and placed in their correct positions. Also seen in this picture are the rendered trees "planted" over the terrain surface.

When the 3D models were being produced, GVIS experts sent the STM template to ZTAC users and explained the technical solution that had been proposed in order to satisfy their requirements. GVIS experts also took this opportunity to understand the level of detail that is required in the modelling process. For this process several snapshots from the Whitegate flood mapping were taken and presented to the users, and they were asked to advise the top three elements they noticed at first. It was found that users were mostly interested in seeing the land topography followed by buildings, vehicles, water surfaces (which took up a large proportion of the scene) and trees. The greatest amount of time that users spent on navigation in the scene was related to details of the buildings. Therefore the team decided to reduce the details of trees for this visualisation and use the pre-existing simple plant models contained in Uniscope.

As mentioned above, the key project of the second phase development of Zhushan Town was the conference centre. This key infrastructure needed to be reflected in this visualisation as well. Compared with other villas scattered in the area, the conference centre

was much larger in size with a very different facade. The development team consulted the construction plan and architecture drawings, and in the same method used for other buildings, built up the model in 3ds MAX (Figure 7.24a; 7.24b).

Figure 7.24a Conceptual art of the conference centre. This conceptual art was shared by the ZTAC planning devision.

Figure 7.24b Model created in 3ds MAX (face northeast). This screen snapshot shows the overview of the site when the conference centre is placed in its location.

The final output created by the design team provided a 3D landscape of Zhushan Town (1st and 2nd phase) with extraordinary detailed 3D features (Figure 7.25). Shifting view points and zooming were very smooth with no redundancy as all 3D features are rendered very quickly on

UNISCOPE platform (Figure 7.26; 7.27).

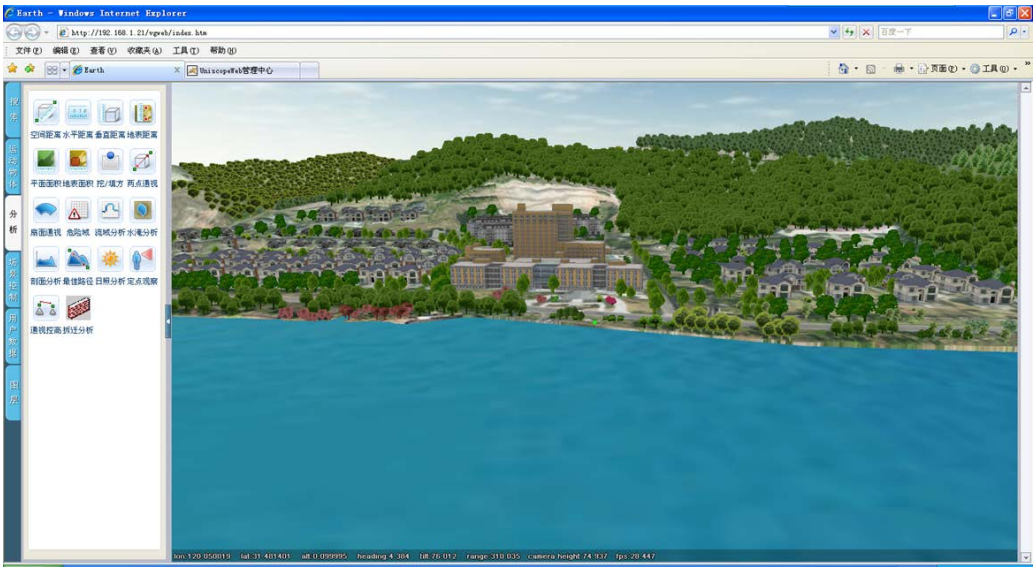


Figure 7.25 System interface (face northeast). This screen snapshot shows an overview of the software interface. The main body of the window is the display area and all the tools are categorised and placed on the left.

GVIS experts suggested that a toolkit containing some basic spatial analysis tools should be added to the system. This suggestion was further realised providing tools such as measuring spatial distance, horizontal distance and vertical distance (Figure 7.28), surface area, inter-visibility, watershed analysis, profile analysis, cut and fill volume calculation, and best route analysis.

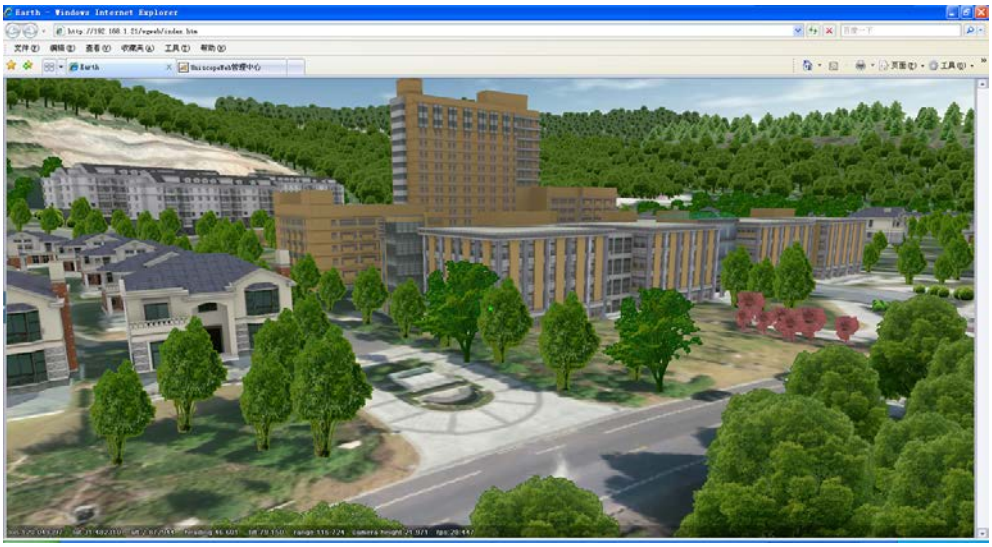


Figure 7.26 Change viewpoints in navigation (face southeast)

Figure 7.27 Zoom in to see details of the objects. This screen snapshot shows the different details of the buildings and the different textures applied to the models.

Figure 7.28 Vertical distance (height) measurement. This screen snapshot shows the 3D measurement tool provided in the software.

As a flood risk analysis tool, the system allows users to define the height of the water surface and observe the flooding scenarios (Figure 7.29a; 7.29b; 7.29c). All the spatial analysis tools can be used at the same time and scenes can be output as static imagery.

Figure 7.29a Users can define water level. This screen snapshot shows the scenario when the input value of the water level is changed into 2m when the lake banks are already flooded.

Figure 7.29b Change water level to see a different view. The water level is further increased when roads, trees next to the banks and some buildings are flooded.

Figure 7.29c Water level can be set to extreme values. In this screen snapshot, the water level is set to 15m which is unlikely to happen in the real world.

Phase Five: Usability test

As the essential part of usability testing, the design team went through all the navigation tools and analysis tools to spot technical flaws and examined all the 3D objects in the scene to make sure the spatial placement was correct. GVIS experts proposed a usability test of 30 minutes approximately, which contained three parts: introduction to the Uniscope platform

(2 minutes), a practical test with small tasks (10 minutes) and discussion (10 minutes). To help users get familiar with the system, a hand-out on how to use the software was produced by the development team. Similar questions used for the Whitegate case study were adopted in this test with slight changes to fit the content (Table 7.8).

Table 7.8 Questions to be accomplished by users with the system provided

Please find out the answers with the visualisation provided.
How many buildings in total are there in the scene?
How many floors does the apartment building A have?
Can you measure the height of the conference centre?
At what water level will the main road in front of the site be flooded?
At what water level will the annex building of the conference centre be flooded?
Can you measure the distance from Villa 6B to the conference centre?

Uniscope is web-based, thus the system can only be accessed from authorised domain addresses. Therefore the Zhuanshan Town flood simulation system was physically hosted and maintained at the Mapping Institute, which made it easy to be updated and maintained, as well as to be connected to the city emergency management system currently being deployed. The usability testing was performed at the ZTAC office led by the GVIS experts and two system developers. Three staff officials from ZTAC attended the test, where they were given a brief introduction to the system and a hand-out with instructions and questions (see *Appendix 9: Hand-out for Zhushan Town Flood Simulation Project*). The participants were asked to work on their own desktop computers, accessed the system and went through the tasks given in the hand-out. The project staff from the Mapping Institute remained stand-by during the test in case any questions were raised by the participants (Figure 7.30).

Figure 7.30 ZTAC staff testing the product (Source: photograph by author, 2012). The ZTAC officials were asked to try to use the system following the instruction of the hand-out.

Overall compliments were given in particular for the significantly improved 3D visual effects. Users were impressed by the photo-realistic 3D features displayed in the scene and they believed that the visual display would help improve the quality of decision making. Users found the system was easy enough to use. The interface provided a similar using experience to Google Map, which made the participants feel particularly comfortable. They were also satisfied with the out-of-box web-based structure of the system because they could access it directly using an Internet browser without worrying about software installation.

7.3.4 Conclusion

Like the previous case, all the work were stretched out based on the five-phase approach. User requirement collection was prioritized at the beginning of the project and the adopted STM working scripts was very helpful when instructing the prototyping works. The cooperation between developers and GVIS experts was quite successful and the interaction and communication with users worked as well as planned. From a project point of view, it presented

another example of applying advanced GVIS technologies into the area of flood risk mapping. The output system employed professional GVIS software and the level of detail of the 3D landscape modelling represented possibly the latest 3D representation technology advancement in city and urban management realm.

Positive feedbacks from users confirmed the success of choosing the platform and development efforts devoted to the production of a high resolution 3D model. The success was also based on a good understanding of user requirements and technical solutions proposed by GVIS experts. The professional Uniscope platform in this case study solved the following problems:

- the support of high resolution and detailed 3D model creation as well as handling mass 3D rendering;
- the cross-platform collaboration with other software (e.g. 3ds MAX);
- the artistic design of the interface such as windows, toolbars and buttons;
- the system access, setup, update and maintenance.

However, it should be noted that the facilitation of the system demonstrated above usually means a significant increase in project costs, which can become a major constraint for privately funded projects. Additionally the ZTAC officials showed such a great interest in visual effect which made GVIS experts change the original plan and employed UNISCOPE in order to reach the required realism. The discussion later on with ZTAC officials suggested that ZTAC would like to be the pioneer of applying the latest 3D technologies for digital and smart town management among the public sectors in the city. This interesting attitude of users can be further explained by taking into consideration the different social and technical settings in China.

This case study took place in China, where technical application development used for decision making, especially for government bodies, is usually administration driven. The beneficial side of this mode is that new technologies can be applied very quickly and an application can be completed in a relatively short time, whereas the problematic side is that many ad-hoc GVIS applications fail to fully meet users' expectations and it is mostly due to lack of understanding of user requirements. This also explains why it is important to involve GVIS experts in the UECD approach to help coordinate the design process and reduce blinded use of technologies.

7.4 Summary

This whole chapter presents two case studies that are conducted after the new UECD framework being proposed in this thesis. The two cases have a lot in common because they both focus on flood mapping and the output products display the inundation that could potentially affect nearby town lands and provide scenarios of future SLR impacts. At the same time they are quite different due to the different context, different technologies used and different outputs. These two projects were essentially organised to experiment UECD in a real world context so as to gain a preliminary insight into this new design framework and its associated elements such as STM.

Section 4

Discussion and Conclusions

Chapter 8

Discussion and Conclusions

8.1 Conclusions

Because of its visualisation origin, GVIS is largely recognized by its cognitive features linked with the functions offered in helping users discover unknown patterns. These types of functions are further augmented by the adoption of advanced visual display technologies. Arguments are raised though by GVIS scholars and practitioners regarding the problems of the GVIS applications not being able to meet up with users' expectations. It is found in this research, through extensive and in-depth literature review, that the problems are often associated with users' diverse demands for solving specific tasks. Results of the survey in this thesis (see Section 5.2) have suggested that users' preference on different GVIS tools can be very subjective and their views on the usability of these tools can vary significantly. In this sense, usability of a GVIS tool can be diversified due to specific user characteristics and specific usage situations.

Enhancing usability is critically important to ensure a sustainable future of GVIS, but much of the focus in practice has been put on upgrading techniques and the possibility of improving the design process is yet not explored.

In order to address this issue, this research presents a new design framework called Usability Enhanced Coordinated Design (UECD), which amplifies the inputs of end-users and reinforces the communication between users and designers so as to form a more coordinated workflow. UECD can be generally divided into five phases: data sourcing, user requirement elicitation, Subject-Technology Matching (STM), prototyping and usability testing and the design process involves three groups of people – users, GVIS experts and designers. GVIS experts will be actively involved in all phases coordinating the organisation of the design and development activities. Their major tasks include sourcing supportive dataset, collecting and analysing user requirements, providing assistance to prototyping and conducting usability testing. The concept of STM is brought forward in this research as the basis of UECD. This new theoretical concept refers to the activity that experts interpret and abstract key information from user requirements and the information are converted into working scripts used for instructing product development. This is an original idea of putting users at the centre of the design by letting them work closely with GVIS experts and STM will help maximise the value of users' inputs. An output STM document contains the key subjects to be addressed by the design functions of the product, and expected technical solutions recommended by the experts, in order to make good use of field knowledge and expertise.

Furthermore, this research argues that incorporating user requirements and GVIS expertise in a more effective way provides a sound solution to the overall improvement of GVIS

design. The idea of establishing STM template set and re-using STM scripts can significantly ease the design cycle, reduce the risk of failing user expectation and avoid blinded employment of expensive or inappropriate visualisation technologies. By doing this, the design processes will become more effective and the output tools will become more focused and adaptable when facing complex geographic problems.

The two case studies presented in this research provide first-hand insights into the practice of UECD. On one hand, they show the great potential of using this coordinated design and STM to enhance the usability of the outputs. On the other, they test the theoretical elements of UECD and help identify future improvements. The two demonstrations also open the door for future research to further refine and develop the theoretical elements of UECD so as to make it a useful methodology for GVIS practitioners.

8.2 Research Questions Answered

At the beginning of this thesis, it is stated that the whole research is structured surrounding two main questions, thus the completion of this research involves the resolution of these questions.

Question 1: How can GVIS usability be conceptualised and measured?

The interest in usability commenced in the 1980s, when scientists were putting traditional methods into the area of exploring human factors in the computer environment (Shneidman, 1998; Dumas, 1988). The idea of usability and its associated engineering practice, for computer application, became one of the key aspects for people to describe a sound design (Whiteside, *et al.*, 1988), which is the case for modern computer-assisted cartography and other GVIS and GIS products as well. When GVIS technologies began to be applied extensively to all

fields, scholars also began to be concerned about the reasons behind those applications that fail the functional needs and consequently began to question what GVIS usability is meant to be (Slocum, *et al.*, 2001). Some of the most visited GVIS usability problems include its definition and significance, how to evaluate the usability of GVIS applications and identifying useful guidelines for GVIS product design (Perlman, 1997; Sheppard, 2005; Fuhrmann and Pike, 2005; Fuhrmann, *et al.*, 2005; Andrienko, 2006; Lloyd, *et al.*, 2007; Demšar, 2007). These explorations also infer moving of the focus of current GVIS practice from innovating HIC techniques to developing more usability focused design methodology. Drawn on the current understanding of usability, this research claims that in GVIS production, rather than prioritizing evaluation and follow-up improvements, it is more important to incorporate usability enhancement throughout the whole design process. At the same time, this challenge is tasking current GVIS practice not just to focus on upgrading user-centred technologies, but also on developing user-centred design approaches.

Literature studies suggest that there has been no universal definition of usability so far and in terms of the content of usability, a number of explorations have been made by pioneer usability practitioners (Woodson, 1981; Nielsen, 1993; Butler, 1996; Quesenbery, 2001; Rogers, *et al.*, 2011). The most widely applied definition in industry comes from ISO9241-11, which clarified the concept as a mix of effectiveness, efficiency and satisfaction (ISO, 1998). Due to the uncertain definition of usability, there has been yet no agreed definition for GVIS usability and its multi-dimensional nature has instigated explorations from all aspects. Generally speaking, contemporary GVIS tools can be seen as a type of HCI application for use in a specific domain, thus the ISO definition can be adopted cautiously given the differences between GVIS and

regular information visualisation and data visualisation. A common view shared by many scholars in this area is that GVIS is more demanding on cognitive functions, making it even harder to implicitly describe the dimensions of the concept (Fuhrmann, *et al.*, 2005; Andrienko, 2006; Demšar, 2007). By reviewing relevant works on this aspect, this research finds that the discovered dimensions of usability have imposed challenges on its evaluation and augmentation.

It is found in this research that usability of a product, as a rather abstract concept, is difficult to quantify and measure. The general usability testing methods of HCI (Dix, *et al.*, 2004; Nielsen, 1993; Rogers, *et al.*, 2011) have been adopted widely in GVIS field. The selective and combined use of these methods has become the centre of evaluating GVIS usability and some examples on this aspect can be found from experiments pioneered by Andrienko *et al.* (2002), Tobón (2002), Rosson and Carroll (2002), Haklay and Tobón (2003), Edsall (2003), Koua and Kraak (2004), Dykes *et al.* (2008), Robinson (2005), Sidlar and Rinner (2007), Nivala *et al.* (2007) and Roth and Harrower (2008). The whole range of usability evaluation cases emphasise the fact that usability testing through the use of different methods, has become the essential element of GVIS production and relevant problems such as understanding users and getting them fully involved are still to be addressed with regard to where and how the GVIS tool is applied.

Question 2: How to enhance usability of GVIS tool from a product development perspective?

Technologies are constantly being updated in the area of GVIS in order to meet the continuing needs of spatial exploration and associated analytical tasks, examples of which have been presented in this thesis as well (see Section 2.3.1). Advancements such as 3D and VR are

meant to serve users' spatial cognition purposes. However as mentioned before, enhancing usability by improving technology is unlikely enough to fully solve usability issues because pushing technology towards users does not necessarily mean giving what they want from a UCD point of view. In this sense, improvements can be made to the design and development process, where user expectation and requirement should be incorporated and reflected on. The argument thus is that a product can only meet users' needs when it has been designed with sufficient consideration of user requirements.

As reviewed in this research, the debate between technology-driven and user-centred (driven) is not novel and the acceptance of the latter has been overwhelmingly popularised in almost all present HCI fields. UCD, which is the framework based on user-centred consideration, consequently has attracted numerous followers. However it is still too early to say that current designs are fully user-centred. The key problem identified by scholars is the communication barrier between users and developers (product designers), which needs to be solved by introducing a medium (Harrower, 2003; Lauesen, 2005; Ware and Bobrow, 2005; Lloyd, *et al.*, 2007; Roth and Harrower, 2008).This medium is usually referred as improved interface, whereas in this research it refers to a specific type of person – GVIS expert, who has sufficient knowledge and experience on GVIS application. In a UECD framework as proposed in this research, the experts will be responsible for bridging the communication gap between users and designers via their own interpretation of inputs from the other two parties. With such communication processes, relevant knowledge, experience and expertise can be more effectively shared in the workflow.

The central idea of UCD is to place users at the centre of the design and development

cycle, thus users get more chance to be involved in the process, which is however not easy to do in practice. It has long been a problem for usability practitioners in terms of how to get users involved effectively and how to make their involvement play effectively in the design phase. Yet in particular there have been very few fruitful explorations in the area of GVIS design. To respond to this situation, this thesis proposes the idea of STM, which is essentially a specific task for GVIS experts to extract the key information out of user requirements and to propose technical solutions based on their own expertise. The generated STM document provides an overview of those primary components to be delivered by the tool according to user's expectation, in which sense the document can be used to instruct the following prototyping. All three parties can also use this document as a reference to trace the outputs of each stage of the process.

GVIS applications are increasingly demanded for all types of spatial exploration, perception, communication and decision making. It is not just a matter of what kind of functions can be delivered by new tools, but also a matter of how the tools can be made more accessible and usable to users. New technology use in GVIS, such as 3D display, has enabled a tool to perform a wider range of tasks. This leads to growing demands for effective and efficient performance of the tool. Events like coastal inundation often demand a quick reaction in decision making, which increasingly relies on the support of advanced technologies such as GVIS. How to produce a useful and usable GVIS application more effectively becomes an associated challenge. This thesis believes that the new UECD approach proposed sheds light on a new way of re-using the knowledge and techniques contained in a GVIS practice, so as to benefit subsequent designs.

8.3 Major findings and their significance

The significant finding of this research can all be summarised into the word “UECD”. On the one hand, “UECD” can be referred to the Usability Enhanced Coordination Design framework which is the core product of the research; On the other, “UECD” can be referred to the abbreviation for “Understanding, Exploring, Constructing and Developing” which will be explained later on. By revisiting the double meaning of “UECD”, this section thereby revisits and highlights the major achievements of this research as follows:

1) The key finding of this research is the proposal of **Usability Enhanced Coordination Design** framework as a response to the increasing usability concern in GVIS practice. This research believes that GVIS usability augmentation should be realised through an optimised design process, based on concepts drawn from UCD. UCD has a comparatively long history, but has never been approached as the basis of developing a new framework.

The nature of UECD is a new type of coordinated workflow led by GVIS experts and driven by user requirements. Compared with UCD, UECD takes a step forward and gives a lot more instructions on how to deploy the approach and organise tasks at each stage of the process. The two flood mapping case studies provide good demonstrations on how UECD can be carried out step-to-step in practice and make it easy for other relevant studies or practices to adopt and improve the framework. In addition, UECD is developed based on STM which is also newly brought forward in this research to answer to the need of a better way to reflect user requirements in GVIS design. The unique structure of STM makes it easy to be transferred between GVIS projects and possible to be adopted by another design protopying. This research thus enriches the functionality of STM by introducing the mechanism of template set, which

further extends the practicality and potential of UECD. In this sense, through the proposal of UECD, this research integrates a unique view point as well as many creative ideas into a well-discussed topic of the field.

2) "UECD" represents "Understanding, Exploring, Constructing and Developing", which summarise the major tasks completed in this research. More specifically,

This study presents a comprehensive understanding of GVIS and usability. In order to establish a solid theoretical foundation for the proposal of UECD, this thesis reviews the definition, key functions and applications, evolvement and innovation and future challenges of GVIS as well as the conception and evaluation of usability and UCD. By investigating the evolving conception and application of GVIS, this research stresses the great need of producing useful and usable GVIS tools to meet up with users' growing requirements. Parallelly based on current understanding of usability and extensive application of UCD, this research calls for a modification to traditional GVIS design according to UCD guidelines.

In this sense, the thesis presents an up-to-date and yet a critical report of those key knowledge elements involved in a GVIS usability study. Among the above review, a number of important questions are raised. For instance, it is pointed out that the cognitive nature makes GVIS different from other common HCI applications, which makes it critically important to understand characteristics of users both as individuals and as groups. It is also argued that the complexity nature of usability makes it difficult to be explicitly defined or evaluated and thus approaching GVIS usability enhancement remains quite open. These sort of questions discussed in this thesis point out several research orientations for further studies.

This thesis focuses on exploring influences of users' characteristics on their concerns

of GVIS usability issues. The survey conducted as part of the research anticipates that adopting advanced display technology does not necessarily brings better usability. By testing a range of flooding maps with users from Ireland and China, the experiment discovers a rather diverse feedback from audience in terms of their preferred usage of different tools. The survey findings support the complexity of usability perception and its connection with user characteristics and become an important part of the foundation of the proposal of UECD.

This thesis brings forward an original idea of constructing a framework to enhance GVIS usability by improving the design and development approach. The construction begins with the identification of key features of GVIS usability and the emerging need of improvement to traditional HCI design approach. UCD is then brought into this construction and used as a template of developing a usability focused approach. To leverage user inputs, this research constructs the idea of STM as a new mechanism to maximise user inputs to the design prototyping. In order to deliver the best output, this research constructs a new type of workflow where GVIS expert(s) are introduced into the design process to bridge the communication between users and designers and to coordinate UECD workflow. Additionally this research constructs the concept of STM template set, which is an experimental concept that can potentially increase the overall efficiency of GVIS designs.

This thesis extends the discussion by further developing the UECD framework and its associated concepts via case studies and potential applications. UECD involves a number of new theoretical elements that are only at conceptual stage, and they need to be tested in a real-world environment to go through a self-evaluation process. Therefore this research organises two case studies, with the same topic of flooding mapping but with slightly different contexts, to

carry out UECD framework steop-by-step with real users and real data. As a result of such work, this research manages to obtain first-hand data in terms of how the proposed coordinated workflow functions practically. By doing the two cases, together with the survey conducted beforehand, the thesis then develops the research into a good combination of theoretical exploration and practical application.

8.4 Directions for Further Research

This research uses a mainly experimental approach to explore controversial topic. It lays foundations that offer many opportunities for future studies and the new UECD and its associated concepts are hopefully to be developed by further reserach. There are several tasks that can be included in the next stage of this research:

1) It is important to make UECD known to a wider range of audience immediately to receive as many peer-based reviews as possible. As a new theory, the rationality and integrity need to be further examined and matured by different views, which will help seek answers to questions such as how to set up systematic guidelines for GVIS experts to do perform STM needs to be further explored and how to develop the idea of STM template set into a consolidated theory by incorporating knowledge and practice from AI studies. Additionally apart from the case studies conducted in this research, UECD needs to be experimented and evaluated by other scholars in more different GVIS design cases, where all the lessons learnt will help fix problems and improve the functionality of the approach. UECD is meant be applied as a generic approach to all application cases and modification can be made whenever necessary to respond to specific requirements. Therefore in order to reinforce this argument, the research plans to source at least two projects, with a different focus other than flood mapping, where UECD can be

experimented. This is to accumulate success application cases of UECD in practice and to spot potential difficulties and problems when the approach is carried out in a different situation.

2) Future research needs to further clarify the key components of UECD and present a well-defined description of what are they. The theory is for the first time proposed in this thesis and some of the elements are still subject to further correction. For example, *GVIS expert* is a newly raised concept defined as the type of personnel that has rich knowledge of developing GVIS technology as well as experience of applying GVIS to solve specific problems. The boundaries between users, GVIS experts and designers are made distinct when illustrating and explaining the workflow, whereas the boundaries can actually be fuzzy in practice. Sometimes GVIS experts can be users or designers at the same time, where the workflow will not strictly follow the described route. Therefore future research should identify possible circumstances that UECD will be carried out differently and clarify how the approach works (or may work) in those circumstances.

3) This research should consolidate the theoretical basis of STM by further clarifying how precisely it can be operated. STM relies largely on GVIS experts' interpretation of user requirements, thus how to decompose those requirements into subjects remains a question. A set of principles, called a "four-question" approach in this thesis, is introduced as a sample of how to abstract subjects from requirements. Experiments are needed to support the operation of such approach or an alternative one. Besides, future research should extend the exploration on STM document regarding how to make it carry more beneficial information for subsequent design. This type of information can be the description of the context (or usage situation) that the GVIS tool will be applied to, or the technical roadmap with description of the major tasks at

each stage of the design and highlights the phases that end-users will be directly involved, or a summary of user feedback from completed usability tests containing both the successful and unsuccessful practices of the product.

4) It is also this research's intention to extend the exploration on STM template set construction. Foreseeable difficulties at this stage will include the number of recorded empirical design templates, the quality of such stored templates and the mechanism of updating templates. Future experiments can start from some small-scale experiments conducted internally, for instance, at a certain organisation like the Changzhou Surveying and Mapping Institute. STM documents can be created for those completed GVIS projects led by the institute (e.g., Zhushan Town flood visualisation) and these documents become the initial template set. This base is open to consultation by subsequent projects and can be enriched gradually with more input STM cases over time.

5) The workshop survey needs to recruit more audience so as to obtain a diverse response from different users. The next step of Whitegate project is thus to publish all GVIS tools online on a website well-received in Cork and invite as many local communities as possible to view and experience the use of modern GVIS technologies. With a considerable amount of replies, the results can be collected to further analyse the effectiveness of different GVIS tools on communicating flooding risk in Whitegate. By increasing local public awareness and participation in this way, it is hoped that a similar but more rounded and sophisticated visualisation toolkit can be initiated by follow-up research for Cork Harbour coastal management and it will eventually become the primary flood information exchange platform with complete public access.

6) In terms of future case studies, the research will focus on maximising the usage of the toolkit. The next step is to improve the ground details and accuracy of existing 3D models and to enlarge the coverage of the database to adjacent areas. The presentation functions should be served online and open to general public, while the editing and analytical functions should remain internally used only. An online feature will be added as an extra feature into the current system to offer users a platform to exchange their views and comments as well as to raise questions about flood risk management at ZTAC. In a long-term, the current system will also be integrated to a smart management GIS system of the whole city, which will be established using the same platform Uniscope. As a result of such integration, the current system will be extended to a more sophisticated management toolkit and flood risk analysis will become part of it.

8.5 Final Remarks

Knowing our world is very different nowadays thanks to the wide employment of modern technologies like GVIS, with which geographic problems now can be presented on screen in both 2D and 3D display and with the assistance of specialised analytical tools, decision making is more scientifically supported and thus has been significantly improved. This thesis has shown a lot of the latest innovations and developments of GVIS technologies, for which GVIS practitioners' constant efforts of adding more value to current practice have become the prime driver of extensive GVIS application. However along with the growing use of GVIS technologies, arguments are also raised particularly with regard to usability issues and it is claimed that technological upgrading of a GVIS tool should only considered successful when it actually helps

make the tool more useful and usable. A widely acknowledged view is that there should be more substantial improvements made to the improvement of GVIS design approach, or the creation of such approach that aims at addressing usability enhancement. This is why this piece of research deliberately brings forward the new UECD as a way of responding to this challenge.

GVIS usability issues are attracting more and more attention and obviously it has been increasingly acknowledged that usability, as a cross boundary concept, needs constant effort from not only from people in GVIS field, but also from scholars in fields like software development, product design, HCI engineering, AI, psychology, human factors studies and even social studies as well. Just like an old Chinese idiom says, "*throw out a brick to get a gem*" or the equivalent western idiom says "*fling away a sprat to catch a herring*". The proposal of UECD intends to break the ice and shed light on the facilitation of UCD framework in the specific area of GVIS. It is hoped that this thesis has been inspiring and intriguing enough to prompt more studies and valuable insights into this interesting area of science.

Section 9

References and Appendices

Reference

3D Nature, n.d. Dolomiti Bellunesi National Park – Italy [image online] Available at:<http://www.3dnworld.com/users/27/images/immagine_1_large.jpeg> [Accessed 12/09/2012]

Abran, A., Khelifi, A., Suryn, W. and Seffah, A., 2003. Consolidating the ISO Usability Models. In: *11th International Software Quality Management Conference*. Glasgow, Scotland, UK, 23-25 April 2003.

Abras, C., Maloney-Krichmar, D. and Preece, J. 2004. User-Centered Design. In Bainbridge, W., eds. 2004. *Encyclopaedia of Human-Computer Interaction*. Thousand Oaks: Sage.

Amstrong, M.P. and Densham, P.J., 2008. Cartographic support for locational problem-solving by groups. *International Journal of Geographical Information Science,* 22(7), pp.721-749.

Andrienko, G.L. and Andrienko, N.V., 1999. Knowledge Engineering for Automated Map Design in DESCARTES. In: *7th ACM International Symposium on Advances in Geographic Information Systems.* Kansas City, USA, 2-6 November 1999, ACM-GIS'99, pp.66-72.

Andrienko, N.V. and Andrienko, G.L., 2006. The complexity challenges to creating useful and usable geovisualisation tools. In: *4th International Conference on Geographic Information Science.* Münster, Germany, 20-23 September 2006.

Andrienko, N.V., Andrienko, G.L., Voss, H., Bernardo, F., Hipolito, J. and Kretchmer, U., 2002. Testing the usability of interactive maps in commonGIS. *Cartography and Geographic Information Science,* 29(4), pp.325-342.

Anselin, L., Syabri, L. and Kho, Y., 2006. GeoDa: An introduction to spatial data analysis. *Geographical Analysis,* 38(1), pp.5-22.

Apple Computers Inc., 2001. The "Dock", a feature of the "Mac OS X" operating system [online] Available at:< http://www.apple.com/macosx/theater/dock.html > [Accessed 2001-2004]

Arnaud, A. and Davoine, P-A., 2009. Temporal Geovisualisation in risk area. In: *24th International Cartographic Conference (ICC2009)*. Santiago, Chile, 15-21 November 2009, p.17.

Aronoff, S., 1991. *Geographic Information Systems: a Management Perspective*. Ottawa: WDL Publications.

Artimo, K., 1994. The Bridge between Cartographic and Geographic Information Systems. In MacEachren, A.M. and Taylor D.R.F., eds. 1994. *Visualisation in Modern Cartography*. Oxford: Pergamon, pp.45-61.

Avatar, 2009. [film] Directed by James Cameron. USA: 20th Century FOX

Azuma, R.T., 1997. A Survey of Augmented Reality. *Teleoperators and Virtual Environments,* 6 (4), pp. 355-385.

Baek, E.-O., Cagiltay, K., Boling E. and Frick, T., 2008. User-centered design and development. In: Spector J.M., Merrill M.D., van Merrienboer, J. and Driscoll, M.P., eds. *Handbook of research on educational communications and technology.* 3rded. New York: Taylor & Francis, pp. 659-670.

Baldonado, M.W., Woodruff, A. and Kuchinsky, A., 2000. Guidelines for using multiple views in information visualisation. In: *5th International Working Conference on Advanced Visual Interfaces.* Palermo, Italy, 23-26 May 2000, ACM Press, pp.110-119.

Barbieri-Low, A.J., 2007. *Artisans in Early Imperial China*. Seattle: University of Washington Press.

Bass, L. and John, B.E., 2003. Linking usability to Software architecture patterns through general scenarios. *The Journal of Systems and Software*, 66(3), pp.187-197.

Batty, M., Chapman, D., Evans S., Haklay, M., Kueppers, S., Shiode, N., Smith, A. and Torrens, P.M., 2001. Visualising the city: Communicating urban design to planners and decision-makers. In: Brail R.K. and Klosterman, R.E., eds. 2001. *Planning Support Systems: Integrating Geographic Information Systems, Models and Visualisation Tools*. Redlands: ESRI Press, pp.405-443.

Bell, J., 1993. *Doing Your Research Project – A Guide for First-Time Researchers in Education, Health and Social Science*. 2nd ed. Buckingham: Open University Press.

Benyon, D., Turner, P. and Turner S., 2005. *Designing Interactive Systems: People, Activities, Contexts, Technologies*. Edinburgh: Addison Wesley.

Bevan, N., 2006. International Standards for HCI. In: Ghaoui, C., *Encyclopedia of Human Computer Interaction.* Hershey: Idea Group Reference, pp.362-373.

Bevan, N. and Azuma, M., 1997. Quality in user: Incorporating human factors into the software engineering life cycle. In: *3rd IEEE International Software Engineering Standards Symposium and Forum.* Walnut Creek, USA, 1-6 June 1997, pp.169-179.

Beyer, H. and Holtzblatt, K., 1998. *Contextual Design: Defining Customer-centered Systems.* San Diego: Academic Press.

Bickman, L. and Rog, D.J., 1998. *Handbook of Applied Social Research Methods.* London: Sage.

Bishop, I.D. and Rohrmann, B., 2003. Subjective responses to simulated and real environments: a comparison. *Landscape and Urban Planning*, 65(4), pp.261-277.

Blinn, J. 1999. Transcription of keynote address at SIGGRAPH 98. *Computer graphics*, 33(1), pp.43-47.

Bødker, S., 1995. *Deliverable D 1.5.1: The EuroCODE Conceptual Framework: Framework Finalization—the Process*. Aarhus: Aarhus University Press.

Boehm, B., 1984. Software engineering economics. *IEEE Transactions on Software Engineering,* 10(1), pp.4-21.

Boehm, B., 1988. A spiral model of software development and enhancement. *Computer*, 21(5), pp.61-72.

Bryman, A., 2008. *Social Research Methods*. 3rd ed. Oxford: Oxford University Press.

Butler, K.A., 1996. Usability Engineering Turns 10. *Interactions*, 3(1), pp.58-75

Buttenfield, B.P. and Beard, M.K., 1994. Graphical and geographical components of data quality. In: Unwin, D. and Hearnshaw, H., eds. 1994. *Visualisation in Geographic Information Systems*. London: John Wiley & Sons. pp. 150-157.

Cai, G., 2008. Modelling Contextual Knowledge for Adaptive Geographic Visualisation [online] In: *International conference on Developments in Visualisation and Virtual Environments in Geographic Information Science*, Hong Kong, China, 7-8 January 2008. Available at:<http://www.iseis.cuhk.edu.hk/downloads/vge/13.pdf>[accessed 04/10/2010]

Capra, M., 2007. Comparing Usability Problems Identification and Description by Practitioners and Students. In: *51st Human Factors and Ergonomics Society Annual Meeting*. Baltimore, USA, 1-5 October 2007, 51(5), pp.474-477.

Card, S.K., Mackinlay J.D. and Shneidermann, B., eds. 1999. *Readings in Information Visualisation: Using Vision to Think*. San Francisco: Morgan Kaufmann.

Carroll, J.M., 2000. Five reasons for scenario-based design. *Interacting with Computers*, 13(1), pp.43-60.

Carter, R.W.G., 1991. Sea-level changes. In: McWilliams, B.E., ed. 1991. *Climate Change: Studies on the Implications for Ireland*. Dublin: Stationery Office, pp.125-171.

Carter, R.W.G., Devoy, R.J.N. and Shaw, J., 1989. Late Holocene sea levels in Ireland. *Journal of Quaternary Science*, 4(1), pp.7-24.

Cazenave, A., and Nerem, R.S., 2004. Present-day sea level change: observations and causes. *Reviews of Geophysics*, 42(3), pp.139-159.

Chin, J.P., Diehl, V.A. and Norman, K.L., 1988. Development of an instrument measuring user satisfaction of the human-computer interface. In: Soloway, E., Frye, D. and Sheppard S.B., eds. *The SIGCHI Conference on Human Factors in Computing Systems (CHI'88)*, 15-19 May, 1988, Washington, DC, USA, New York, NY: ACM, pp.213–218.

Chrisman, N., 2002. *Exploring Geographic Information systems.* 2nd ed. New York: Wiley.

Chrisman, N., 2006. *Charting the Unknown: How Computer Mapping at Harvard Became GIS*. Redlands: ESRI press.

Church, J.A., Gregory, J.M. Huybrechts, P., Kuhn, M., Lambeck, K., Nhuan, M.T., Qin, D. and Woodworth, P.L., 2001. Changes in sea level. In: Houghton *et al.*, eds. 2001. *Climate Change 2001: The Scientific Basis*. Cambridge: Cambridge University Press, pp.639-693.

Church, J.A. and White, N.J., 2006. A 20th century acceleration in global sea-level rise. *Geophysical Research Letters*, 33(1):L01602.

Clarke, K.C., Hoppen, S. and Gaydos, L., 1997. A self-modifying cellular automaton model of historical urbanization in the San Francisco Bay area. *Environment and Planning B: Planning and Design*, 24(2), pp.247-261.

Clarkson, M. 2009. Design Visualisation and the Desktop Engineer. *Technology for Design Engineering* [online] Available at:<http://www.deskeng.com/articles/aaanfz.htm> [Accessed 04/09/2012]

Cohen, D. 2006. Mapping Recent History. *Digital Humanities: Theory & Practice* [online] Available at:<http://www.dancohen.org/blog/posts/mapping_recent_history> [accessed 02/09/2012]

Consolvo, S., Arnstein L. and Franza, B.R., 2002. User study techniques in the design and evaluation of a ubicomp environment. In: *4th International Conference on Ubiquitous Computing.* UbiComp '02, Göteborg, Sweden, 29 September-1 October, 2002, pp.73-90.

Constantine, L.L. and Lockwood, L.A.D., 2002. Usage-centered engineering for web aplications. *IEEE Software*, 19(2), pp.42-50.

Coolen, J., 2008. Top 10 usability highs of Mac OS. *Smashing Magazine* [online] Available at:<http://www.smashingmagazine.com/2008/08/12/top-10-usability-highs-of-the-mac-os/> [Accessed 10/09/2012]

Cooper, A., 1999. *The inmates are running the asylum: Why high-tech products drive us crazy and how to restore the sanity*. Indianapolis: Sams Publishing.

Cooper, M.J.P., Beevers M.D. and Oppenheimer, M., 2005. *Future Sea-level Rise and the New Jersey Coast* [online] Princeton University Available at:<http://www.princeton.edu/step/people/faculty/michael-oppenheimer/recent-publications/Future-Sea-Level-Rise-and-the-New-Jersey-Coast-Assessing-Potential-Impacts-and-Opportunities.pdf> [Accessed 20/08/2011]

Creswell, J.W., 1994. *Research Design: Qualitative and Quantitative Approaches*. Thousand Oaks: Sage.

Cutting, J.E. and Vishton, P.M., 1995. Perceiving layout and knowing distances: The integration, relative potency, and contextual use of different information about depth. In: Epstein, W. and Rogers, S., eds. *Handbook of Perception and Cognition.* San Diego: Academic Press, 5, pp.69-117.

Davis, F. D., 1989. Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS Quarterly*, 13(3), pp. 319–340.

de Bra, P. and Calvi, L., 1998. AHA: a generic adaptive hypermedia system. In: *2nd Workshop on Adaptive Hypertext and Hypermedia.* Pittsburgh, USA, June 20-24 1998.

de Souza, F. and Bevan, N., 1990. The use of guidelines in menu interface design: evaluation of a draft standard. In: *3rdIFIP INTERACT International Conference on Human-Computer Interaction.* Cambridge, UK, 27-31 August 1990, pp. 435-440.

Demšar, U., 2007. Investigating visual exploration of geospatial data: An exploratory usability experiment for visual data mining. *Computers, Environment and Urban Systems*, 31(5), pp.551-571.

Denzin, N.K. and Lincoln Y.S., eds. 2005. *The Sage Handbook of Qualitative Research*. Thousand Oaks: *Sage.*

Department of Environment, Heritage and Local Government. 2001. *National Spatial Strategy: Coastal Zone Management – Summary and Policy Implications* [online] Available at:<http://www.irishspatialstrategy.ie/docs/report24.pdf> [Accessed 14/10/2010]

Devoy, R.J.N., 1990. Sea-level changes and Ireland. *Technology Ireland*, 22, pp.24-30.

Devoy, R.J.N., 1995. Deglaciation, earth crustal behaviour and sea level changes in the determination of insularity: a perspective from Ireland. In: Preece, R.C., ed. 1995. *Island Britain: A Quaternary Perspective*. London: Geological Society Publication House. Special Publication 96, pp.181-208.

Devoy, R.J.N., 2000a. Climate warming and the links to the coast. *Inland Coastal Estuarine Waters*, 3, pp.4-5.

Devoy, R.J.N., 2000b. Implications of accelerated sea-level rise for Ireland. In: De La Vega-Leinert, A.C., Nicholls, R.J. and Tol, R.S.J., eds. *European Vulnerability and Adaptation to Impacts of Accelerated Sea-level Rise.* SURVAS Expert Workshop, Hamburg, Germany, 19-21 June 2000, pp.33-46.

DiBiase, D.W., 1990. Visualisation in the earth sciences. *Earth and Mineral Sciences Bulletin* (Pennsylvania State University), 59(2), pp.13-18.

DiBiase, D., MacEachren, A.M, Krygier, J.B. and Reeves, C., 1992. Animation and the role of map design in scientific visualisation. *Cartography and Geographic Information Systems,*19(4), pp.201-214.

Dix, A., Finlay, J., Abowd, G. and Beale, R., 2004. *Human-computer interaction*. 3rd ed. Harlow: Pearson Education.

Dobson, J.E., 1983. Automated geography. *The Professional Geographer*, 35(2), pp.135-143.

Dodge, M., McDerby, M. and Turner, M., eds. 2008. Geographic Visualisation: Concepts, Tools and Applications. Chichester: John Wiley & Sons, Ltd.

Döllner, J., Kolbe, T.H., Liecke, F., Sgouros, T. and Teichmann, K., 2006. The virtual 3D city model of Berlin – managing, integrating and communicating complex urban information. In: *25th International Symposium on Urban Data Management.* Aalborg, Denmark, 15-17 May 2006.

Dumas, J., 1988. *Designing user interfaces for software*. Englewood Cliffs: Prentice- Hall.

Dumas, J., 2007. The great leap forward: The birth of the usability profession (1988-1993). *Journal of Usability Studies,* 2(2), pp.54-60.

Dumas, J. S. and Redish, J. C., 1993. *A practical Guide to Usability Testing*. Norwood: Ablex Publishing.

Dunne, S., Hanafin, J., Lynch, P., McGrath, R., Nishimura, E., Nolan, P., Ratnam, J.V., Semmler, T., Sweeney, C., Varghese, S. and Wang, S., 2008. *Ireland in a Warmer World – Scientific Predictions of the Irish Climate in the Twenty-First Century*, Met Éireann, [online] Available at:<http://www.tara.tcd.ie/jspui/handle/2262/19699> [Accessed 03/04/2012]

Dykes, J., 1998. Cartographic Visualisation: Exploratory Spatial Data Analysis with Local Indicators of Spatial Association Using Tcl/Tk and cdv. *The Statistician*, 47(3), pp.485-497.

Dykes, M., McDerby, M. and Turner, M. eds., 2008. Geographic Visualisation: Concepts, Tools and Applications. Chichester: John Wiley & Sons, Ltd.

Earnshaw, R.A., 1992. Visualisation techniques. In: Brodlie, K.W., Carpenter, L.A., Earnshaw, R.A., Gallop, J.R., Hubbold, R.J., Mumford, A.M., Osland, C.D. and Quarendon, P., eds. 1992. *Scientific visualisation: Techniques and applications*. New York: Springer.

Edsall, R.M., 2003. Design and usability of an enhanced geographic information system for exploration of multivariate health statistics. The Professional Geographer, 55:146–160.

Ely, M., 1991. *Doing Qualitative Research: Circles within Circles*. Abingdon: Routledge Falmer.

Environment Service of Northern Ireland. 1995. *Delivering Coastal Zone Management in Northern Ireland*. Belfast: Environment Service.

ESPACE. 2006. *ESPACE – European Spatial Planning: Adapting to Climate Events, Decision Testing Tools Interactive Resource Kit* [online] Available at<http://www.espace-project.org/part1/publications/reading/espace/Espace%20Tools2.htm> [Accessed 20/10/2010]

Environmental Systems Research Inc., 2005. *GIS in the Defense and Intelligence Communities* [online] Available at:<http://www.esri.com/library/brochures/pdfs/gis-in-defense-vol2.pdf> [Accessed 08/10/2010]

Environmental Systems Research Inc., 2007. ArcGIS 9-What is ArcGIS 9.2? [online] Available at:< http://webhelp.esri.com/arcgisdesktop/9.2/pdf/what_is_arcgis.pdf> [Accessed 07/01/2014]

Fabrikant, S.I., 2005. Towards an understanding of geovisualisation with dynamic displays: issues and prospects. In: *2005 AAAI Spring Symposium Series.* Stanford University, Stanford, USA, 21-23 March 2005, pp.6-11.

Fisher, P., 1994. Randomization and sound for the visualisation of uncertain spatial information. In: Unwin, D. and Hearnshaw, H., eds. 1994. *Visualisation in Geographic Information Systems.* London: John Wiley & Sons, pp.181-185.

Fisher, P. and Unwin, D., eds. 2002. *Virtual Reality in Geography*. London: Taylor & Francis.

Fitts, P.M., 1992. The information capacity of the human motor system in controlling the amplitude of movement. *Journal of Experimental Psychology: General,* 121(3), pp.262-269.

Fitzpatrick, R., 1998. *Strategies for Evaluating Software Usability* [online]. Available at:<http://arrow.dit.ie/scschcomart/1/>[Accessed 07/21/2010]

Fuhrmann, S. and Pike, W., 2005. User-centred design of collaborative geovisualisation tools. In: Dykes, J., MacEachren, A.M. and Kraak, M.-J., eds. Exploring Geovisualisation, Amsterdam, Netherlands: Elsevier, pp.591-609.

Fuhrmann, S., Ahonen-Rainio, P., Edsall, R., Fabrikant, S., Koua, E., Tobon, C., Ware, C. and Wilson, S., 2005. Making useful and usable geovisualisation: design and evaluation issues. In: Dykes, J., MacEachren, A. and Kraak, M., eds. *Exploring Geovisualisation*. Amsterdam: Elsevier, pp.553-565.

Gahegan, M., Takatsuka, M., Wheeler, M. and Hardisty, F., 2002. Introducing GeoVISTA Studio: an integrated suite of visualisation and computational methods for exploration and knowledge construction in geography. *Computers, Environment and Urban Systems*, 26(4), pp.267-292.

Gärling, T. and Golledge, R.G., eds. 1993. *Behavior and Environment: Psychological and Geographical Approaches*. Advances in Psychology. Vol. 96. Amsterdam: Elsevier.

Gediga, G., Hamborg, K. and Düntsch, I., 1999. The ISO Metrics usability inventory: An operationalisation of ISO 9241-10. *Behaviour and Information Technology*, 18(3), pp.151-164.

Gemma, 2011. Cartography – from past to present. Ordnance Survey Blog [online] Available at:<http://blog.ordnancesurvey.co.uk/2011/03/cartography-%E2%80%93-from-past-to-present/> [Accessed 04/09/2012]

GeoDa Press, 2012. Spatial Autocorrelation [online] Available at:<https://www.geodapress.com/> [Accessed 10/09/2012]

Gessel, B., 2007. 3D Cartographic animation: visualising disaster on the Columbia River. In: *27th Annual ESRI International User Conference.* San Diego, USA, 18-22 June 2007.

Gewin, V., 2004. Mapping Opportunities. *Nature*, 427(6972), pp.376-377.

Ghauri, P., Grønhaug K. and Kristianslund, I., 1995. *Research Methods in Business Studies – A Practical Guide.* Harlow: Prentice Hall.

Golledge, R.G., ed. 1999. *Wayfinding Behavior: Cognitive Mapping and Other Spatial Processes*. Baltimore, Maryland: Johns Hopkins University Press.

Goodchild, M.F., 1992. Geographical information science. *International Journal of Geographical Information Systems,* 6(1), pp.31-45.

Gornitz, V.M. and Lebedeff, S., 1987. Global sea level changes during the past century. In Nummendal, D. *et al.*, eds. 1987. *Seal Level Fluctuation and Coastal Evolution*. Tulsa: Society for Economic Paleontologists and Mineralogists 41, pp.3-16.

Gornitz, V., Couch, S. and Hartig, E.K., 2001. Impacts of sea level rise in the New Work City metropolitan area. *Global Planet Change*, 32, pp.61-88.

Gouda, M., Karner, K. and Tatschl, R., 2002. Dam Flooding Simulation Using Advanced CFD Methods. In: *5th World Congress on Computational Mechanics*. Vienna, Austria, 7-12 July 2002.

Gould, J.D., 1988. How to design usable systems (except). In: Baecker R. and Buxton W., eds. 1988. *Readings in Human-Computer Interaction*: *A Multidisciplinary Approach*. New York: Morgan-Kaufman, pp.93-115.

Gould, J.D., Boies, S.J. and Lewis, C., 1991. Making usable, useful, productivity-enhancing computer applications. *Communications of the ACM*, 34(1), pp.75-85

Gould, J.D., Boies, S.J. and Ukelson, J., 1997. How to Design Usable Systems. In: Helander, M., Landauer, T.K. and Prabhu, P.V., eds. 1997. *Handbook of Human-Computer Interaction*. Amsterdam: Elsevier, pp.231-254.

Gould, J.D. and Lewis, C., 1985. Designing for usability: Key principles and what designers think. Communications of the ACM, 28(3), pp.300-311.

Göktürk, M., 2013. Fitts's Law [online] Available at:< http://www.interaction-design.org/encyclopedia/fitts_law.html> [Accessed 03/01/2014]

Grant Associates, n.d. [image online] Available at:<http://www.grant-associates.uk.com/projects/78-parks-public-spaces/2928-new-cross-gate-ndc-centre.aspx> [Accessed 04/09/2012]

Greenbaum, J. and Kyng, M., 1991. Introduction: Situated Design. In: Greenbaum, J. and Kyng, M., eds. 1991. *Design at Work: Cooperative Design of Computer Systems*. Hillsdale: Lawrence Erlbaum, pp.1-24.

Guo, D., Gahegan, M., MacEachren, A. and Zhou, B., 2005. Multivariate analysis and geovisualisation with an integrated geographic knowledge discovery approach. *Cartography and Geographic Information Science*, 32(2), pp.113-132.

Haining, R., Wise, S. and Signoretta, P., 2000. Providing scientific visualisation for spatial data analysis: criteria and an assessment of SAGE. *Journal Geographic Systems*, 2(2), pp.121-140.

Haklay, M.E., 2002. Vistual reality and GIS: applications, trends and directions. In: Fisher, P. and Unwin, D., eds. 2002. *Virtual Reality in Geography*, pp.45-57. London: Taylor & Francis.

Haklay, M.E. and Tobón, C., 2003. Usability Evaluation and PPGIS: Towards a user-centered approach. International Journal of Geographical Information Science, 17 (6) 577 - 592.

Halcrow Group Ltd., 2008. Lee Catchment Flood Risk Assessment and Management Study: Hydrology Report [online] Available at:< http://www.leecframs.ie/downloads/documents/REP004_HydrologyReport.pdf> [Accessed 08/01/2014]

Harley, J.B. and Woodward, D. 1987. *The History of Cartography*. Chicago: University of Chicago Press.

Harrower, M., 2003. Tips for designing effective animated maps. *Cartographic Perspectives*, 44(44), pp.63-65.

Harrower, M. and Sheesley, B., 2005. Designing better map interfaces: a framework for panning and zooming. *Transactions in GIS*, 9(2), pp.77-89.

Haupt, C. and Huber, A.B., 2008. How axons see their way – axonal guidance in the visual system. *Frontiers in Bioscience*, 13(8), pp.3136-3149.

Hearnshaw, H.M. and Unwin, D.J., eds. 1994. *Visualisation in geographical information systems*. London: Wiley & Sons.

Heckbert, P., 1987. Ten unsolved problems in rendering. In: *Graphics Interface '87*, Ontario, Canada, 5-9 April 1987.

Henneman, R.L., 1999. Design for Usability: Process, Skills, and Tools. *Information Knowledge Systems Management*, 1(2), pp.133-144.

Henry, P., 1998. *User-Centred Information Design for Improved Software Usability*. Boston: Artech House.

Hibbard, B., 1999. Top ten visualisation problems. *Computer Graphics (CG) Quarterly*, 33(2), pp.21-22.

Holynski, M., 1988. User-adaptive computer graphics. *International Journal of Man-Machine Studies*, 29(5), pp.539-548.

Hornby, A.S., 1985. *Oxford Advanced Learner's Dictionary of Current English*. Oxford: Oxford University Press.

Huang, Z., Zhang, W., Wu, H., Fan, J., Jiang, P., Chen, T., Li, Z. and Huang, B., 2000. Sea level rise projection in 2030 for Pearl River Delta and its defensive strategies. *Science in China*, 30(2), pp.202-208.

Huang, H., Bartlett, D. and Wu, K., 2011. Sea level rise and coastal zone management: A Chinese perspective. In: *1st International Conference on Revisiting the Socio-Political and Technological Dimensions of Climate Change.* Preston, UK, 19-20 May 2011, pp.125-141.

Hudson, W., 2008. The Challenges of User-Centred Design [online]. In: *7th International Conference on Computer-Aided Design of User Interfaces 2008*. Albacete, Spain, 11-13 June, 2008 Available at:<http://www.syntagm.co.uk/design/articles/challenges_of_ucd.pdf> [Accessed 07/03/2012]

ICSM, n.d. [image online] Available at:<http://www.icsm.gov.au/mapping/history.html> [Accessed 04/09/2012]

IPCC, 2001a. *Climate Change 2001: The Scientific Basis*. Contribution of working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change. New York: Cambridge University Press.

IPCC. 2001b. *Climate Change 2001: Impact, Adaptation, and Vulnerability*. Contribution of working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change. New York: Cambridge University Press.

IPCC, 2007a. *Climate Change 2007: The physical Science Basis*. Contribution of working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge: Cambridge University Press.

IPCC, 2007b. *Climate Change 2007: Impacts, Adaptation and Vulnerability*. Contribution of working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge: Cambridge University Press.

IPCC, 2013. *Climate Change 2013: The Physical Science Basis-Summary for Policymakers*. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [online] Available at:www.climatechange2013.org [Accessed 08/01/2014].

ISO, 1991. ISO/IEC 9126. *Software Engineering-product evaluation-quality characteristics and guidelines for their use*. Geneva: ISO

ISO, 1998. ISO 9241-11 *Ergonomic requirements for office work with visual display terminals (VDTs) – Part 11 Guidance on usability*. Geneva: ISO.

ISO, 1999. ISO 13407 *Human-centred design processes for interactive systems*. Geneva: ISO.

ISO, 1999-2001. *ISO/IEC 14598 Information Technology –software product evaluation*. Part 1: General overview (1999); Part 2: Planning and management (2000); Part 3: Process for developers (2000); Part 4: Process for acquirers (1999); Part 5: Process for evaluators (1999); Part 6: Documentation of evaluation modules (1998). Geneva:ISO

ISO, 2001-2004. *ISO/IEC 9126 Software engineering-product quality*. Part 1: Quality model (2001); Part 2-3: External/Internal metrics (2003) and Part 4: Quality in use metrics (2004). Geneva: ISO

Jamieson, S., 2004. Likert Scales: How to (Ab)use them. *Medical Education*, 38, pp.1217-1218.

Jern, M., Johansson, S., Johansson, J. and Franzen, J., 2007. The GAV Toolkit for Multiple Linked Views. In: *5th International Conference on Coordinated and Multiple Views in Exploratory Visualisation.* Zurich, Switzerland, 2-2 July 2007, pp.85-97.

Johnson, R., 1998. *User-Centered Technology: A Rhetorical Theory for Computers and Other Mundane Artifacts*. Albany: State University of New York Press.

Johnson, M.P., 2006. Decision models for the locations of community corrections centers. *Environment and Planning B: Planning & Design*, 33(3), pp.393-412.

Jokela, T., Livari, N., Matero, J. and Karukka, M., 2003. The Standard of User-Centered Design and the Standard Definition of Usability: Analyzing ISO 13407 against ISO 9241-11. In: *Latin American Conference on Human-Computer Interaction*. Rio de Janeiro, Brazil, 17-20 November 2003, pp.53-60.

Jones, C.E., Haklay, M., Griffths, S. and Vaughan, L., 2009. A less-is-more approach to geovisualisation – enhancing knowledge construction across multidisciplinary teams. *International Journal of Geographic Information Science*, 23(8), pp.1077-1093.

Jung, H.W., Kim, S.G. and Chung, C.S., 2004. Measuring software product quality: a survey of ISO/IEC 9126. *IEEE Software*, 21(5), pp.88-92.

Keim, D.A. and Ankerst, M., 2001. Visual Data Mining and Exploration of Large Databases. Tutorial *at Conference on Principals of Knowledge Discovery and Data Mining*. Freiburg, Germany, 3-5 September 2001.

Keim, D.A., 2002. Information visualisation and visual data mining. *IEEE Transactions on Visualisation and Computer Graphics*, 8(1), pp.1-8.

Keller, P.R. and Keller, M.M., 1993. *Visual cues, practical data visualisation*. Piscataway: IEEE Press.

Kerren, A., Stasko, J.T., Fekete, J.D. and North, C., 2007. Workshop report: information visualisation-human-centred issues in visual representation, interaction and evaluation. *Information Visualisation*, 6(3), pp.189-196.

Keyser, H., 2011. *Iowa State's METaL lab develops multiple ways to experience virtual reality. Telepresence Options*, [online] Available at:<http://www.telepresenceoptions.com/2011/12/iowa_states_metal_lab_develops/> [Accessed 12/09/2012]

Kim, T.H., Cova, T.J. and Brunelle, A., 2006. Exploratory map animation for post-event analysis of wildfire protective action recommendations. *Natural Hazards Review*, 7(1), pp.1-11.

Kirakowski, J., 1996. The software usability measurement inventory: background and usage. In: Jordan, P. W., Thomas, B., Weerdmeester, B. and McClelland, L.L., eds. *Usability Evaluation in Industry*. Taylor and Francis, London, UK, pp.169-178.

Knorr, E. and Gruman, G., 2011. *What cloud computing really means*, [online] Available at:<http://www.infoworld.com/d/cloud-computing/what-cloud-computing-really-means-031>[Accessed 11/06/2011].

Kossiakoff, A., Sweet, N.W., Seymour, S.J. and Biemer, S.M., 2011. *Systems engineering: principles and practice*. 2nd ed. Hoboken: John Wiley & Sons.

Koua, E.L. and Kraak, M.J., 2004. A usability framework for the design and evaluation of an exploratory geovisualisation environment. In: the 8th international conference on information visualisation, London, 14-16 July 2004. IEEE Computer Society Press, pp. 153-158.

Kraak, M-J., 2003. Geovisualisation Illustrated. *ISPRS Journal of Photogrammetry and Remote Sensing*, 57(5-6), pp.390-399.

Kraak M.-J. and Ormeling, F.J., 2003. *Cartography: visualisation of geospatial data*. 2nd ed. Harlow: Pearson Education.

Krueger, R.A. and Casey, M.A., 2000. *Focus Groups: A Practical Guide for Applied Research.* 3rd ed. Thousand Oaks: Sage.

Kuhn, S., 1996. Design for people at work. In Winograd, T., ed. 1996. *Bringing Design to Software.* Chapter 14, New York: Addison-Wesley.

Kulyk, O., Kosara, R., Urquiza, J. and Wassink, I., 2007. *Human-Centred Aspects*. In: Human-centred Visualisation Environments*.* Lecture Notes in Computer Science Tutorial 4417. Springer-Verlag, Berlin, pp.13-75.

Kyng, M., 1995. Creating Contexts for Design. In: Carroll, J.M., ed. 1995. *Scenario-based Design: Envisioning Work and Technology in System Development.* New York: Wiley, pp.85-107.

Lambeck, K. and Bard, E., 2000. Sea level change along the French Mediterranean Coast for the past 30,000 years. *Earth and Planetary Science Letters*, 175, pp.203-222.

Langefors, B., 1971. *Theoretical analysis of information systems*. Lund: Studentlitteratur.

Lauesen, S., 2005. *User Interface Design: A Software Engineering Perspective*. Harlow: Addison Wesley.

Lee, H., Lee, J. and Yang, H.S., 2002. Real-time LOD: Marching-cube-and-octree-based 3D Object Level-of-detail Modelling (*Unpublished Tech Report submitted to Korea Science and Engineering Foundation*). Korea Advanced Institute of Science and Technology, [online] Available at:<http://www.evl.uic.edu/vchand2/thesis/papers/Marching%20Cubes.pdf> [Accessed 30/01/2012]

Letondal, C. and Mackay, W.E., 2004. Participatory programming and the scope of mutual responsibility: balancing scientific, design, and software commitment. In: *8th Biennial Participatory Design Conference (PDC).* Toronto, Canada, 27-31 July 2004, 1, pp.31-41.

Leuliette, E., Nerem, R.S. and Mitchum, G.T., 2004. Calibration of Topex/Poseddon and Jason altimeter data to construct a continuous record of mean sea level change. *Marine Geodesy*, 27(1), pp.79-94.

Lewis, J.R., 1995. IBM computer usability satisfaction questionnaires: Psychometric evaluation and instructions for use. *International Journal of Human-Computer Interaction*, 7(1), pp. 57-78.

Liarokapis, F., Greatbatch, I., Mountain, D., Gunesh, A., Brujic-Okretic, V. and Raper, J., 2005. Mobile Augmented Reality Techniques for GeoVisualisation. In: *9th International Conference on Information Visualisation.* London, UK, 6-8 July 2005, pp.745-751.

Liebenberg, E. and Demhardt, I.J. (Eds.), 2012. History of Cartography [electronic book]: International Symposium of the ICA Comission, 2010. Berlin, New York: Springer.

Limina, n.d., Incorporating user-centred design in a waterfall development lifecycle [online] Available at :<http://limina-ao.com/approach/waterfall.html> [Accessed 20/09/2012]

Lin, Z., 2002. Construction of flood control engineering and countermeasures for flood disaster mitigation in Taihu Basin. *Journal of Lake Sciences (Chinese),* 14(1), pp.12-18.

Ling, Y., Chen, Y. and Wang, Y., 2004. Cognition Theory-based Research on Adaptive user Interface for Geovisualisation System. In: *12th International Conference on Geoinformatics – Geospatial Information Research: Bridging the Pacific and Atlantic.* Gavle, Sweden, 7-9 June 2004, pp.424-430.

Ling, Y., Chen, Y. and Wang, Y., 2005. Cognitive basis of adaptive user interface for cartographic visualisation system. *ACTA GEODAETICA et CARTOGRAPHICA SINICA (Chinese)*, 34(3), pp.277-282.

Lloyd, R., 1989. Cognitive maps: Encoding and decoding information. *Annals of the Association of American Geographers*, 79(1), pp.101-124.

Lloyd, R., 1997. *Spatial Cognition: Geographic Environments*. Dordrecht: Kluwer Academic.

Lloyd, D., Dykes, J. and Radburn, R., 2007. Understanding geovisualisation users and their requirements – a user-centred approach. In: Winstanley, A.C, ed., GIS Research UK 15th Annual Conference (GISRUK 15), Maynooth, Ireland, pp.209-214.

Lloyd, D., 2009. *Evaluating human-centered approaches for Geovisualisation*. *Unpublished Doctoral Thesis.* City University London Press.

Longley, P.A., Goodchild, M.F., Maguire, D.J. and Rhind, D.W., 2005. *Geographical Information Systems and Science*. Chichester: John Wiley & Sons.

Luke, R., Clement, A., Terada, R., Bortolussi, D., Booth, C., Brooks, D. and Christ, D., 2004. The promise and perils of a participatory approach to developing an open source community learning network. In: *8th Biennial Participatory Design Conference (PDC)*. Toronto, Canada, 27-31 July 2004, pp.11-19.

Lund, A.M., 2001. Measuring Usability with the USE Questionnaire. Usability and User Experience Newsletter, [online] Available at:< http://www.stcsig.org/usability/newsletter/0110_measuring_with_use.html> [Accessed 23/07/2012]

Lynch, K., 1960. *The Image of the City*. Cambridge: MIT Press

MacEachren, A.M., 1994. Visualisation in modern cartography: Setting the agenda. In: MacEachren, A.M. and Taylor, D.R.F., eds. 1994. *Visualisation in Modern Cartography*. Oxford: Pergamon, pp.1-12.

MacEachren, A.M., 1995. *How Maps Work: Representation, Visualisation and Design*. New York: Guilford, pp.137-143, 355-400.

MacEachren, A.M., 2001. Cartography and GIS: Extending collaborative tools to support virtual teams. *Progress in Human Geography*, 25(3), pp.431-444.

MacEachren, A.M., 2005. Moving geovisualisation toward support for group work. In: Dykes, J., MacEachren, A.M. and Kraak, M.-J., eds. *Exploring Geovisualisation*. Amsterdam, Netherlands: Elsevier, pp.445-461.

MacEachren, A.M. and Ganter, J.H., 1990. A pattern identification approach to cartographic visualisation. *Cartographica*, 27(2), pp.64-81.

MacEachren, A.M., Gahegan, M., Pike, W., Brewer, I., Cai, G., Lengerich, E. and Hardisty, F., 2004. Geovisualisation for knowledge construction and decision-support. *Computer Graphics and Applications*, 24(1), pp.13-17.

MacEachren, A.M., Hardisty, F., Dai, X. and Pickle, L., 2003. Supporting visual analysis of federal geospatial statistics. *Communications of the ACM*, 46(1), pp.59-60.

MacEachren, A.M. and Kraak, M-J., 1997. International Cartographic Association Commission on Visualisation & Virtual Environments: Terms of Reference 1999-2003 [online] Available at:<http://www.geovista.psu.edu/sites/icavis/agenda.html> [Accessed 12/09/2012]

MacEachren, A. M. and Kraak, M.-J. 1997. Exploratory cartographic visualisation: Advancing the agenda. Computers & Geosciences 23(4), pp.335-343.

MacEachren, A.M. and Kraak, M.J., 2001. Research challenges in geovisualisation. Cartography and Geographic Information Science, Special Issue on Geovisualisation, 28(1):3-12.

MacEachren, A.M. and Taylor, D.R.F., eds. 1994. *Visualisation in Modern Cartography*. Oxford: Pergamon.

Marble, D.F., 1999. Geographic information system technology and decision support system. In: *32nd Annual Hawaii International Conference on System Sciences*. Maui, USA, 5-8 January 1999, 6, pp.67-68.

Marble, D.F., 1990. Geographic information systems: an overview. In: Peuquet, D. and Marble, D.F., eds. 1990. *Introductory Readings in Geographic Information Systems*. London: Taylor & Francis.

Marine Institute, 2005. Ireland's Ocean economy & resources [electronic book]. Galway: Marine Institute. Available at:< http://oar.marine.ie/handle/10793/98> [Accessed 08/01/2014]

Marsh, S.L., 2007. *Using and Evaluating HCI Techniques in Geovisualisation: Applying Standard and Adapted Methods in Research and Education*. Unpublished Doctoral Thesis, City University London.

Marshall, C. and Rossman, G.B., 2006. *Designing Qualitative Research*. 4th ed. Thousand Oaks: Sage.

Max-Planck-Gesellschaft zur Förderung der Wissenschaften e.V., n.d. Virtual Tübingen [online] Available at:<http://virtual.tuebingen.mpg.de/index.html> [Accessed 10/09/2012]

Mayerich, D., Kwon, J., Sung, C., Abbott, L., Keyser, J. and Choe, Y., 2011. Fast macro-scale transmission imaging of microvascular networks using KESM. *Biomedical Optics Express*, 2(10), pp.2888-2896.

McCormick, B.H., DeFanti, T.A. and Brown, M.D., eds. 1987. Visualisation in scientific computing--A synopsis. *IEEE Computer Graphics and Applications*, 7(7), pp.61-70.

McGrath, J., Barry, K., O'Kane, J. and Kavanagh, R., 2003. *High Resolution DEM and Sea Level Rise in the centre of Cork Blue City Project*, [online] Available at:<http://www.opw.ie/hydrology/data/speeches/M_McGrath_et%20_al.pdf>[Accessed 07/09/2011]

McGuffin, M.J. and Balakrishnan, R. 2005. Fitts'Law and Expanding Targets: Experimental Studies and Designs for User Interfaces. *ACM Transactions on Computer-Human Interaction (TOCHI)*, 12(4), pp. 388-422.

Mendes, D., 2011. The Reliability of Usability Evaluations, [online] Available at:<http://diegomendes.com/wp-content/uploads/2011/06/Mendes-Diego-HF750-THE-RELIABILITY-OF-USABILITY-EVALUATIONS.pdf> [Accessed 11/05/2012]

Milosz, M., van Lammeren, R. and Hoogerwerf, T., 2007. Usability of 3D geo-visualisation for spatial orientation. In: van den Brink, A., van Lammeren, R., van de Velde, R. and Däne, S., eds. 2007. *Imaging the future: Geo-visualisation for participatory spatial planning in Europe*. Wageningen: Wageningen Academic, *Mansholt Publication Series Vol 3*, pp. 119-126.

Mitasova, H., Bernstein, D., Drake, T.G., Harmon, R. and Miller, C.H., 2003, Spatio-temporal analysis of beach morphology using LIDAR, RTK-GPS and Open source GRASS GIS. In: 2003 the International Conference on Coastal Sediments, Tamps, Florida, May 2003.

Monmonier, M., 1990. Strategies for the visualisation of geographic time-series data. *Cartographica*, 27(1), pp.30-45.

Morgan, D. L., 1997. *Focus Groups as Qualitative Research*. 2nd ed. Thousand Oaks: Sage.

Mülder, J., Säck-da-silva, S. and Bruns, D., 2007. Understanding the role of 3D visualisation: the example of Calden Airport expansion, Kassel, Germany. In: van den Brink, A., van Lammeren, R., van de Velde, R. and Däne, S., eds. 2007. *Imaging the future: Geo-visualisation for participatory spatial planning in Europe*. Wageningen: Wageningen Academic, *Mansholt Publication Series Vol 3*, pp.75-87.

Muller, M.J., Haslwanter, J.H. and Dayton, T., 1997. Participatory practices in the software lifecycle. In: Helander, M., Landauer, T.K. and Prabhu, P., eds. 1997. *Handbook of Human-computer Interaction.* 2nd ed. Amsterdam: Elsevier, pp.255-297.

Mysorekar, S.R., 2006. *A Geospatial Fire Risk Analysis of Athens.* Ohio. M.Sc. Ohio State University.

National Coastal Erosion Committee. 1992. *Coastal Management: A case for action*. Dublin: County and City Engineers Association and the Irish Science and Technology Centre. EOLAS, Vol.1 and Vol.2, p30 and p87.

Nerem, R.S., Leuliette, E. and Cazenave, A., 2006. Present-day sea level change: A review. *Comptes Rendus Geoscience*, 338(14), pp.1077-1083.

Nielsen, J., 1993. *Usability Engineering*. Boston: Academic Press.

Nivala, A-M, Sarjakoski, L. T. and Sarjakoski, T., 2007. Usability methods' familiarity among map application developers. *International Journal of Human-Computer Studies*, 65(9), pp. 784-795.

Nöllenburg, M., 2007. Geographic Visualisation. In: Kerren A., Ebert, A. and Meyer, J., eds. 2007. *Human-Centered Visualisation Environments.* Berlin: Springer.

Norman, D.A. and Draper, S.W., 1986. *User centered system design: new perspectives on human-computer interaction*. Hillsdale: Lawrence Erlbaum.

Norman, D.A., 1988. *The Psychology of Everyday Things*. New York: Doubleday.

Norman, D.A., 2002. *The Design of Everyday Things*. 2nd ed. New York: Basic Books.

Nozik, K., 2009. *Making sustainable cities real: Autodesk and NCDC affect urban environments. Imaging Notes*, [online] Available at:<http://www.imagingnotes.com/go/article_free.php?mp_id=156> [Accessed 05/09/2012]

Oestreich, K., 2009. *Building a Real-World IaaS Cloud Foundation*, [online] Available at:<http://cloudcomputing.sys-con.com/node/976449>[Accessed 11/06/2011]

Ogao, P.J. and Kraak, M.-J., 2002. Defining visualisation operations for temporal cartographic animation design. *International Journal of Applied Earth Observation and Geoinformation*, 4(1), pp.23-31.

Olmos, A., Boddeker, S. and McIntosh, A., 2009. *Emerging Web Browsing Alternatives. Archives & Museum Informatics*, [online] Available at:<http://www.museumsandtheweb.com/mw2009/papers/olmos/olmos.html> [Accessed 20/09/2012]

Oppermann, R. and Reiterer, R., 1997. Software evaluation using the 9241 evaluator usability evaluation methods. *Behaviour and Information Technology*, 16(4), pp.232-245.

Pajorova, E., Hluchy, L., Halada, L. and Slizik, P., 2007. *3D visualisation tool for virtual models of natural disasters*, [online] Available at:<ups.savba.sk/~eva/Papers/Virtual_Laval_07.pdf>[Accessed 19/10/2010]

Palmer, J.W., 2002. Web Site Usability, Design, and Performance Metrics. *Information Systems Research*, 13(2), pp.151-167.

Parry, M.L., 2000. *Assessment of Potential Effects and Adaptations for climate change in Europe: Summary and conclusions*. Norwich: University of East Anglia Press. p.24.

Patel, N., Clawson, J., Voida, A. and Lyons, K., 2009. Mobiphos: A Study of user engagement with a mobile collocated—synchronous photo sharing application. *International Journal of Human-computer Studies,* 67(12), pp.1048-1059.

Paula Filho, W.P., 2006. A software process for time-constrained course projects. In: *28th International Conference on Software Engineering*. Shanghai, China, 20-28 May 2006, pp.707-710.

Perlman, G., 1997. Practical Usability Evaluation. In: *CHI '97 Extended Abstracts on Human Factors in Computing Systems*, NY: ACM, pp.168-169.

Peterson, M.P., 1993. Interactive cartographic animation. *Cartography and Geographic Information Science*, 20(1), pp.40-44.

Peterson, M.P., 1994. Cognitive issues in cartographic visualisation. In: MacEachren A.M. and Tayor, D.R.F., eds. 1994. *Visualisation in Modern Cartography*. Oxford: Pergamon, pp.27-43.

Philbrick, A.K., 1953. Towards a Unity of Cartographical Forms and Geographical Content. *Professional Geographer*, 5(5), pp.11-15.

Philips, R.J. and Noyes, L., 1978. An objective comparison of relief maps produced with the SYMAP and SYMVU programs. *Bulletin of the Society of University Cartographers*, 12, pp.13-25.

Pleizier, I.D., van Lammeren, R.T., Scholten, H.J. and van de Velde, R., 2003. *Using Virtual Reality as an Information Tool in Spatial Planning*, [online] Available at:<http://www.feweb.vu.nl/gis/virtorg/people/irene/documents/ESF%20Paper.doc>[Accessed 19/10/2010]

Plumlee, M. and Ware, C., 2003. An Evaluation of Methods for Linking 3D Views. In: *ACM 2003 Symposium on Interactive 3D Graphics*. Monterey, Canada, 27-30 April 2003, pp. 193-201.

Poser, K., Kreibich, H. and Dransch, D., 2009. Assessing Volunteered Geographic Information for Rapid Flood Damage Estimation. In: *12th AGILE International Conference on Geographic Information Scienc*e. Hannover, Germany, 2-5 June 2009.

Prümper, P., 1999. Test it: ISONORM 9241/10. In: *8th International Conference on Human-Computer Interaction*. Munich, Germany, 22-27 August 1999, 1, pp. 1028-1032.

Quaye-Ballard, J.A., 2003. Visualisation of land property for the urban environment. Enschede, ITC.

Quesenbery, W., 2001. The five dimensions of usability. In: Albers, M. and Mazur, B., eds. 2003. *Content and Complexity: Information Design in Technical Communication*. Mahwah: Erlbaum, pp.75-93, 81-102.

Raper, J.F., 1989. *Three-Dimensional Applications in Geographical Information Systems*. London: Taylor & Francis.

Rees, P. and Turton, I., 1998. Guest Editorial: geocomputation: solving geographical problems with new computing power. *Environment and Planning A*, 30(10), pp.1835-1838.

Reiterer, H. and Oppermann, R., 1993. Evaluation of user interfaces: EVADIS II – a comprehensive evaluation approach. *Behaviour and information technology*, 12(3), pp.137-148.

Rhyne, T-M., 2003. Information and Scientific Visualisation: Separate but Equal or Happy Together at last. In: *2003 IEEE Visualisation Conference*. Seattle, USA, 19-24 October 2003, pp. 611-614.

Robertson, P.K., 1991. A methodology for choosing data representations. *IEEE Computer Graphics and Applications*, 11(3), pp.56-67.

Robertson, P. and de Ferrari, L., 1994. Systematic approaches to visualisation: Is a reference model needed? In: Rosenblum, L.J., 1994. *Scientific Visualisation, Advances and Challenges.* London: Academic Press, pp.287–305.

Robinson, A., 2005. Geovisualisation and epidemiology: A general design framework. In: *22nd International Cartographic Conference*. La Coruna, Spain, 9-16 July 2005.

Robinson, A.C., 2006. Highlighting techniques to support Geovisualisation. In: *ICA Workshop on Geovisualisation and Visual Analytics*. Portland, USA, 24 June 2006.

Robinson, A.C., 2011a. Supporting Synthesis in Geovisualisation. *International Journal of Geographical Information Science*, 25(2), pp.211-227.

Robinson, A.C., 2011b. Highlighting in Geovisualisation. *Cartography and Geographic Information Science*, 38(4), pp.374-384.

Robinson, A.H. and Petchenik, B.B., 1976. *The Nature of Maps*. Chicago: University of Chicago Press.

Rogers, Y., Sharp, H. and Preece, J., 2011. *Interaction Design: beyond human-computer interaction.* 3rd ed. Chichester: John Wiley & Sons.

Root, R.W. and Draper, S., 1983. Questionnaires as a software evaluation tool Interface Design 4 -- Analyses of User Inputs. In: *ACM CHI 83 Conference on Human Factors in Computing Systems*, pp.83-87. New York: NY: ACM Press.

Rosson, M.B. and Carroll, J.M., 2002. *Usability Engineering: Scenario-Based Development of Human-Computer Interaction*. San Diego: Academic Press.

Roth, R. and Harrower, M., 2008. Addressing Map Interface Usability: Learning from the Lakeshore Nature Preserve Interactive Map. *Cartographic Perspectives*, 60, pp.46-66.

Rotmans, J., Hulme, M. and Downing, T., 1994. Climate change implications for Europe: an application of the ESCAPE model. *Global Environmental Change – Human and Policy Dimensions*, 4(2), 97-124.

Royal Irish Academy. 2002. *3rd Scientific Statement – Climate and Sea Level Change*. Dublin: Royal Irish Academy.

Rubin, J., 1994. *Handbook of Usability Testing*. New York: Wiley.

Rusby, R., 2008. The Future of Visualisation: Vision 2020. *World Oil*, 229(1), pp.13-13.

Sauro, J., 2012. *Comparison of Usability Testing Methods*, [online] Available at:<http://www.measuringusability.com/blog/method-comparison.php>[Accessed 08/05/2012]

Seffah, A. and Metzker, E., 2004. The Obstacles and Myths of Usability and Software Engineering. *Communications of the ACM*, 47(12), pp.71-76.

Seiderman, A.S. and Marcus, S.E., 1989. *20/20 is not enough: The new world of vision*. New York: Knopf.

Shalf, J. and Bethel, E.W., 2003. The grid and future visualisation system architectures. *IEEE Computer Graphics & Applications*, 23(2), pp.6-9.

Sheppard, S.R.J., 2001. Guidance for crystal ball gazers: developing a code of ethics for landscape visualisation. *Landscape and Urban Planning*, 54(1-4), pp.183-199.

Sheppard, S.R.J., 2005. Validity, reliability and ethics in visualisation. In: Lange, E. and Bishop, I., eds. 2005. *Visualisation in Landscape and Environment Planning: Technology and Applications*. London: Taylor and Francis, pp.79-99.

Shepherd, I., 2008. Travails in the Third Dimension: A Critical Evaluation of Three-dimensional Geographical Visualisation. In: Dodge, M., Derby, M. and Turner, M., eds. 2008. *Geographic Visualisation: Concepts, Tools and Applications*. Chichester: John Wiley & Sons, pp.199-218.

Shneiderman, B., 1998. *Designing the User Interface: Strategies for Effective Human -Computer Interaction*. 3rd ed. Reading: Addison-Wesley.

Sidlar, C. and Rinner, C., 2007. Analyzing the usability of an argumentation map as a participatory spatial decision support tool. URISA Journal, 19(1), 47-55.

Silverman, D., 2001, *Interpreting qualitative data: Methods for analysing talk, text and interaction: 2nd edition*. London: Sage.

Slocum, T.A., Blok, C., Jiang, B., Koussoulakou, A., Montello, D.R., Fuhrmann, S. and Hedley, N.R., 2001. Cognitive and usability issues in Geovisualisation. *Cartography and Geographic Information Science*, 28(1), pp.61-75.

Slocum, T.A., McMaster, R.B., Kessler, F.C. and Howard, H.H., 2005. *Thematic Cartography and Geographic Visualisation*. 2nd ed. Upper Saddle River: Pearson Education.

Slocum, T.A., McMaster, R.B., Kessler, F.C. and Howard, H.H., 2009. Thematic Cartography and Geovisualisation 3rd ed. (Prentice Hall Series in Geographic Information Science).Upper Saddle River, NJ: Pearson Education.

Stone, D., Jarrett, C., Woodroffe, M. and Minocha, S., 2005. *User Interface Design and Evaluation*. San Francisco, CA: Morgan Kaufmann.

Story, M.F., 1998. Maximizing Usability: The Principles of Universal Design. *Assistive Technology*, 10(1), pp.4-12.

Sutcliffe, A., Ennis, M. and Watkinson, S., 2000. Empirical studies of end-user information searching. *Journal of the American Society for Information Science*, 51(13), pp.1211-1231.

Sutherland, I.E., 1964. SketchPad: a man-machine graphical communication system. In: *DAC'64 SHARE design automation workshop*. Cambridge, USA, 6-7 May 1964, 23, pp.323-328.

Sutherland, I.E., 1966. Ten unsolved problems in computer graphics. *Datamation*, 12(5), pp.22-27.

Swan, J.E., Jones, A., Kolstad, E., Livingston, A. and Smallman, S., 2007. Egocentric depth judgments in optical, see-through augmented reality. *IEEE Transactions on Visualisation and Computer Graphics*, 13(3), pp.429-442.

Swayne, D.F., Lang, D.T., Buja, A. and Cook, D., 2003. GGobi: evolving from XGobi into an extensible framework for interactive data visualisation. *Computational Statistics and Data Analysis*, 43(4), pp.423-444.

Sweeney, J., 1997. *Global Change and the Irish Environment*. Dublin: Royal Irish Academy, p170.

Sweeney, J., 2008. Climate Change – Refining the Impacts for Ireland. *EPA STRIVE Programme 2007-2013*, [online] Available at:<http://www.epa.ie/downloads/pubs/research/climate/sweeney-report-strive-12-for-web-low-res.pdf> [Accessed 16/12/2010]

Taylor, D.R.F., 1991a. A conceptual basis for cartography: New direction for the information era. *Cartographica*, 28(4), pp.1-8.

Taylor, D.R.F., 1991b. *Geographic information systems: The microcomputer and modern cartography (Modern Cartography Series)*. New York: Pergamon, pp.1-21.

Taylor, D.R.F., 1994. Perspectives on visualisation and modern cartography. In MacEachren, A.M. and Taylor, D.R.F., eds. 1994. *Visualisation in Modern Cartography*. Oxford: Pergamon, pp.333-342.

Thrower, N., 1996. *Maps and Civilization: Cartography in Culture and Society*. Chicago: University of Chicago Press.

Tobón, C., 2005. Evaluating geographic visualisation tools and methods: An approach and experiment based upon user tasks. In Dykes, J.A., MacEachren, A.M. and Kraak, M.J., eds. 2005. *Exploring Geovisualisation*. Amsterdam: Elsevier, pp.645-666.

Tomlinson, R., 2007. *Thinking about GIS: Geographic Information System Planning for Managers*. 3rd ed. Redlands: ESRI Press.

Trafton, A., 2009. A new dimension for genome studies. *MIT news* [online] Available at:<http://web.mit.edu/newsoffice/2009/3d-genome.html> [Accessed 04/09/2012]

Trochim, W., 1999. *The Research Methods Knowledge Base*. 2nd ed. Ithaca, NY: Cornell Custom Publishing.

Tullis, T. and Albert W., 2008. Measuring the User Experience: Collecting, Analyzing, and Presenting Usability Metrics. Burlington: Morgan Kaufmann

Turton, I. and Openshaw, S., 1998. High-performance computing and geography: development, issue and case studies. *Environment and Planning A*, 30(10), pp.1839-1856.

UCL, n.d. *Projects: Augmented Round Table for Architecture and Urban Planning* [online] Available at:<http://www.vr.ucl.ac.uk/projects/arthur/> [Accessed 09/09/2012]

UNEP (United Nations Environment Programme). 2008. *Ice and Sea-level change in Global Outlook for Ice and Snow*. Geneva: UNEP.

Unwin, D., 1994. Cartography, ViSC, and GIS. *Progress in Human Geography*, 18(4), pp.516-522.

Unwin, D., 1998. Editorial: computers, geosciences and geocomputation. *Computers and Geosciences*, 24(4), pp.297-298.

USGS. 2010. *Aral Sea*. [image online] Available at:<http://landsat.usgs.gov/Landsat_Missions_40th_Anniversary_gallery_view.php?category=nocategory&thesort=pictureId> [Accessed 05/09/2012]

van Lammeren, R., Ligtenberg, A., Serpa, J., Abreu, J. and Plezier, I., 2007. Geo-visualisation-The e-interaction factor in spatial planning. In: van den Brink, A., van Lammeren, R., van de Velde, R. and Däne, S., eds. 2007. *Imaging the Future: Geo-visualisation for Participatory Spatial Planning in Europe.* Wageningen: Wageningen Academic, *Mansholt Publication Series Vol 3*, pp.89-105.

van Wijk, J.J., 2006. Bridging the gaps. *IEEE Computer Graphics and Applications*, 26(6), pp.6-9.

Veerasamy, A. and Belkin, N.J., 1996. Evaluation of a tool for visualisation of information retrieval results. In: *19th Annual International ACM SIGIR Conference on Research and Development in Information Retrieval*. Zurich, Switzerland, 18-22 August, pp.85-92.

Verbree, E., Maren, G.V., Germs, R., Jansen, F. and Kraak, M.-J., 1999. Interaction in virtual world views – linking 3D GIS with VR. *International Journal of Geographical Information science*, 13(4), pp.385-396.

Wang, Y., 1999. China coastal sea level change. In: Feng, H., 1999. *Vertical Movement of Sea Level and Land in the Coastal Zone of East China*. Beijing: China Ocean Press, pp.8-26.

Wang, Y., Liu, Y., Chen, X. and Chen, Y., 2001. Adaptive geovisualisation: an approach towards the design of intelligent geovisualisation systems. *Journal of Geographical Sciences*, 11, pp.1-8(supplement).

Ware, C. and Bobrow, R., 2005. Supporting visual queries on medium sized node-link diagrams. *Information Visualisation*, 4(1), pp.49-58.

Wassink, I., Kulyk, O., van Dijk, B., van der Veer, G. and van der Vet. P., 2009. Applying a user-centered approach to interactive visualisation design. In Zudilova-Seinstra, E., Adriaansen, T. and van Liere, R., eds. 2009. *Trends in Interactive Visualisation: State-of-the-Art Survey*. London: Springer, pp.175-199.

Weaver, C.E., 2006. *Improvise: A user interface for interactive construction of highly coordinated visualisations*. Unpublished Doctoral Thesis, University of Wisconsin, Madison.

Whitefield, A., Wilson, F. and Dowell, J., 1991. A framework for human factors evaluation. *Behaviour and Information Technology*, 10(1), pp.65-79.

Whiteside, J., Bennett, J. and Holzblatt, K., 1988. Usability engineering: Our experience and evolution. In: Helander, M., ed., 1988. *Handbook of Human-Computer Interaction*. Amsterdam: Elsevier, pp.791-817.

Wilson, T.D., 2000. Human Information Behavior. *Information Science*, 3(2), pp.49-55.

Wixon, D. and Wilson, C., 1997. The usability engineering framework for product design and evaluation, In: Helander, M.G., Landauer, T.K. and Prabhu, P.V., eds. 1997. *Handbook of Human-Computer Interaction. 2nd ed.* Amsterdam: Elsevier, pp.653-687.

Wood, D., 1992. *The power of maps*. New York: Guilford Press.

Wood, M., 2001. The 21st Century World – No future without cartography. *Journal of Geospatial Engineering*, 3(2), pp.77-86.

Woodson, W.E., 1981. *Human Factors Design Handbook: Information and Guidelines for the Design of Systems, Facilities, Equipment, and Products for Human Use*. New York: McGraw-Hill.

Woronuk, D., 2008. *Investigating 3D Geovisualisation for Fire Incident Command*. Unpublished M.Sc Thesis of Texas State University, San Marcos.

Wu, T., 2000. 1999 Catastrophic Flood in Taihu Basin and the Consideration for Taihu Flood Control Planning. *Journal of Lake Science (Chinese)*, 12(1), pp.6-11.

Yan, H., Xu, Y. and Chen, H., 2010. Application Research on Virtual Reality Geographic Information System in Scenic Sites of Nanjing Treasure Dockyard Relics. In: *3rd International Conference on Information and Computing Science (ICIC 2010)*. Wuxi, China, 4-6 June 2010, 1, pp.278-281.

Yin, R.K., 1994. *Case study research: Design and methods*. 2nd ed. Thousand Oaks: Sage.

Yu, Z., Wang, Y. and Li, F., 2010. Study on the intelligent map service for adaptive geo-visualisation. In: *18th International Conference on Geoinformatics*. Beijing, China, 18-20 June 2010, pp.1-6.

Zemke, R. and Rossett, A., 2002. A hard look at ISD. *Training*, 39(2), pp.26-28, 30-32.

Zerger, A. and Smith, D.I., 2003. Impediments to using GIS for real-time disaster decision support. *Computer, Environment and Urban Systems*, 27, pp.123-141.

Zhan, X., Sun, Z. and Wang, S., 2011. *Three-dimensional interactive visualisation system for the middle and lower reaches of the Yangtze River*, [online] Available at:<http://www.esrichina-bj.cn/2011/0426/957.html>[Accessed 19/05/2011]

Zhang, D. and Adipat, B., 2005. Challenges, methodologies, and issues in the usability of testing mobile applications. *International Journal of Human-Computer Interaction*, 18(3), pp. 293-308.

Zhang, S., Zhao, D. and Jiang, X., 2010. Virtual reality visualisation of flood submergence forecasting. *Journal of Tsinghua University* (Science and Technology), 50(6), pp.861-864.

Zhu, D., 2003. Jiangsu Marine Environment and Coastal Economic Development. *Water Resources Protection (Chinese)*, 19(6), pp.19-22.

Zipf, A., 2002. User-adaptive maps for location-based services (LBS) for tourism. In: *9th International Conference for Information and Communication Technologies in Tourism (ENTER 2002),* Innsbruck, Austria, 23-25 January 2002, pp. 329-338.

Zlatanova, S., Rahman, A.A. and Pilouk, M., 2002. Trends in 3D GIS development. *Journal of Geospatial Engineering*, 4(2), pp.1-10.

Zone, R., 2007. *Stereoscopic cinema and the origins of 3-D film, 1838-1952*. Lexington: The University Press of Kentucky.

Appendices

Appendix 1: Questionnaire

Questionnaire for geovisualisation usability workshop

Views and opinions expressed in this questionnaire will not be made public. The results from this questionnaire are for statistical purposes only.

Organization

Job Specification

Occupation

Are you aware of climate change?	☐Yes	☐No
Are you aware of a rise in sea levels?	☐Yes	☐No

Which of the following would you consider as important responses to sea level rise? (Choose more than one option if necessary)

☐Implement sound adaptive strategies
☐Raise public awareness
☐More financial support from government and other sources
☐Low carbon economy policy
☐Scientific and informed use of coast and marine resources
☐Employ new and advanced technology
☐Improve coast defence engineering
☐Other

_____

How long has been your involvement with…?

	>10 years	5-10 years	<5 years
marine and coastal management	☐	☐	☐
cartography	☐	☐	☐
geographic information systems	☐	☐	☐

How important is spatial information to your work?

Very important	Important	Neither	Unimportant	Very unimportant
☐	☐	☐	☐	☐

Please see the presentation before continuing

Are you familiar with these types of geovisualisation?	☐Yes	☐No

Please indicate your level of agreement with the following statements

	Strongly agree	Agree	Neither	Disagree	Strongly disagree
The way that coastal inundation is presented is clear and understandable	☐	☐	☐	☐	☐
The visualisations present the correct scenario in the context of future sea level rise	☐	☐	☐	☐	☐
Using these geovisualisations can generally help save our 'mental efforts' when	☐	☐	☐	☐	☐

analyzing sea level impacts					
Using geovisualisations can generally help save the costs (spent on meetings, interviews, field works, etc) for making the decision	☐	☐	☐	☐	☐
Nowadays it is impossible to communicate climate changes issues such as sea level rise without the help of geovisualisation	☐	☐	☐	☐	☐

How effective do you think are these visualisations used for…?

	Very effective	Effective	Neither	Ineffective	Very ineffective
analytical work such as risk assessment, disaster monitoring, etc					
Paper map	☐	☐	☐	☐	☐
2D	☐	☐	☐	☐	☐
3D	☐	☐	☐	☐	☐
Map animation	☐	☐	☐	☐	☐
Virtual reality	☐	☐	☐	☐	☐
communication and participatory work with general public					
Paper map	☐	☐	☐	☐	☐
2D	☐	☐	☐	☐	☐
3D	☐	☐	☐	☐	☐
Map animation	☐	☐	☐	☐	☐
Virtual reality	☐	☐	☐	☐	☐
general decision making					
Paper map	☐	☐	☐	☐	☐
2D	☐	☐	☐	☐	☐
3D	☐	☐	☐	☐	☐
Map animation	☐	☐	☐	☐	☐
Virtual reality	☐	☐	☐	☐	☐

Which one of them…?

	Paper map	2D	3D	Map animation	Virtual reality
do you think is the easiest geovisualisation to use	☐	☐	☐	☐	☐
costs you the least time to finish all tasks	☐	☐	☐	☐	☐

To what extent are these geovisualisations visually attractive to you?

	Very attractive	Attractive	Neither	Unattractive	Very unattractive
Paper map	☐	☐	☐	☐	☐
2D	☐	☐	☐	☐	☐
3D	☐	☐	☐	☐	☐
Map animation	☐	☐	☐	☐	☐
Virtual reality	☐	☐	☐	☐	☐

How satisfied will you be working with these visualisations?

	Very satisfied	Satisfied	Neither	Dissatisfied	Very dissatisfied
Paper map	☐	☐	☐	☐	☐
2D	☐	☐	☐	☐	☐
3D	☐	☐	☐	☐	☐

Map animation	☐	☐	☐	☐	☐
Virtual reality	☐	☐	☐	☐	☐

Thank you for your time!

‘关于地理可视化可用性的讨论’调查问卷

通过该问卷表达的任何观点和看法将不会被公开。调查结果仅供统计使用。

工作单位

从事工作

职务

您是否熟悉气候变化问题?	☐是	☐否
您是否熟悉海平面上升问题?	☐是	☐否

您认为以下哪些是面对海平面上升最需要考虑的问题? (可选择多项)

☐如何研究更有效的适应策略

☐如何提高公众意识

☐如何筹集来自政府及其它方面的资金援助

☐如何落实低碳经济的政策

☐如何更为科学的开发利用海洋资源

☐如何大量应用新技术手段

☐如何改善海岸堤防工程

☐其它

_____

您在以下方面的工作经验是?

	>10 年	5-10 年	<5 年
海洋及海岸带管理	☐	☐	☐
制图	☐	☐	☐
地理信息系统	☐	☐	☐

空间信息对于您的工作有多重要?

很重要	重要	一般	不重要	很不重要
☐	☐	☐	☐	☐

在完成以下所有问卷内容前请先观看一段幻灯片陈述

您熟悉这些地理可视化的产品吗?	☐是	☐否

请标明您对以下陈述的赞同程度

	很赞同	赞同	一般	不赞同	很不赞同
这些可视化展示海岸淹没的方法清楚易懂	☐	☐	☐	☐	☐
这些可视化对于未来海平面上升的模拟很正确	☐	☐	☐	☐	☐
采用这样的可视化手段可以帮助减少我们分析时的‘脑力消耗’	☐	☐	☐	☐	☐
采用这样的可视化手段在总体上可以降低工作成本（如会议，走访，实地考察等）	☐	☐	☐	☐	☐
现在如果不借助地理可视化手段，我们没有办法去解释和交流类似于海平面上升这样的气候变化问题	☐	☐	☐	☐	☐

您认为这些可视化产品在以下的应用方面效果如何?

	很有效	有效	一般	无效	很无效
专业的分析工作（风险评估，易损分析，灾害监测等）					
纸质地图	☐	☐	☐	☐	☐
二维可视化	☐	☐	☐	☐	☐
三维可视化	☐	☐	☐	☐	☐
动态可视化	☐	☐	☐	☐	☐
虚拟现实	☐	☐	☐	☐	☐
信息公开，特别是与普通大众的交流					
纸质地图	☐	☐	☐	☐	☐
二维可视化	☐	☐	☐	☐	☐
三维可视化	☐	☐	☐	☐	☐
动态可视化	☐	☐	☐	☐	☐
虚拟现实	☐	☐	☐	☐	☐
一般的决策制订					
纸质地图	☐	☐	☐	☐	☐
二维可视化	☐	☐	☐	☐	☐
三维可视化	☐	☐	☐	☐	☐
动态可视化	☐	☐	☐	☐	☐
虚拟现实	☐	☐	☐	☐	☐

哪一种可视化产品?

	纸质地图	二维可视	三维可视	动态可视	虚拟现实

		化	化	化	
您认为使用起来最简单	☐	☐	☐	☐	☐
您觉得完成所给作业所用时间最短	☐	☐	☐	☐	☐

这些可视化产品是否能够在视觉上吸引您?

	很吸引	吸引	一般	不吸引	很不吸引
纸质地图	☐	☐	☐	☐	☐
二维可视化	☐	☐	☐	☐	☐
三维可视化	☐	☐	☐	☐	☐
动态可视化	☐	☐	☐	☐	☐
虚拟现实	☐	☐	☐	☐	☐

总体来说您对这些可视化产品的使用是否满意

	很满意	满意	一般	不满意	很不满意
纸质地图	☐	☐	☐	☐	☐
二维可视化	☐	☐	☐	☐	☐
三维可视化	☐	☐	☐	☐	☐
动态可视化	☐	☐	☐	☐	☐
虚拟现实	☐	☐	☐	☐	☐

感谢您的宝贵时间!

Appendix 2: Questionnaire Counts

	Red: survey in Ireland 19 respondents		Green: survey in China 15 respondents
The numbers are the counts received by each question			

	Strongly agree	Agree	Neither	Disagree	Strongly disagree
Q①	8	11	0	0	0
	8	6	1	0	0
Q②	0	8	6	3	2
	1	6	7	1	0
Q③	2	6	6	5	1
	5	6	2	1	1
Q④	0	4	10	2	3
	7	5	0	3	0
Q⑤	9	9	1	0	0
	10	3	2	0	0

	Very effective	Effective	Neither	Ineffective	Very ineffective
Q⑥					
P1	1	13	2	2	1
	0	4	9	2	0
P2	4	13	2	0	0
	2	11	2	0	0
P3	4	13	2	0	0
	7	6	2	0	0
P4	3	10	6	0	0
	4	7	4	0	0
P5	2	9	7	1	0
	1	6	6	2	0
Q⑦					
P1	3	12	1	3	0
	2	12	1	0	0
P2	2	13	1	3	0
	1	9	5	0	0
P3	3	14	2	0	0
	4	8	3	0	0
P4	8	8	3	0	0

	5	10	0	0	0
P5	8	5	4	2	0
	3	9	3	0	0
Q⑧					
P1	2	10	4	3	0
	0	5	8	2	0
P2	4	10	3	2	0
	0	10	5	0	0
P3	4	13	1	1	0
	5	8	2	0	0
P4	3	11	3	2	0
	9	5	1	0	0
P5	1	6	8	4	0
	1	3	9	2	0

	P1	P2	P3	P4	P5
Q⑨	7	6	4	1	0
	5	5	4	1	0
Q⑩	5	7	7	0	0
	4	6	5	0	0

Q⑪					
	Very attractive	Attractive	Neither	Unattractive	Very unattractive
P1	1	6	7	5	0
	0	0	3	8	4
P2	2	8	6	3	0
	0	1	6	8	0
P3	5	10	4	0	0
	2	12	1	0	0
P4	11	4	4	0	0
	9	6	0	0	0
P5	10	4	5	0	0
	4	10	1	0	0

Q⑫					
	Very satisfied	Satisfied	Neither	Dissatisfied	Very dissatisfied
P1	2	8	5	4	0
	0	10	2	3	0
P2	3	9	6	1	0

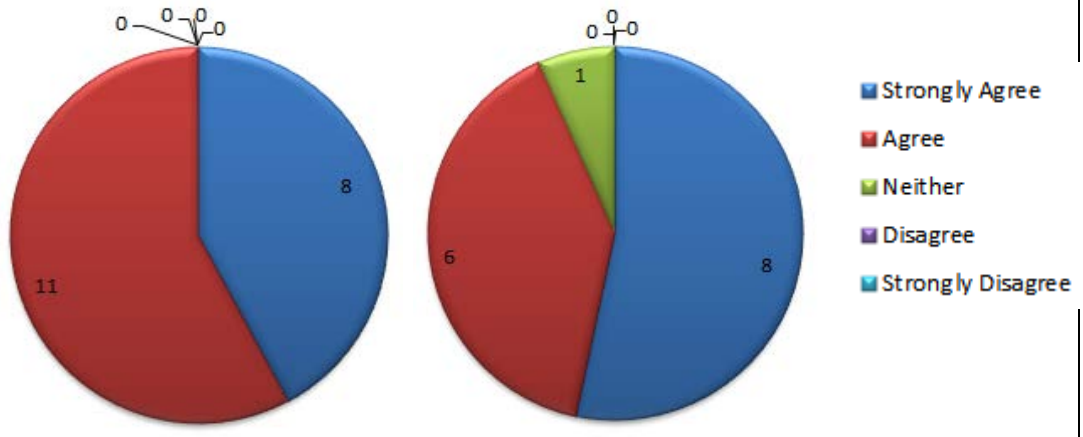
	0	8	6	1	0
P3	5	10	4	0	0
	5	8	2	0	0
P4	4	8	7	0	0
	4	4	5	2	0
P5	3	6	8	2	0
	1	5	6	3	0

Appendix 3: Questionnaire Analysis

(pie charts and bar charts for all questions)

Question 1

Q1	"The way that coastal inundation is presented is clear and understandable." Please indicate your level of agreement with this statement.



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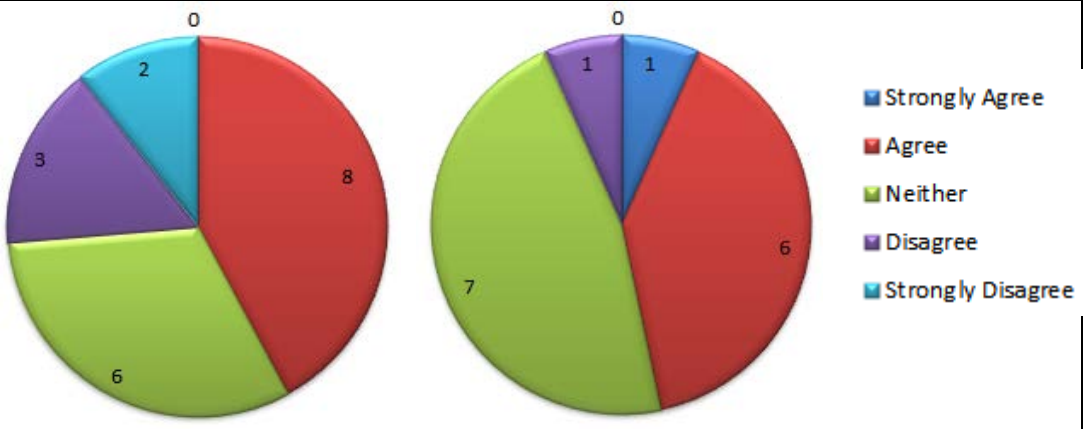
Question 2

Q2	"The visualisations present the correct scenario in the context of future sea-level rise." Please indicate your level of agreement with this statement.



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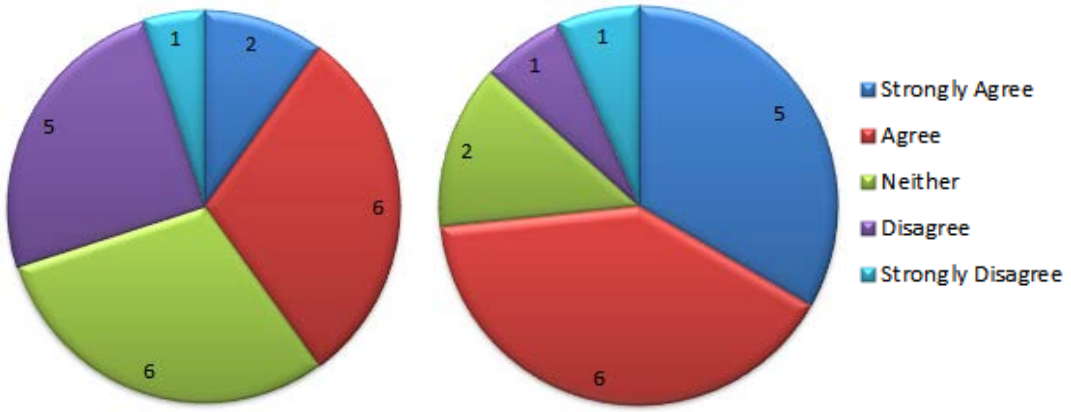
Question 3

Q3	"Using these geovisualisations can generally help save our 'mental efforts' when analyzing sea-level rise impacts." Please indicate your level of agreement with this statement.



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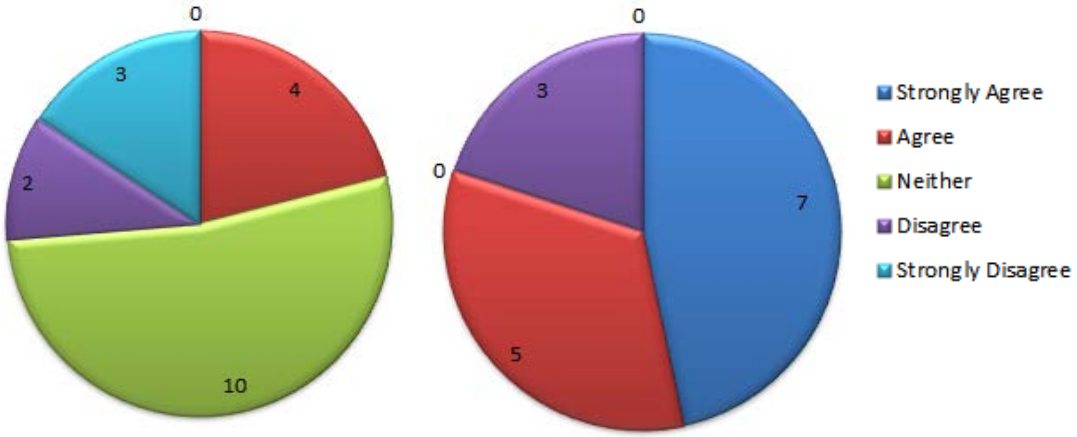
Question 4

Q4	"Using geovisualisations can generally help save the costs (spent on planning, meetings, interviews, field works, etc) for making the decision." Please indicate your level of agreement with this statement.



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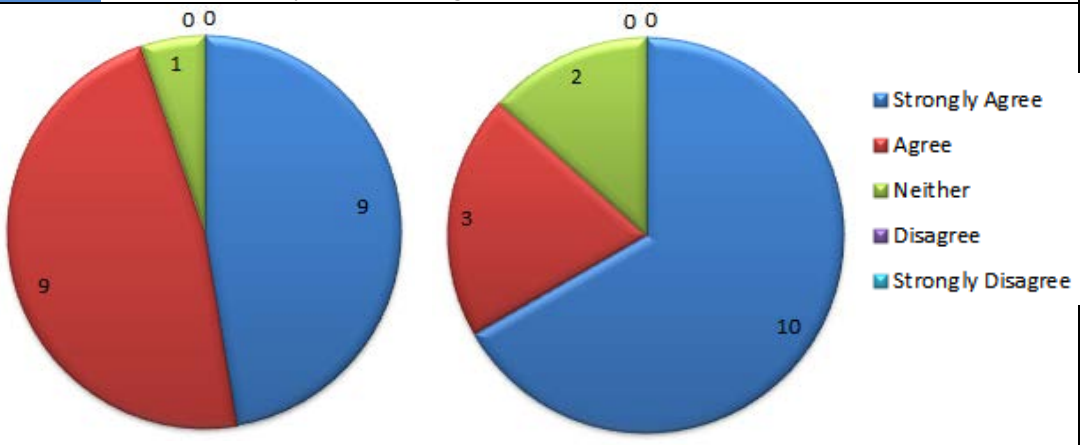
Question 5

Q5	"Nowadays it is impossible to communicate climate change issues such as sea-level rise without the help of geovisualisation." Please indicate your level of agreement with this statement.



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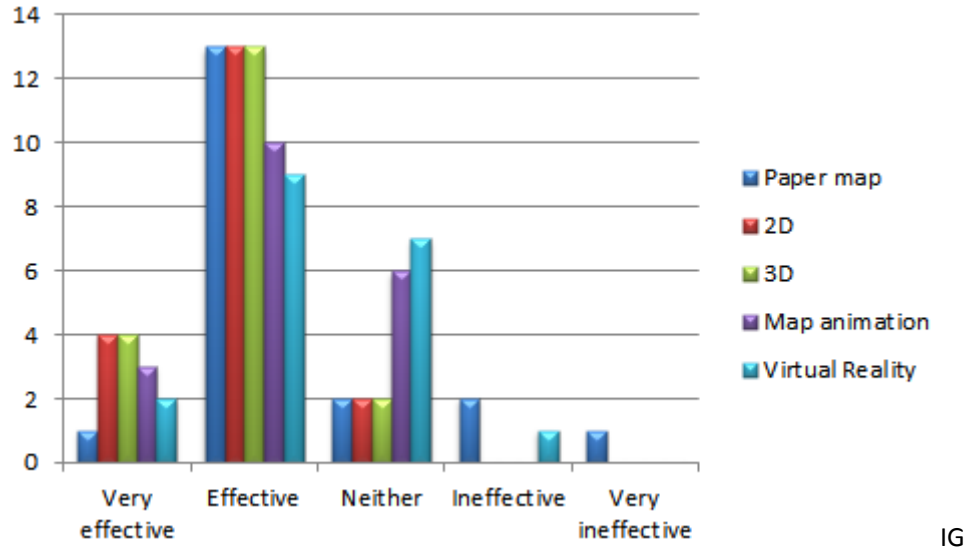
Question 6

Q6	"How effective do you think are these visualisations used for analytical work such as risk assessment, disaster monitoring, etc?" Please indicate your level of agreement with each product.



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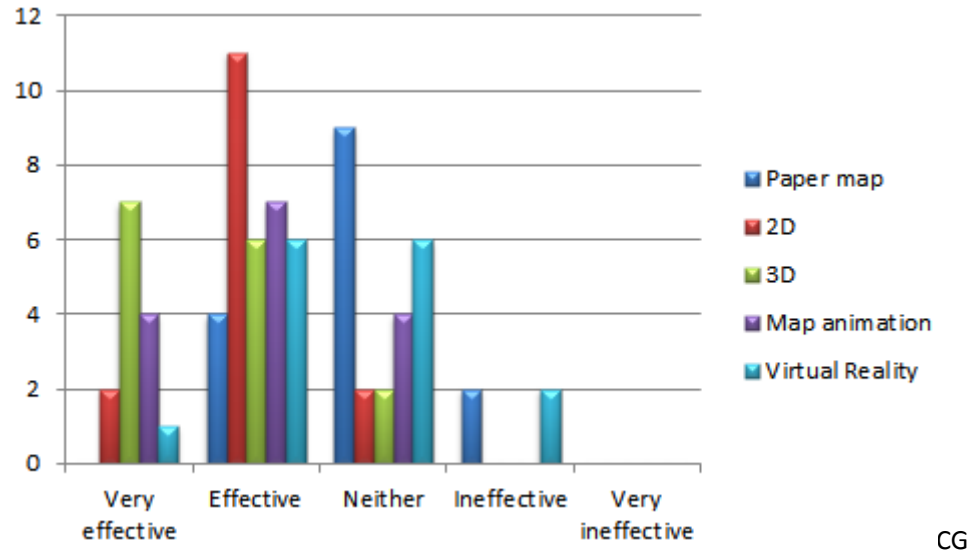

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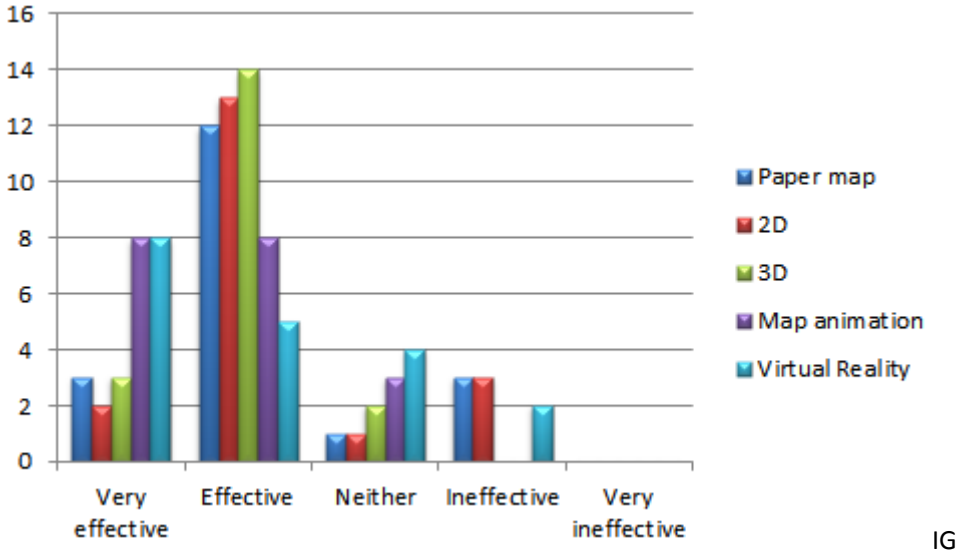
Question 7

Q7	"How effective do you think are these visualisations used for communication and participatory working with general public?" Please indicate your level of agreement with each product.



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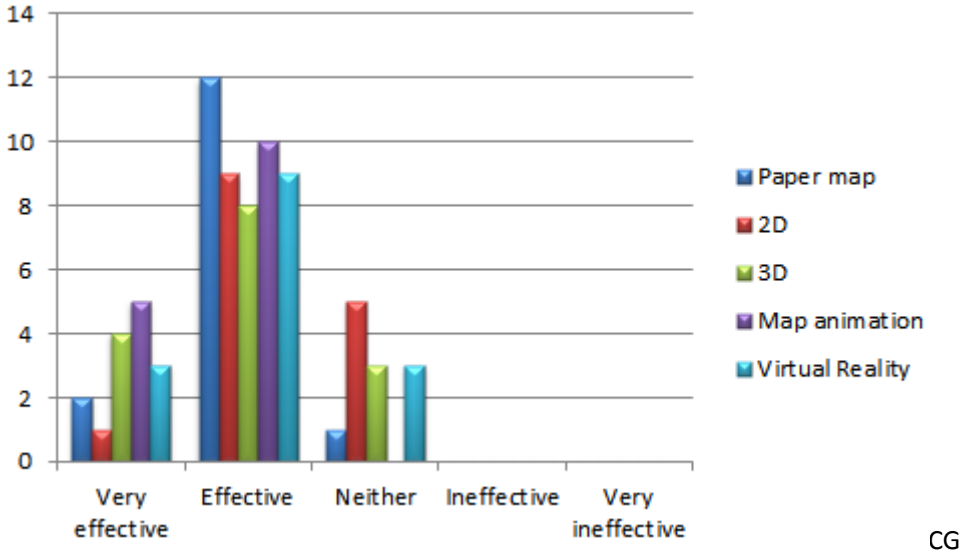

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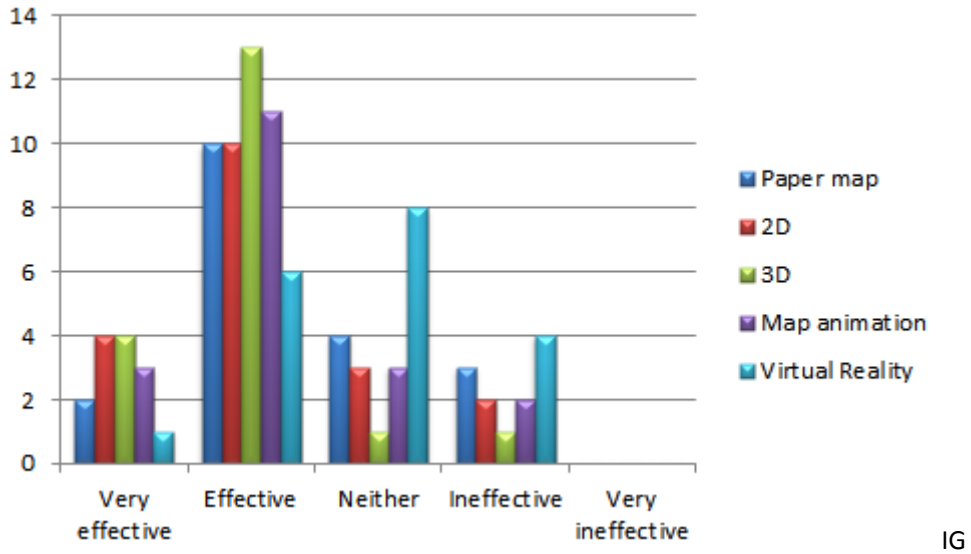
Question 8

Q8	"How effective do you think are these visualisations used for general decision making?" Please indicate your level of agreement with each product.



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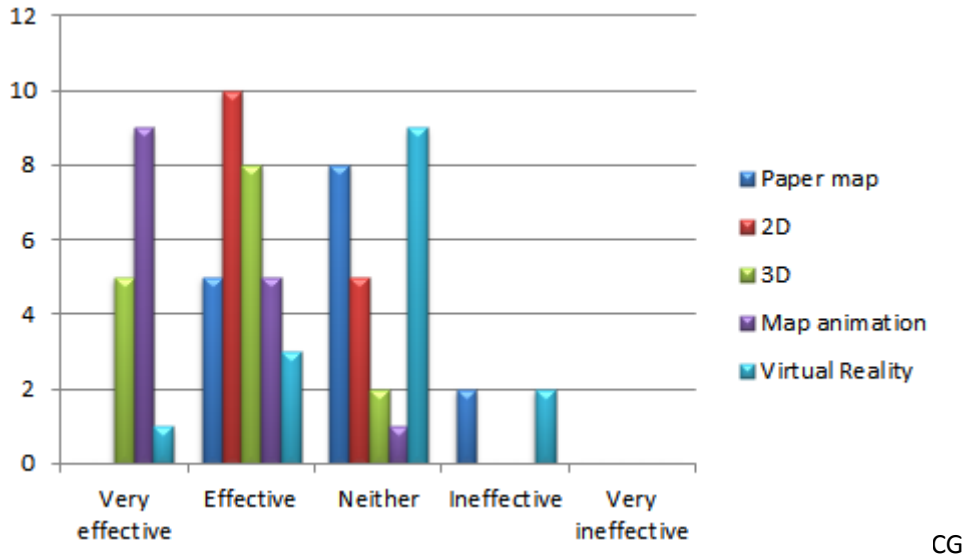

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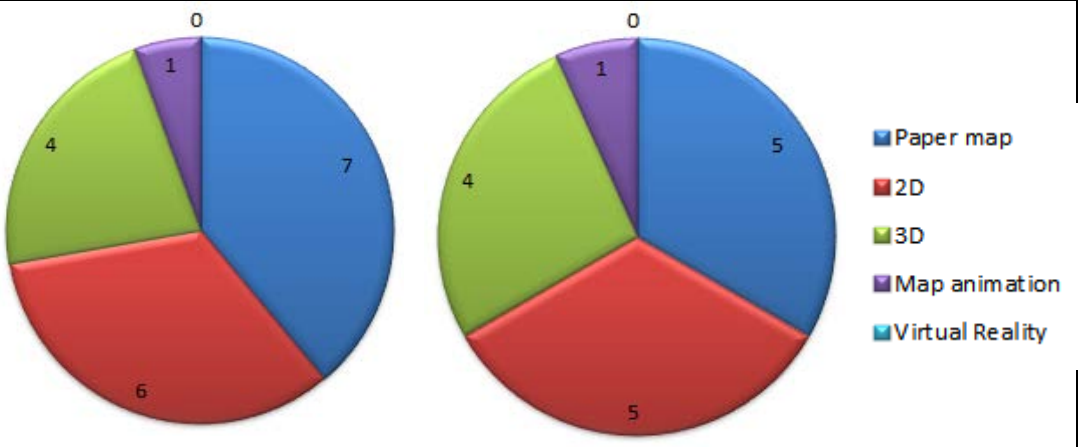
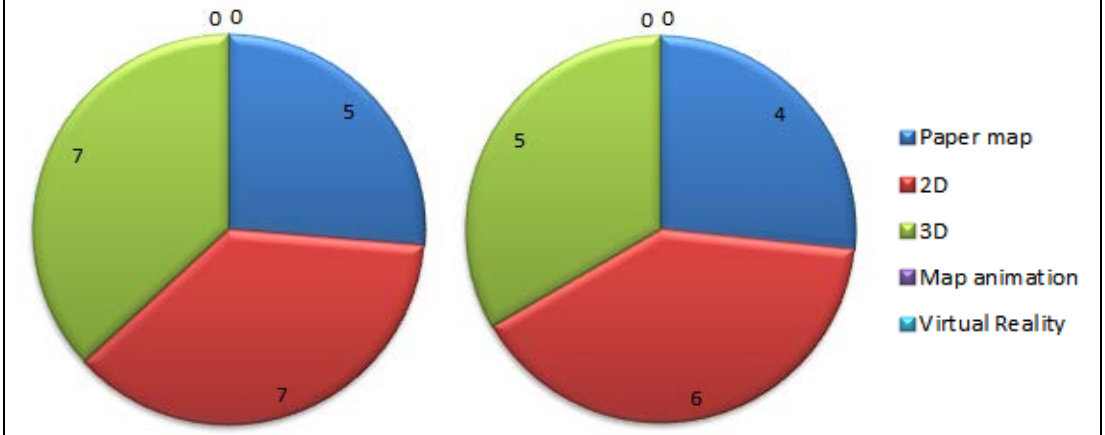
Question 9

Q9	"Which one of them do you think is the easiest to use?"



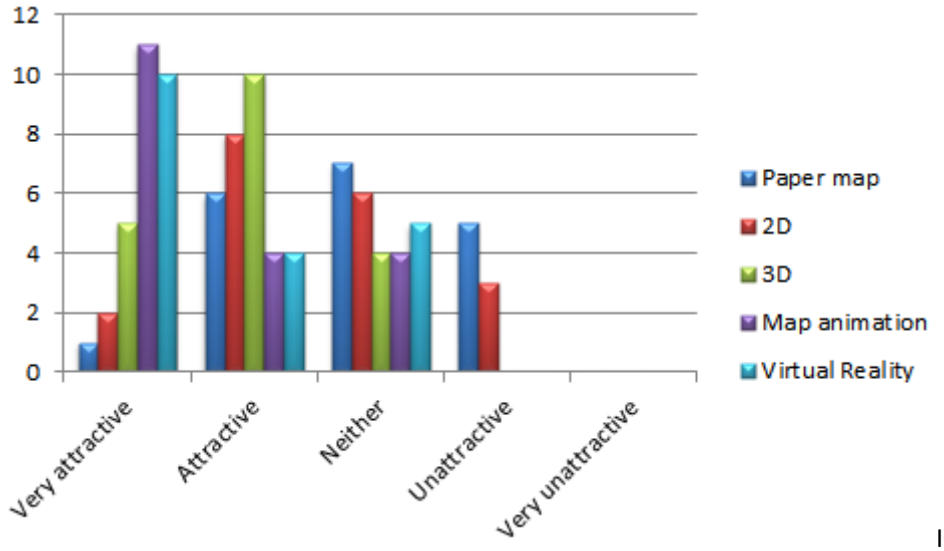
Question 10

Q10	"With which of them costs you the least time to finish all the tasks?"



Question 11

Q11	"To what extent are these geovisualisations visually attractive to you?" Please indicate your level of agreement with each product.



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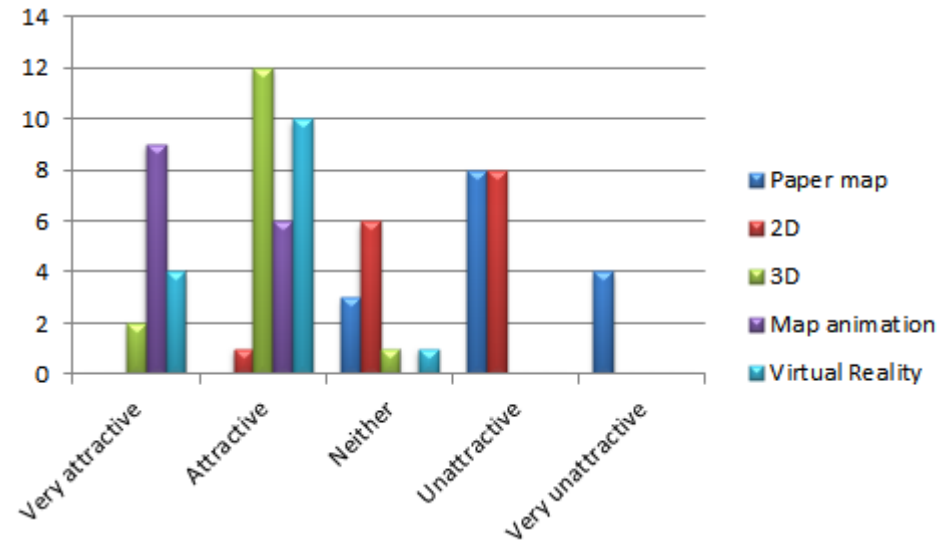

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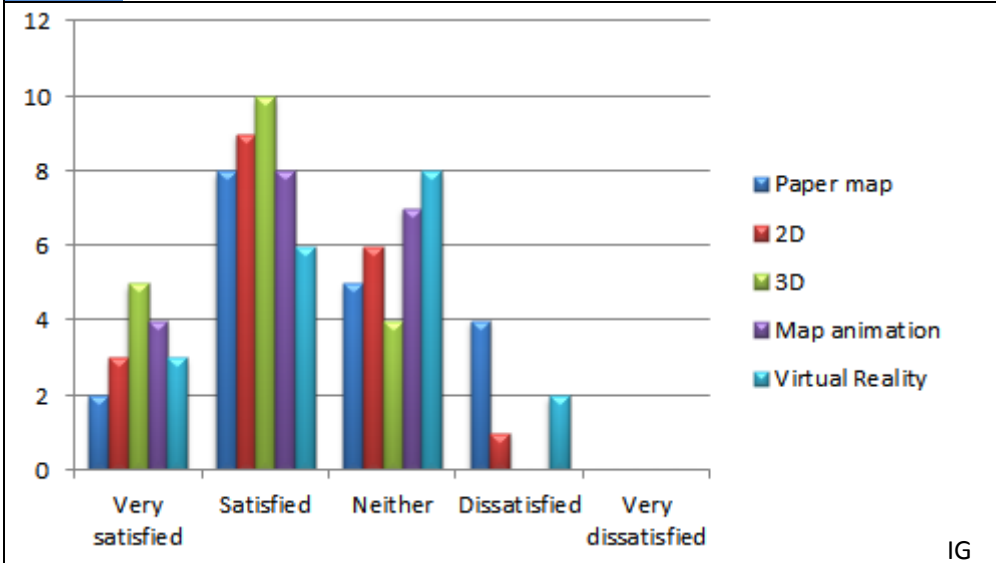
Question 12

Q12	"How satisfied will you be working with these visualisations" Please indicate your level of agreement with each product.



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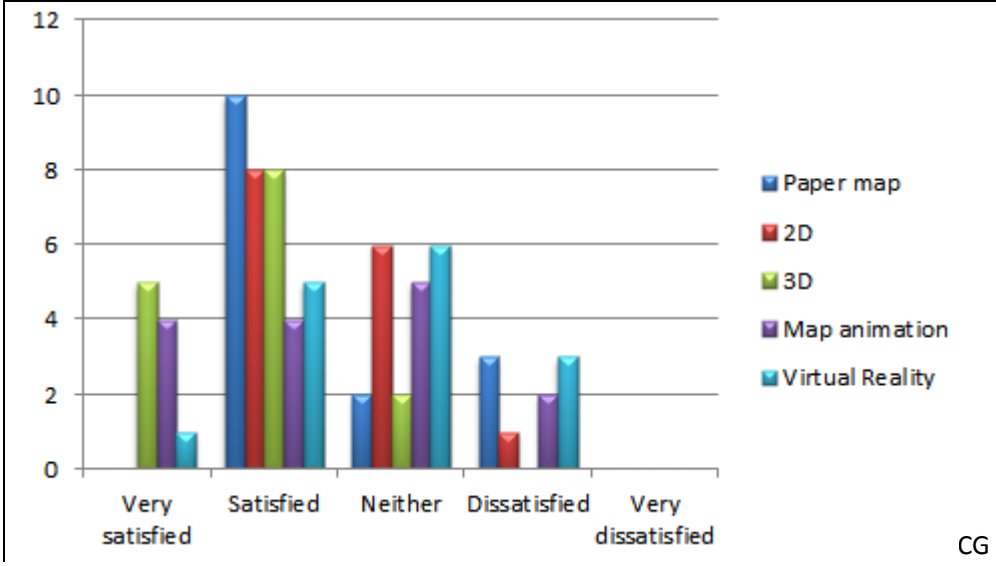

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Appendix 4: Workshop Presentation (Ireland)

Usability-focused geovisualization
---- a case of coast flooding

05-Oct-2010 at NMCI

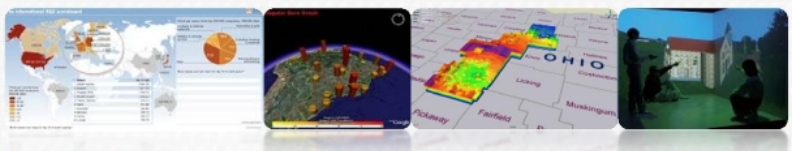
Concepts

Geovisualization

"Visualization in Scientific Computation（ViSC）" was brought forward in 1987 by the National Science Foundation (*McCormick et al., 1987*).

The process of geovisualization includes exploration, confirmation, synthesis and presentation (*DiBiase, 1990*).

The future of geovisualization is user-oriented application with sufficient interaction (*MacEachren, 1994*).



Case: C.A.L.P Kimberley Visualization Project

-- "We make pictures out of data and local knowledge, including 'future pictures' to help people understand choices and options"

-- "We work with scenarios and provide possible future pathways for coastal stakeholders"

Source: CALP (2009)

Here come the questions……

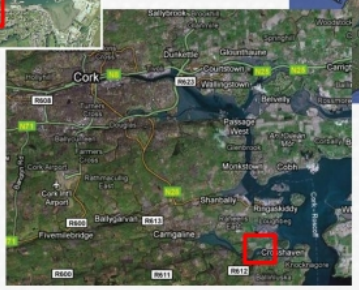
-- "evidence for the successful adoption of geo-visualization techniques has been limited" *Slocum et al. (2001)*

-- "the use of visualization tools by people different from the tool designers seems to be quite limited" *Andrienko (2006)*

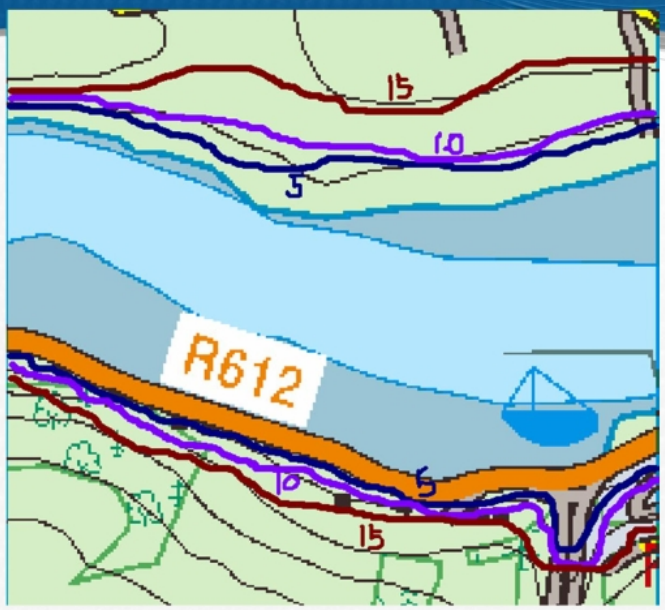
-- "are novel tool designs actually usable and useful for knowledge discovery and decision making?" *Fuhrmann et al. (2005)*

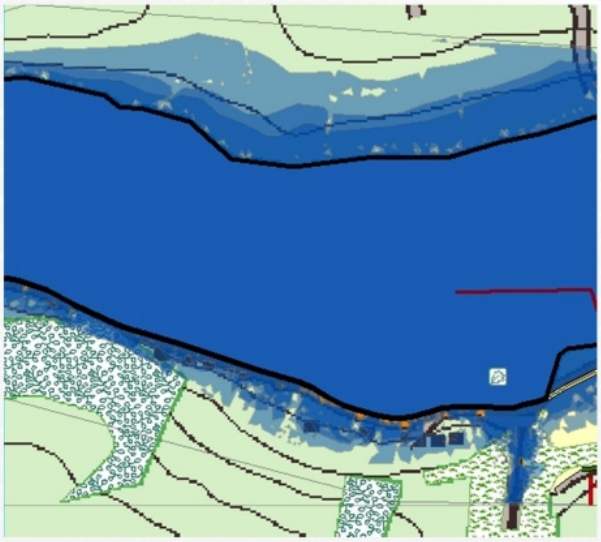
Study site

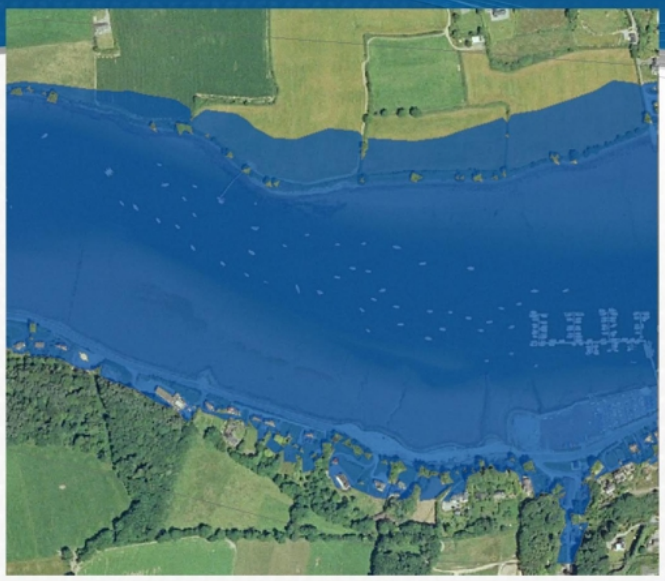
Crossheaven, Cork, Ireland

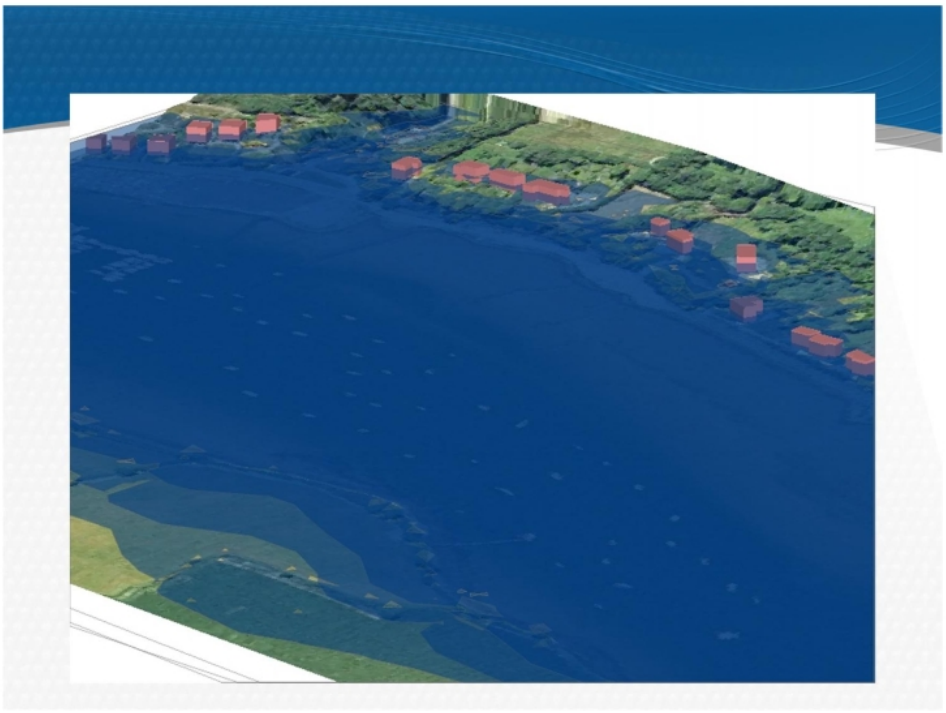


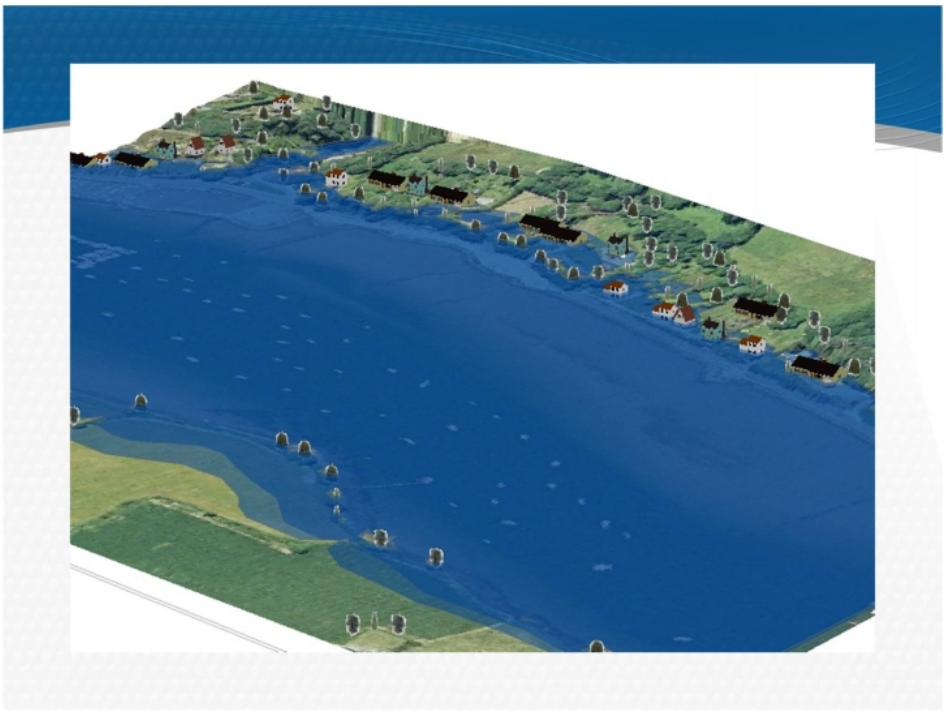
How we visualize the flooding



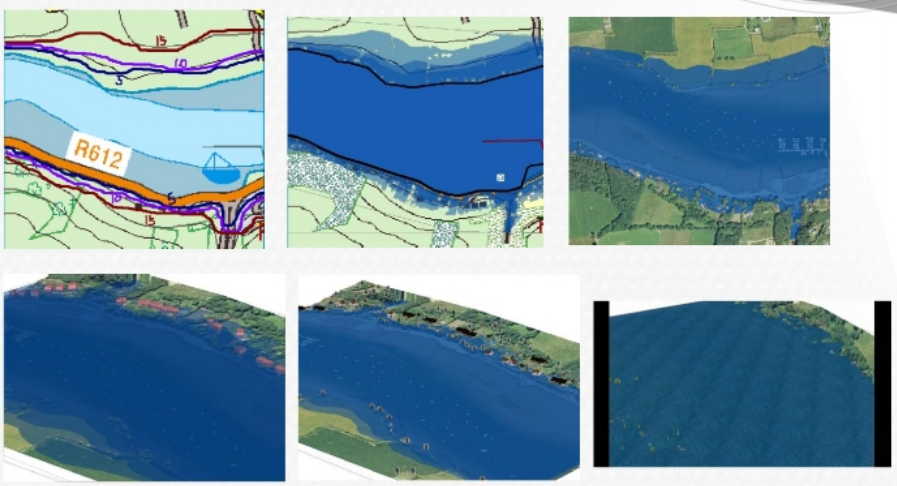








For the same flooding, we can visualize as…



Appendix 5: Workshop Presentation (China)

调查内容

本调查的目的是探讨地理可视化技术在海岸带管理中的应用，以海平面上升造成的洪水淹没为例子，展示一系列针对此命题常见/常用的可视化产品，在此基础上探讨地理可视化产品的“适用性”问题。

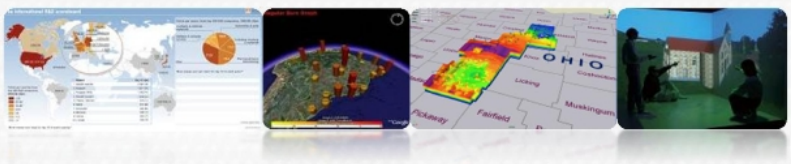
概念说明

地理可视化的概念

“科学计算可视化（ViSC）”概念在1987年由美国国家科学院提出 (*McCormick et al., 1987*).

地理可视化应该包括发现，确认，综合和表达 (*DiBiase, 1990*).

地理可视化的未来是以用户为中心，与用户充分交互(*MacEachren, 1994*).



Case: C.A.L.P Kimberley Visualization Project

-- "We make pictures out of data and local knowledge, including 'future pictures' to help people understand choices and options"

-- "We work with scenarios and provide possible future pathways for coastal stakeholders"

Source: CALP (2009)

关于海平面上升的可视化项目

Flood simulation for lowlands in Northern Jiangsu, China -- Wuhan University, 1999
Inundation risk simulation for lowlands of Northern Adriatic Sea – University of Padova, 2002
Sea Level Change and Spatial Planning in the Baltic Sea Region – University Stuttgart, 2004
Future Sea Level Rise and the New Jersey Coast – Princeton University, 2005
Role of visualization in Participatory Coastal Management – University of East Anglia, 2008
Collaborative for Advanced Landscape Planning – University of British Colombia, 2009
Facing up to Rising Sea-level: Retreat? Defend? Attack? – Institution of Civil Engineers, 2009
等等...

关于地理可视化应用的疑问……

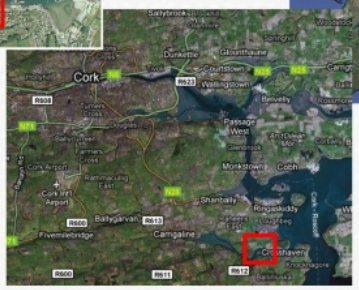
-- "真正意义上成功的地理可视化技术应用例子并不多见"
Slocum et al. (2001)

-- "可视化工具的设计者并没有考虑到用户的特点，所以功能的局限性很突出"
Andrienko (2006)

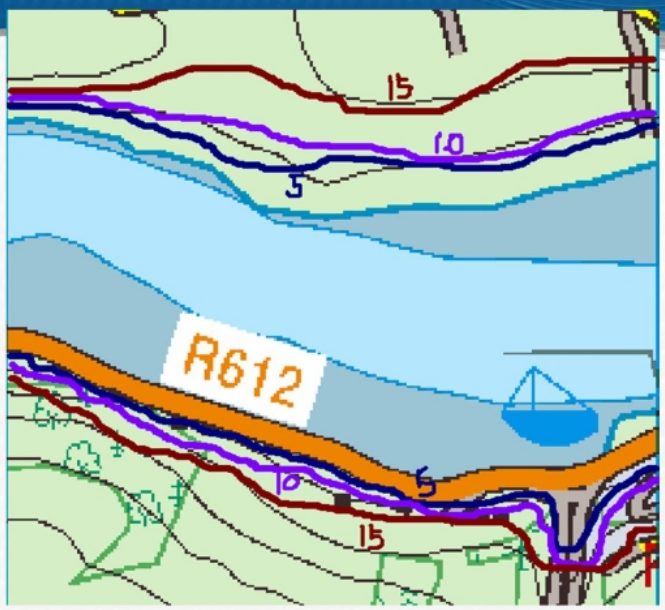
-- "所设计的功能真的有用吗?好用吗?能够真的帮助知识发现和决策支持？"
Fuhrmann et al. (2005)

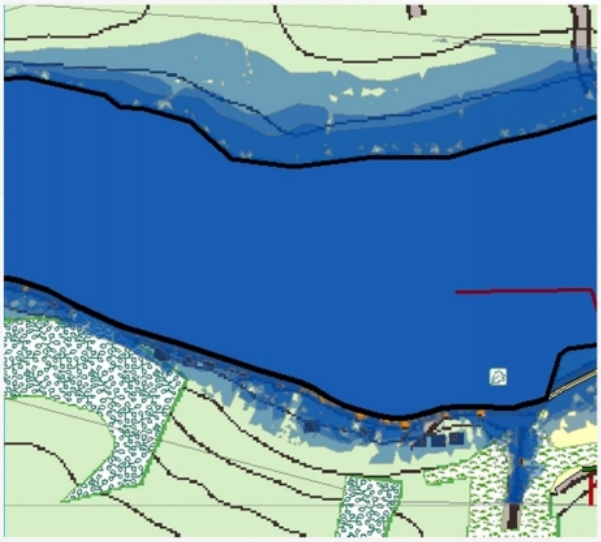
研究区概况

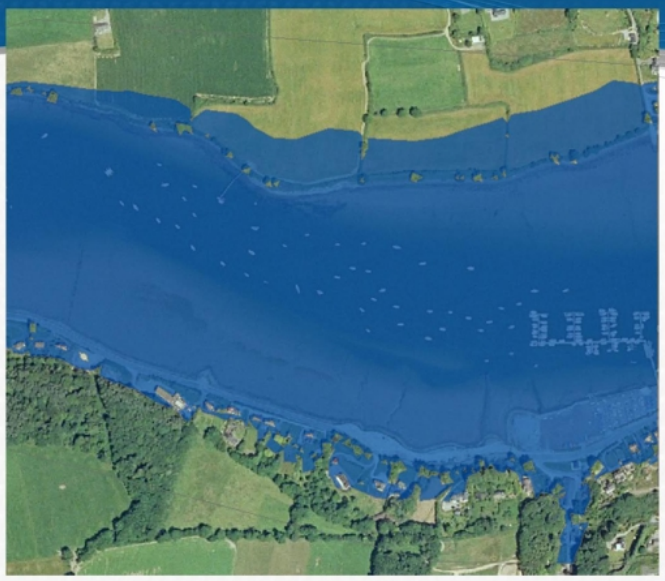
Crossheaven入海口，Cork港
爱尔兰

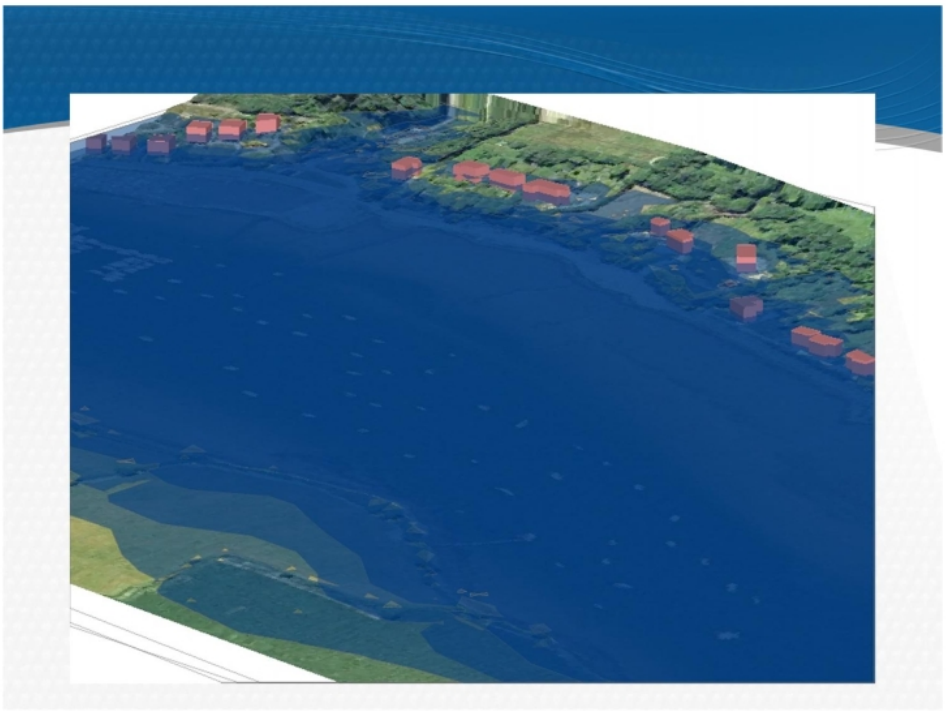


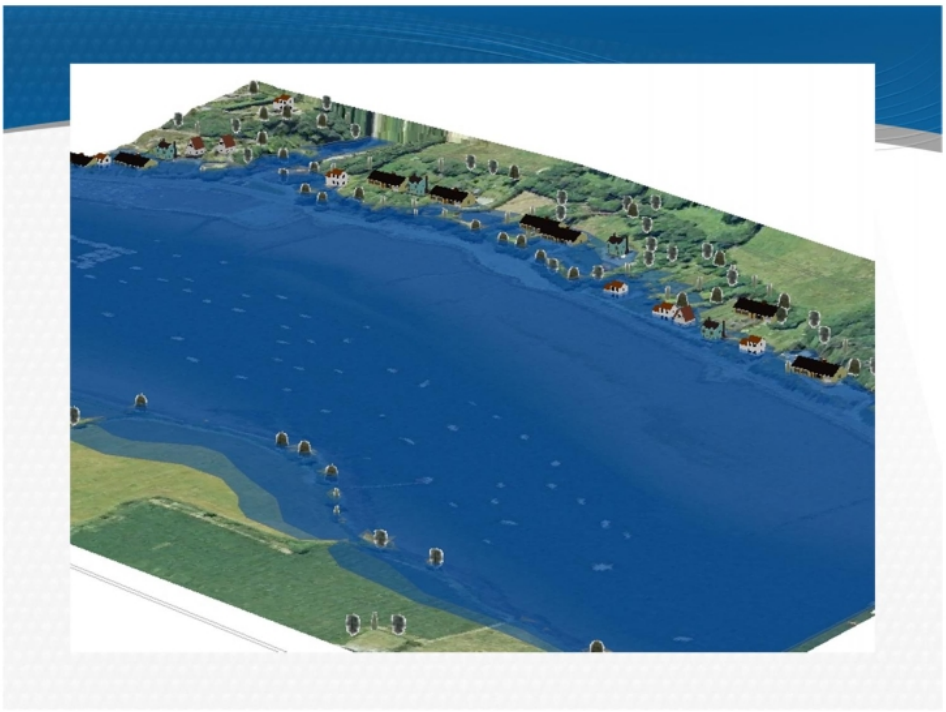
可视化产品



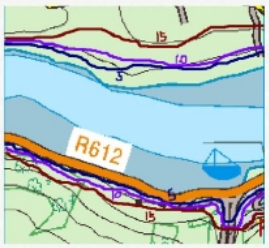


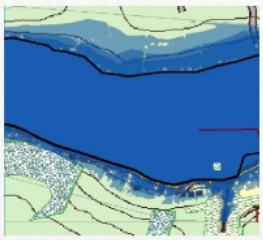


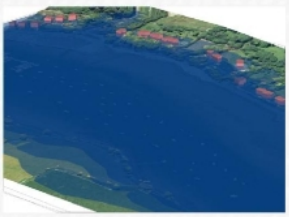


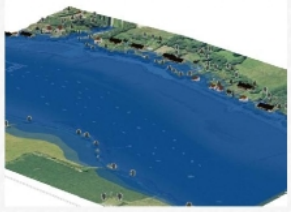


一些列的地理可视化









Appendix 6: Case-based Reasoning System

An active field of research that is closely relevant to the issue of knowledge input from comprehensive knowledge base is that of case-based design, or sometimes called Case-Based Reasoning (CBR). The basic concept of CBR is to solve new problems by adapting previously successful solutions to similar problems (Reisbeck and Schank, 1989[4]). CBR originated from the work by Schank and Abelson (1977)[5], while in early 1980s, the theoretical foundation of CBR was formally established by Schank (1982)[6] with the proposal of the first cognitive model and application of CBR. We will not spend too many words here on the history of CBR, but those interested should refer to Marir and Watson (1994)[7]. As regard to what comprise a *case*, Kolodner (1992)[8] states that it should include:

- the *problem* that gives describes the context where the case occurred,
- the *solution* that is proposed to the problem, and
- the *outcome* or result after the problem is attempted with the solution.

Bergmann *et al.* (2005)[9] states that a case describes one particular diagnostic situation and it records several features and their specific values occurred in that situation.

The core of CBR is a case base that includes a number of cases, which are all independent

[4] Reisbeck, C.K. and R.C. Schank. 1989. *Inside Case-Based Reasoning*. Hillsdale: Lawrence Erlbaum Associates.

[5] Schank, R.C. and R.P. Abelson. 1977. *Scripts, Plans, goals and Understaning*. Hillsdale: Lawrence Erlbaum Associates.

[6] Schank, R.C. 1982. *Dynamic memory: a theory of reminding and learning in computers and people*. Cambridge: Cambridge University Press.

[7] Marir, R. and Watson, I.D., 1994. Case-Based Reasoning: A Categorised Bibliography. *The Knowledge Engineering Review*, 9(4), pp.355-381.

[8] Kolodner, J.L. 1992. An Introduction to Case-Based Reasoning. *Artificial Intelligence Review*, 6, pp.3-34.

[9] Bergmann, R. J. Kolodner and E. Plaza. 2005. Representation in case-based reasoning. *The Knowledge Engineering Review*, 20, pp.209-213.

from each other, and each case describes one particular situation. Surrounding this base, there are four main phases in a CBR workflow – retrieve, reuse, revise and retain, which form up a cyclical process (Aamodt and Plaza, 1994[10]). Illustrated in the following figure, a new problem enters the cycle as a *new case*, which is then used to *retrieve* a case from established collection of previous cases (case base). The *retrieved case* and *new case* together become, through *reuse*, a *solved case*, in other words a proposed solution to the initial problem. The *solved case* is tested via *revise* process of being applied to the real context and becomes either a confirmed solution or a case that has to be further repaired (modified) by experts. The follow-up *retain* process is to retain useful experience during the *reuse*, and the case base is then updated either by a new case added, or a modification of existing cases. In order to ensure an optimum performance of the base, all the phases of work rarely occur without human intervention. Szykman *et al.* (2001)[11] promotes the use of extra tools including debugger, evaluator and justifier to maintain a sustainable operation of the system. Until recently, CBR still remains it very active role in design of all types of systems. The concept and theoretical model of CBR has also been explored and updated by researchers through applications in various domains (Gayer *et al.*, 2007[12]; Knox *et al.*, 2010[13]; Akashah *et al.*, 2011[14]).

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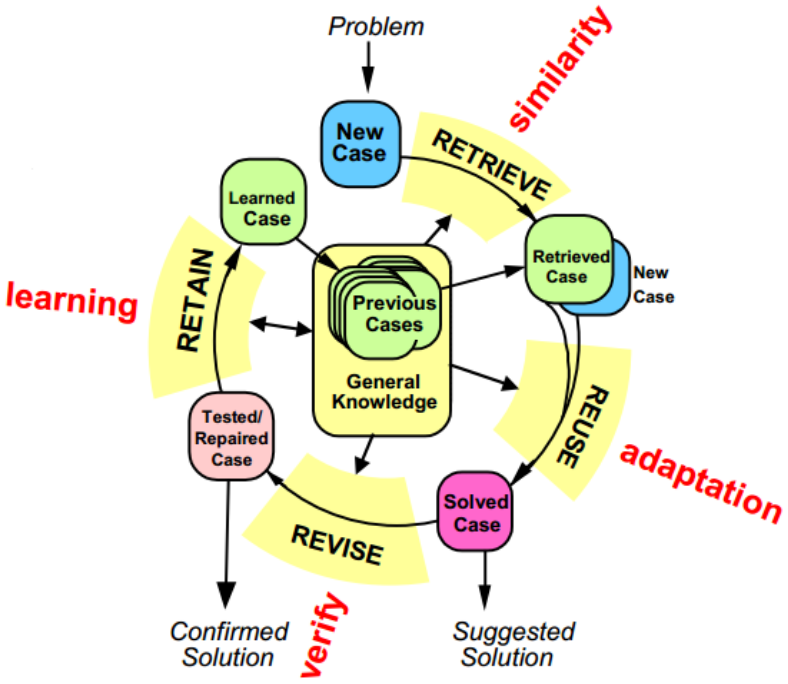
[10] Aamodt, A. and Plaza, E., 1994. Case-Based Reasoning: Foundational Issues, Methodological Variations, and System Approaches. *AI Communications*, 7(1), pp.39-59.

[11] Szykman, S., R.D. Sriram and Regli, W.C., 2001. The Role of Knowledge in Next-generation Product Development Systems. *Journal of Computing and Information Science in Engineering*, Mar(1), pp.3-11.

[12] Gayer, G., I. Gilloa and O. Lieberman. 2007. Rule-Based and Case-Based Reasoning in Housing Prices. *The B.E. Journal of Theoretical Economics*, 7(1), pp.1-35.

[13] Knox, S., L. Coyle and S. Dobson. 2010. Using Ontologies in Case-Based Activity Recognition. In: *23rd Florida Artificial Intelligence Research Society Conference*, 19-21 May 2010, Daytona Bean Shores, Florida, USA.

[14] Akashah, E.P.A., S.R. Rizal and Hafiz, M.A., 2011. Knowledge Sharing Platform Framework using Case Based Reasoning. In: *2011 International Conference on Information and Intelligent*



It is not difficult to imagine that given these concepts associated with CBR, most of the researchers will focus on the automation of the cycle or in other words, from AI perspective, how to make the system automatically synthesize new solutions based on previous ones. The difficulty still remains for machine to look for prominent differences between the new case and retrieved case, and apply rules that take into account those rules when proposing a new solution (Watson and Marir, 2000[15]). Many of the CBR software tools certainly make a contribution at the same time to make the theory feasible. Tools such as CBR-Express, ART*Enterprise, CASUEL, and CasePower represent some of the continuous efforts that mature the technology gradually. The full automation is probably not an easy task to accomplish given the fact that machine recognized only standardized and formatted case contents which raise the question of how to ensure the integrity and accuracy of knowledge when putting into machine-recognizable language? This explains why almost all the systems still host computer-

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Computing, 25-27 November 2011, Hong Kong, China.

[15] Watson, I. and Marir, F., 2000. *Case-Based Reasoning: A Review* [online] Available at: <http://www.ai-cbr.org/classroom/cbr-review.html> [accessed 20/11/2011].

supported design synthesis rather than automated synthesis. Nevertheless, as said by Szykman *et al.* (2000), “the very fundamental need to retrieve and reuse knowledge in subsequent design remains the same.”

Appendix 7: Waterfall or Spiral Development Model?

In software engineering, to include usability testing from the beginning of the product development and through every phase of the project is believed to effectively save redevelopment during the finalization of the product. This is suggesting that the design should be an iterative and cyclical process so that tests can be conducted repeatedly. Gould *et al*. (1991) state the four key points of user centred design:

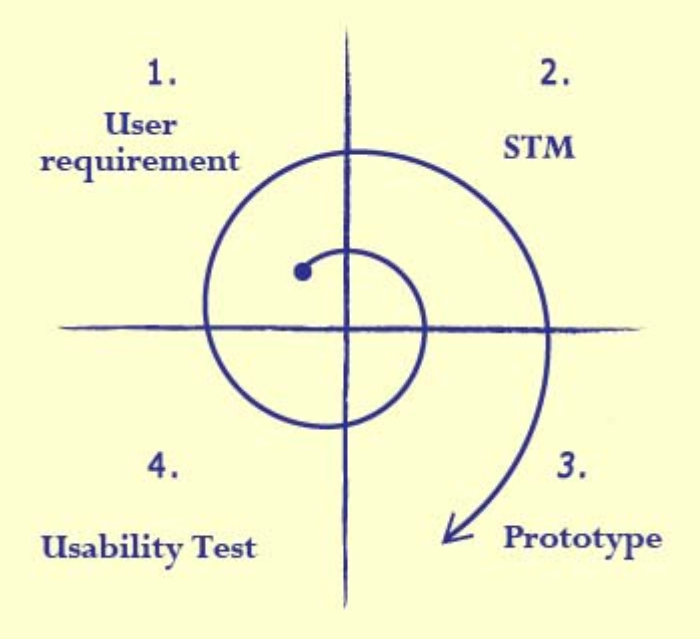
- **Early focus on users**. Product designers should try to understand users' needs as early as possible in the design process.
- **Integrated design**. All aspects of the design should evolve together from the start. Internal design of the product should answer to the needs of users.
- **Early and continual testing**. The rule is simple: the design only works if end-users decide it works. Therefore the only feasible design approach is to incorporate usability testing throughout the process so that users are given chances to deliver feedback on the design before its final release.
- **Iterative design**. Small problems can accumulate and turn to big problems. Designers and developers need to revise the design iteratively through rounds of testing.

There has been a debate for many years between standard waterfall design process and spiral design process. In the earlier method, a project evolves through unilinear and sequential phases, while in the later one, the process is iterative and cyclical (Boehm, 1984). The waterfall method heavily relies on analysis before synthesis, while the spiral method relies on synthesis before analysis, and both of them have advantages over the other for different types of developments. In the waterfall methodology, a very complete product specification will be

generated before a prototype built. The follow-up testing is thus usually limited to verifying product delivers against the original specification. This methodology is easier to be deployed considering project schedule (time) and budget. Spiral methodology encourages the immediate production of prototype after a minimum amount of specification. The prototype initially built contains many details that are intended to be defined and developed during the prototype testing afterwards. The prototype then goes through strict testing and a new prototype is built based on the testing. Such process iterates until the product is believed to be technically sound enough (Boehm, 1988;1996).

Apparently waterfall method is easier to be deployed and managed, and has a considerably lower cost, thus it is usually preferred and used for general design. But when designing some products such as human-computer interfaces, products are hardly to be successful at one stroke, when the spiral method delivers a better performance. The spiral method allows more creativity by designers and developers, and it also makes them easier to make changes to the design as the project evolves. Because all aspects of the project proceed in parallel, changes could be made in different phases for different functional areas of the product, in other words, user feedback can be reflected straight away by the new prototype built after testing. However the challenge is to know how “sound” will be “enough” and as a result how iterations are needed. Therefore it can be too costly to be used for an expensive product design. It is suggested that the waterfall method can be effective for a complex development situation where multiple vendors are responsible for different aspects of the project. If one vendor does the software requirement analysis, another vendor does specification, and another one does testing, and so on, using a waterfall model would be a more clear and efficient way to organize

these activities. Therefore deciding which method to use is important at the start of a product design, and as a matter of fact, a lot of projects use a hybrid approach to allow testing iteration for limited number of specifications of the product that is generally built following a waterfall model (Filho, 2006).



If the project time and budget allow, spiral model can be fully adapted to represent UFGV where the development starts from user requirement collection, goes through STM, prototype, usability test and enters an iterative cycle. However as mentioned earlier, the use of spiral methodology can be limited due to the high demand of time and budget. When proposing UFGV approach above, this research used a waterfall approach shown in the above figure as the basis because a lot of the product specification is proposed through STM and all the information come from collecting and analysing user requirement. These works, incorporated with expert knowledge, will be used to instruct the actual development. Some specifications will then be defined and improved via a usability test with users. In order to make the process seamless and communicative, STM working scripts work as a tool to help users, experts and developers track

the development progress. Also suggested by UFGV is the sufficient communication between users and developers with the help of GV experts. These works all aim to provide well-defined specification for building a prototype that is as close as possible to user expectation and reduce iteration possibly needed afterwards.

Appendix 8: Hand-out for HDip GIS Tutorial

Work on 3D GIS in ArcGIS – A Geovisualisation Practice

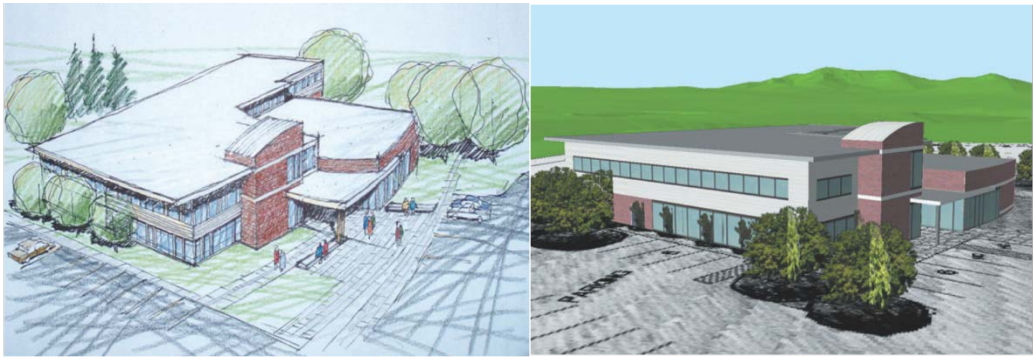
The very first output from a GIS came from a line printer attached to a large mainframe computer. Using individual letters (e.g., "W" for water) or over-striking letters, line printer gray scale maps began to show the patterns and results of the first GIS analyses. In these pioneering years, 3D presentations were not viable due to the limitations of computer performance. Fast-forward 30 years and we have the ability to create dynamic 3D GIS presentations on laptop computers.

While it may be too early to herald the end of the plotter in favor of a virtual display, it is very clear that use of 3D GIS to illustrate and analyze our GIS data is growing. Also likely to succumb to the power of the virtual, 3D GIS dis- plays are the static architectural renderings used to present proposed developments. The following figure illustrates the power of 3D GIS in the visualisation of a proposed new office building.

For years, we in the GIS community have assumed that everyone viewing our work understood the 2D display of information. In reality, we all knew better and as those that have started using 3D to present their analyses can attest, a virtual environment is very convincing in public meetings. The world around us is three-dimensional and it seems natural that presentations of GIS data should move in this direction. How many times have we looked at a zoning map forgetting that zoning also has a height component? Transitioning to 3D GIS need not be an arduous task. Quite the opposite is true.

---Contents adapted from Smith and Friedman (2004)[16]. Modification applied.

[16] Smith, G and J. Friedman. 2004. 3D GIS: A Technology Whose Time Has Come. Earth Observation Magazine. www.eomonline.com

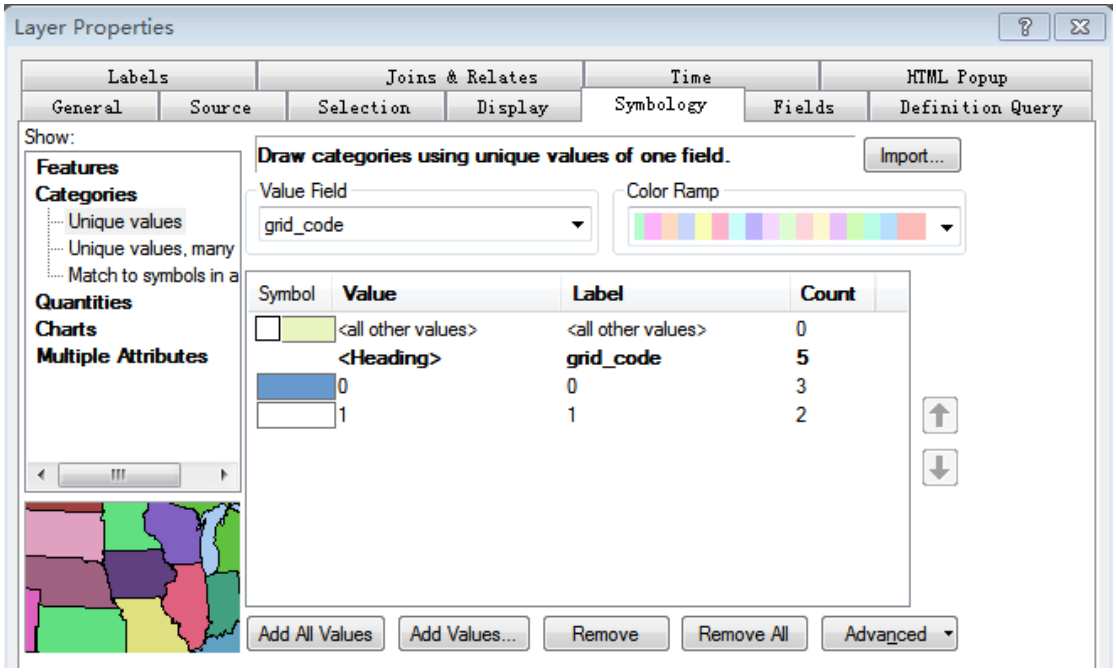


This tutorial is to make you acquainted with some basics of mapping in 3D environment in ArcGIS. Compared with those professional 3D rendering tools, ArcGIS is probably not the best choice to create eye-catching 3D visualisations, but it is hoped that by going through this tutorial, you can get a sense of working with 3D. This tutorial will let you use ArcGIS, ArcScene and Google SketchUp to create a small and simple 3D flooding scenario with given dataset. At the last section of this tutorial, you will also be asked to critically view the use of different 3D GIS mapping.

Section 1. Work in 2D

1. Go to folder C:\\GIS_diploma\geovis. Open the map document *flood_2D*. This map document contains three layers *whitegate_dtm*, *whitegate_dsm* and *whitegate_img*.
2. Turn on *whitegate_dtm* and view the data. Then turn it off and turn on *whitegate_dsm* and view the data. (**What is the difference between the two?)**
3. Turn on *whitegate_dtm* again and click the color ramp. In the pop-up window, select a different **Color Ramp** and click **OK**. (**Does this help you identify the features in the dataset?)** Do the same to *whitegate_dsm*.
4. Click **Add** button, find *flood_layer.gdb*, select *level_0* and **Add**. A new layer will be added into current scene. This layer is to show the standard water level, so it will be more sensible to make the water in blue color.
5. Double click *level_0* → **Layer Properties** → **Symbology** → **Categories** → **Unique values**. Choose grid_code as **Value Field** and **Add All Values**. Double click the color box separately and change **Fill Color** to *Atlantic Blue* for grid_code 0 and

No Color for grid_code 1. Click **OK**.



6. Access **Layer Properties** → **Display** and change **Transparent** value to 30%. Click **Apply** and **OK**.

TASK: Add another two layers *level_2* and *level_4* from *flood_layer.gdb* and symbolize them following the same procedures. Switch between these three layers to see the change of water level and flooded areas. You might get a scene similar to the following one.

7. **Save** the map document. Don't close ArcMap.

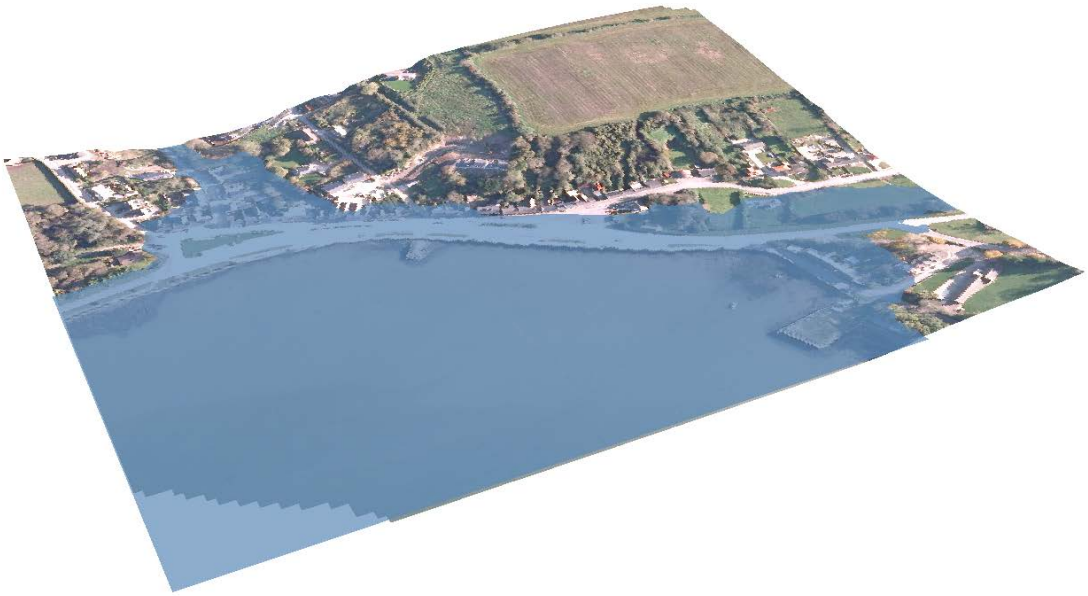
You must have noticed that what we did was still 2D. Yes it was a warm-up to help you recap what we have learned previously in tutorials. Now we will not be able to work out any 3D in ArcMap. Instead we need to use an embedded environment called ArcScene.

Section 2. From 2D to 3D

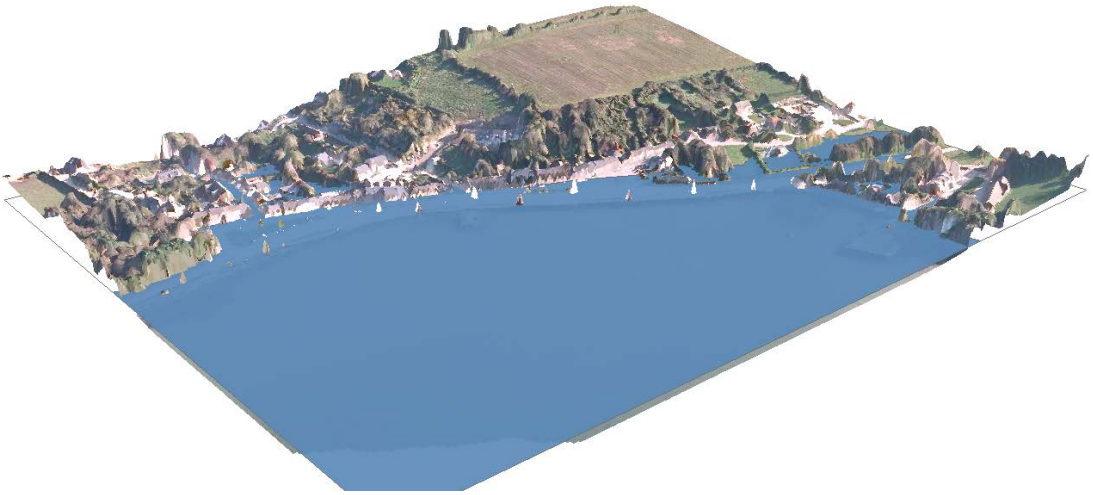
1. Open ArcScene. Open *flood_2D_plus* from geovis folder. This document contains two layers *whitegate_dtm* and *whitegate_img*.
2. To view 3D terrain surface, we need to assign the image dataset with elevation from DTM dataset. To do this, right click *whitegate_img* → **Properties** → **Base Heights** → **Elevation from surfaces**. Tick **Floating on a custom surface** and

select *whitegate_dtm*. Click **OK** and turn off *whitegate_dtm* layer. You should find the image 'stand up' right away.

3. Zoom in to see the details of the features. (**Can you see the cars on the roads?)** Right click *whitegate_img* → **Properties** → **Rendering** and drag the box of **Quality enhancement for raster images** to **High** on the right. **Apply** and **OK**. (**How about now?)**
4. Click **Add** button, find and add *level_4* from *flood_layer.gdb*. Follow 1.5~1.6 to symbolize the water surface again.
5. A static water surface will have one constant water level, thus instead of applying DTM elevation values again, right click level_4 → **Properties** → **Base Heights** and type in 4 as **Layer Offset**. This means to lift the layer up to 4m high.



6. Turn off *level_4* for now. Add *whitegate_dsm* into current scene. Follow 2.2 to set up base heights of *whitegate_img* but using DSM this time.
7. Bring *level_4* back again. You should get a scene similar to the following one.

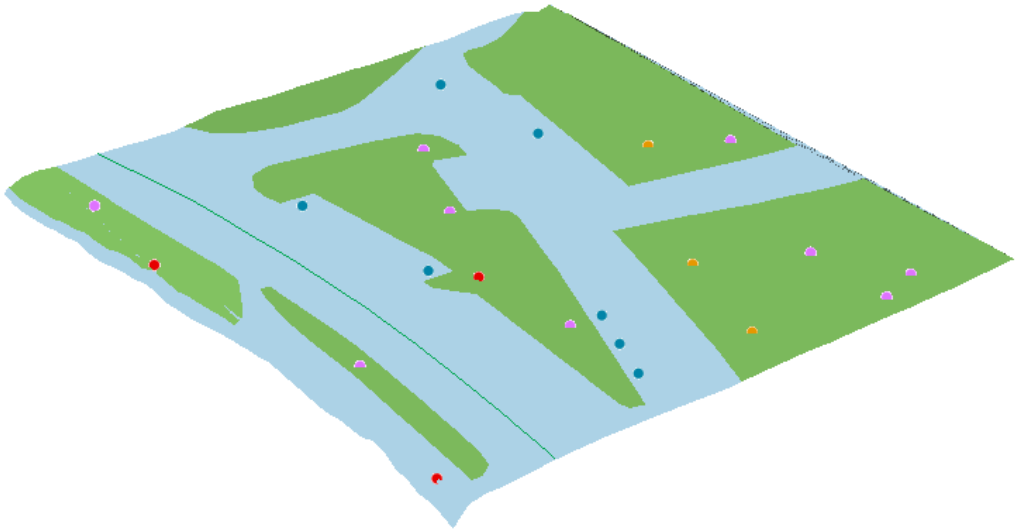


8. **Save** document when you finish.

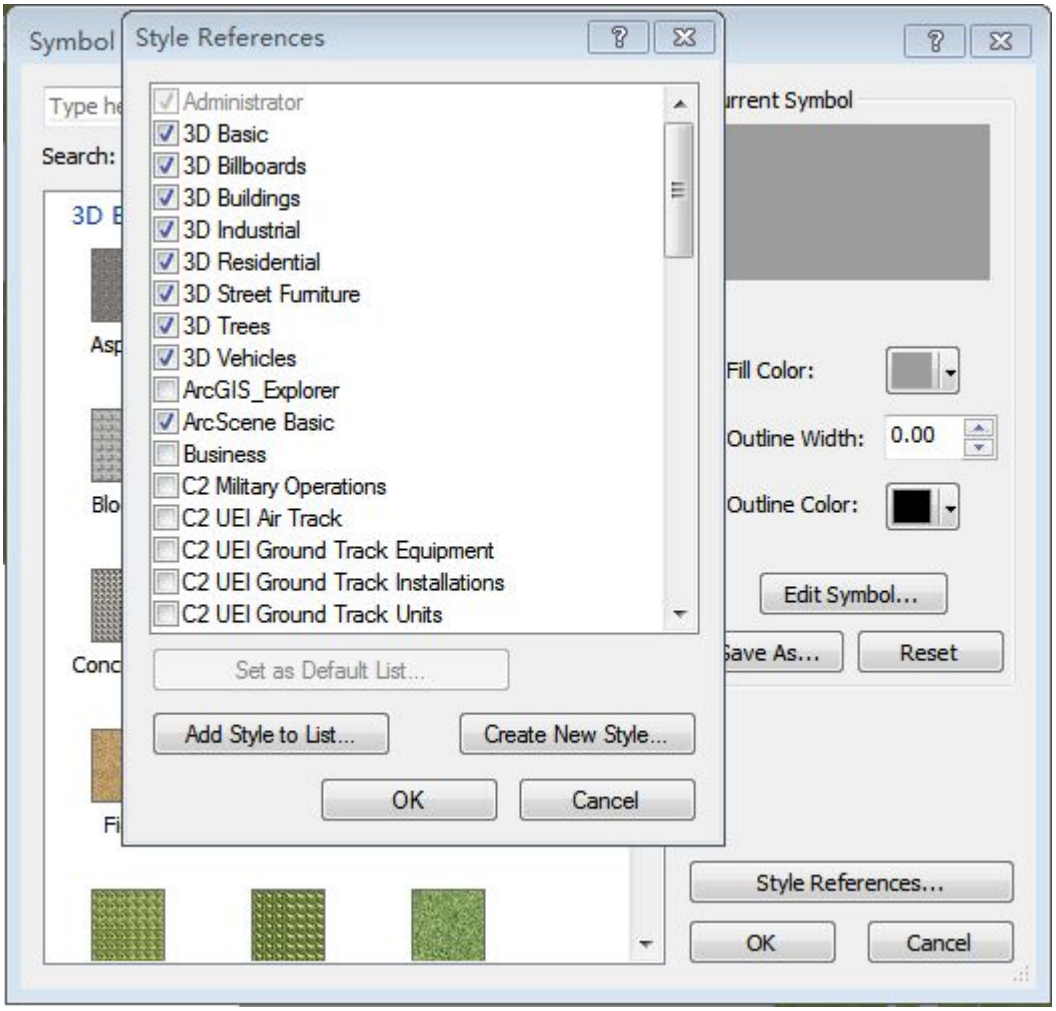
The above was just to create a 3D scene with DTM and DSM models. There was no editing at all to the data. Now it is time to try something slightly complicated and create our own 3D flood scene.

Section 3. Working in 3D

1. Open a new ArcScene window (keep the previous one open) and open flood_3D. This document contains two layers *wg_small_dtm* and *wg_small_img*, which are part of the orginial dataset. Also contained here are a few data layers with features to be symbolized further in 3D.
2. Turn off *wg_small_dtm* and *wg_small_img* and turn on other layers. Follow 2.2 and set up base heights for all those layers using DTM elevation. You should get a scene similar to the following one.

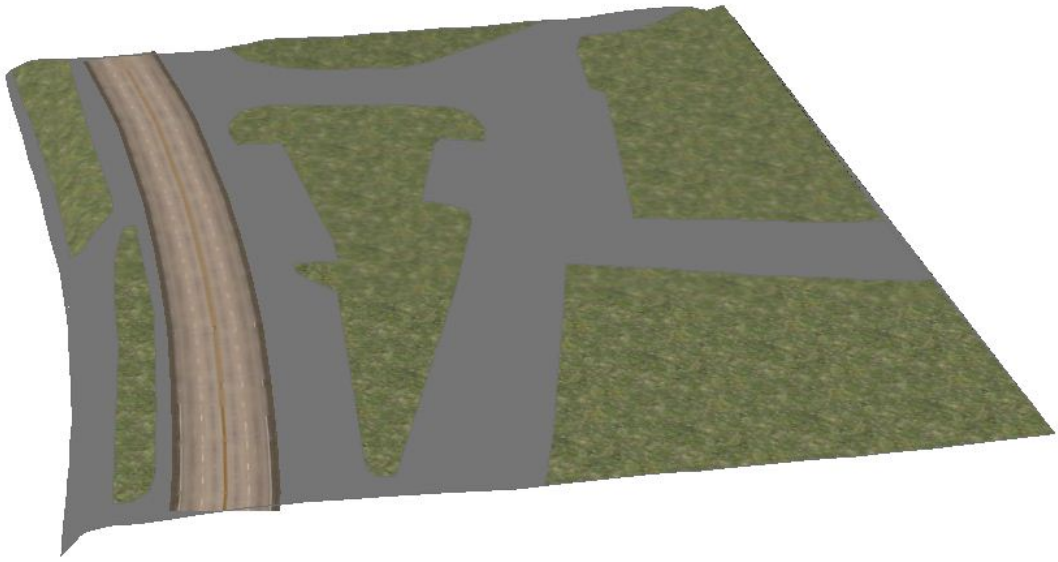


3. The layer *groundsurface* will stay rather simple as background, so we will use simple color to fill in the polygon. Right click *groundsurface* → **Properties** → **Symbology**, and click symbol to access **Symbol Selector**. Select **Gray 50%** as **Fill Color** and click **OK**.
4. Right click *road* → **Layer Properties** → **Symbology**, and type in 'road' for search. ArcGIS has a good collection of textures that can be used, but they don't display as default. Click **Style References** and tick all the boxes that start with '3D'. Seen from their names, all the symbols have been categorized already. Click **OK**. Choose **Three-Lane Freeway** and change the width to **8**. **OK** and **OK** again.



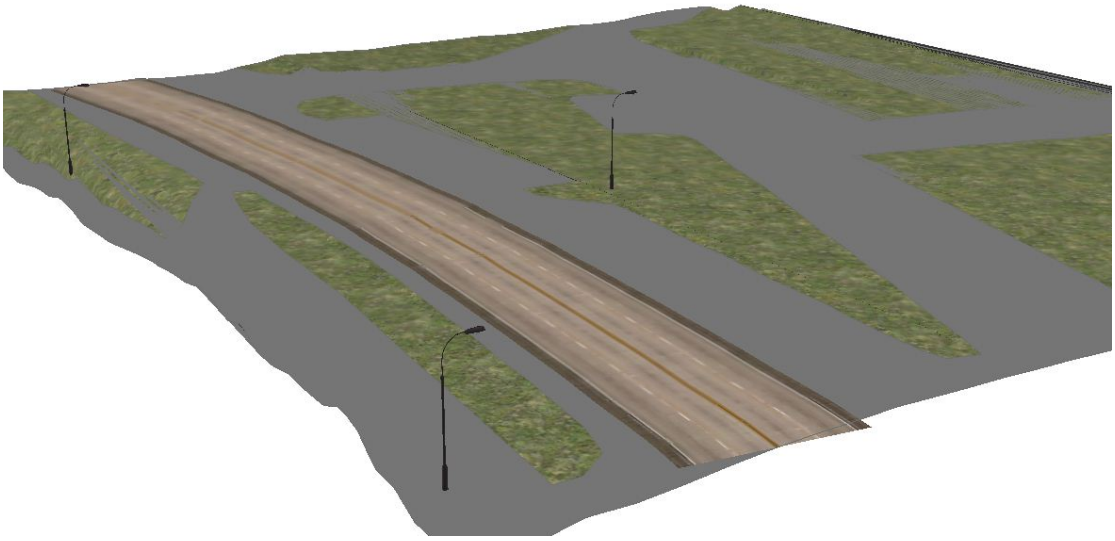
We can also use images from other sources as textures to symbolize features. You can even use a photograph of yourself to fill in a polygon. However, there are many websites that provide high quality textures particularly for computer graphic design. We can take one of such websites as an example. The textures used later in this practical come from a website www.cgtextures.com *which is a good example of such websites. You are highly encouraged to visit the website even after this practical.*

5. Open layer properties of *greenspace*, access **Symbol Selector**, and click **Edit Symbol**. In **Properties**, choose **3D Texture Fill Symbol** as **Type**, click **Texture** button, find **Grass0110_9_S.jpeg** from geovis folder and **Open**. It might take a few seconds for ArcScene to apply the texture. **OK** and **OK** again. Up to now you should have a scene with gray ground, green space and the road.



All the roads, ground and green space we have done so far are not really using 3D models, so now let's symbolize the street lights with pre-existing 3D model from ArcGIS collection.

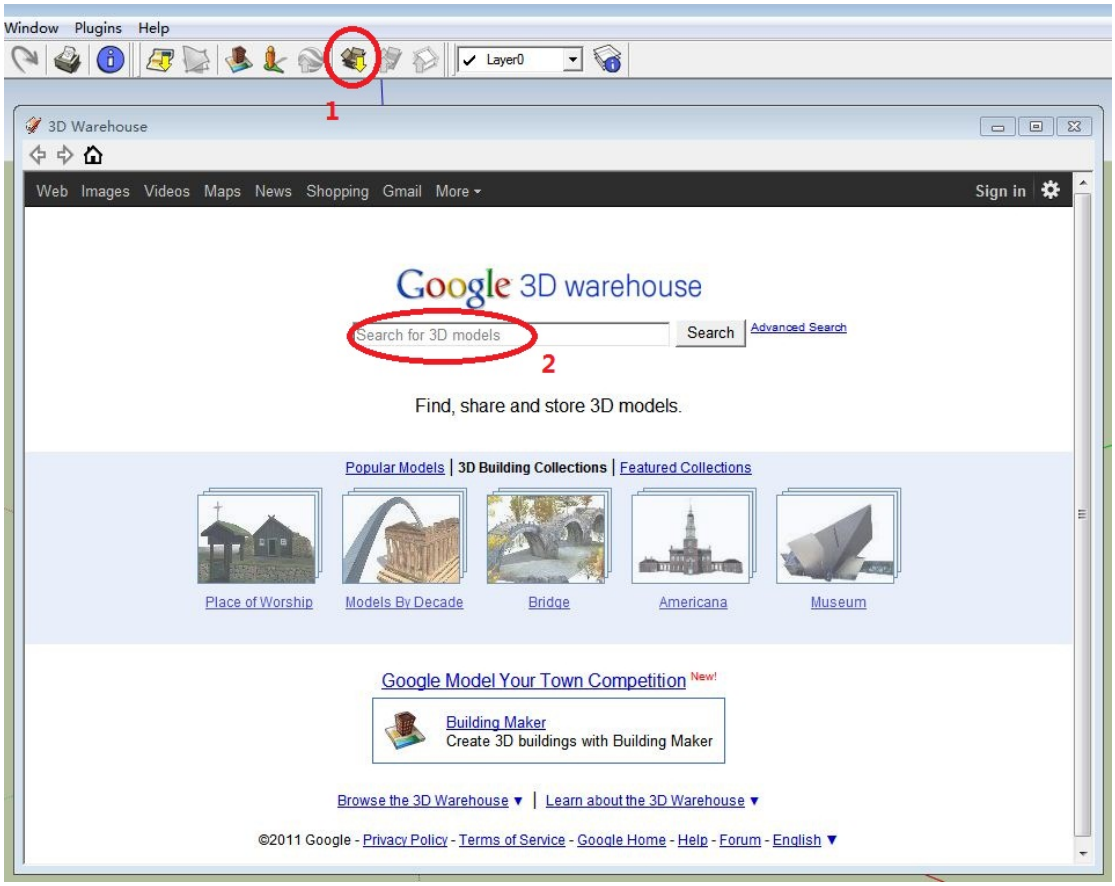
6. Right click *roadlamp* → **Properties** → **Symbology** → **Symbol Selector**. Type in 'street light' in the box and look through all the return symbols. Pick **Street Light 13**, click **OK**, and **OK** again. 3D street lights appear at their locations.



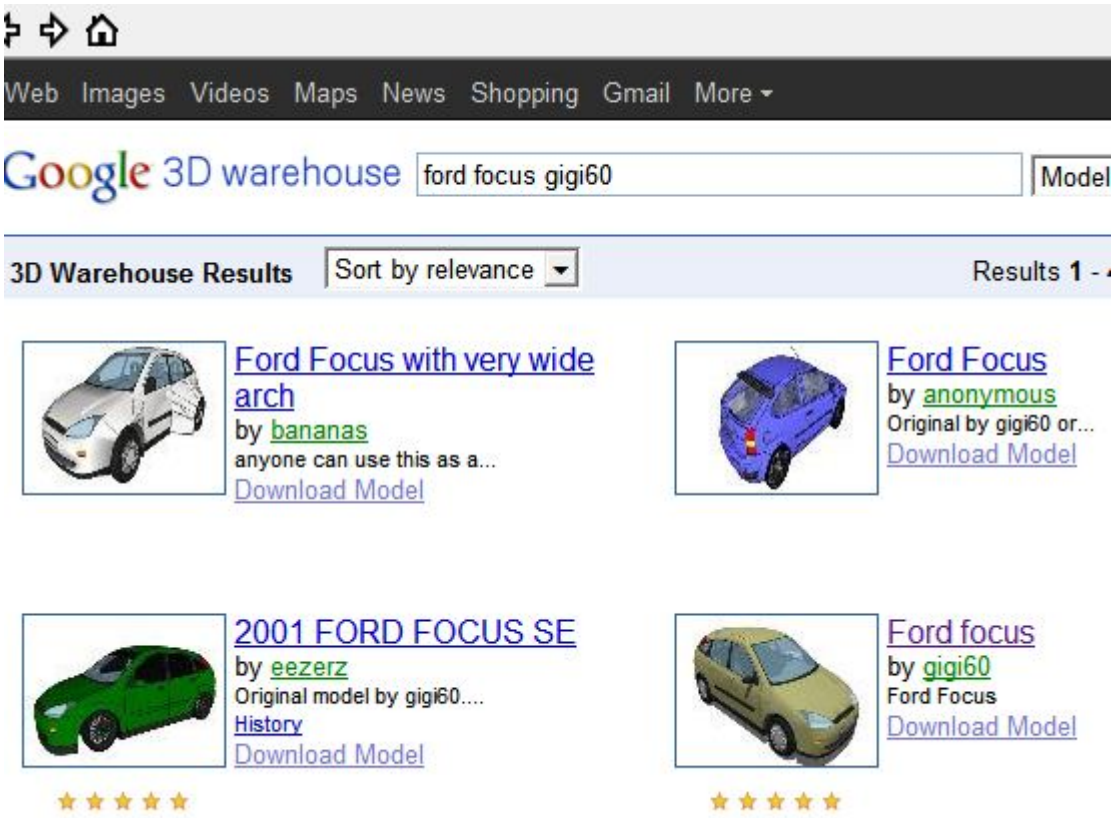
Is it possible to use models from other sources? You probably know that millions of

people are now using Google SketchUp to create their own 3D objects. SketchUp Warehouse thus contains an enormous collection of 3D models which are free to access and use. Now we are going to use 3D models from Google SketchUp to visualise cars and buildings.

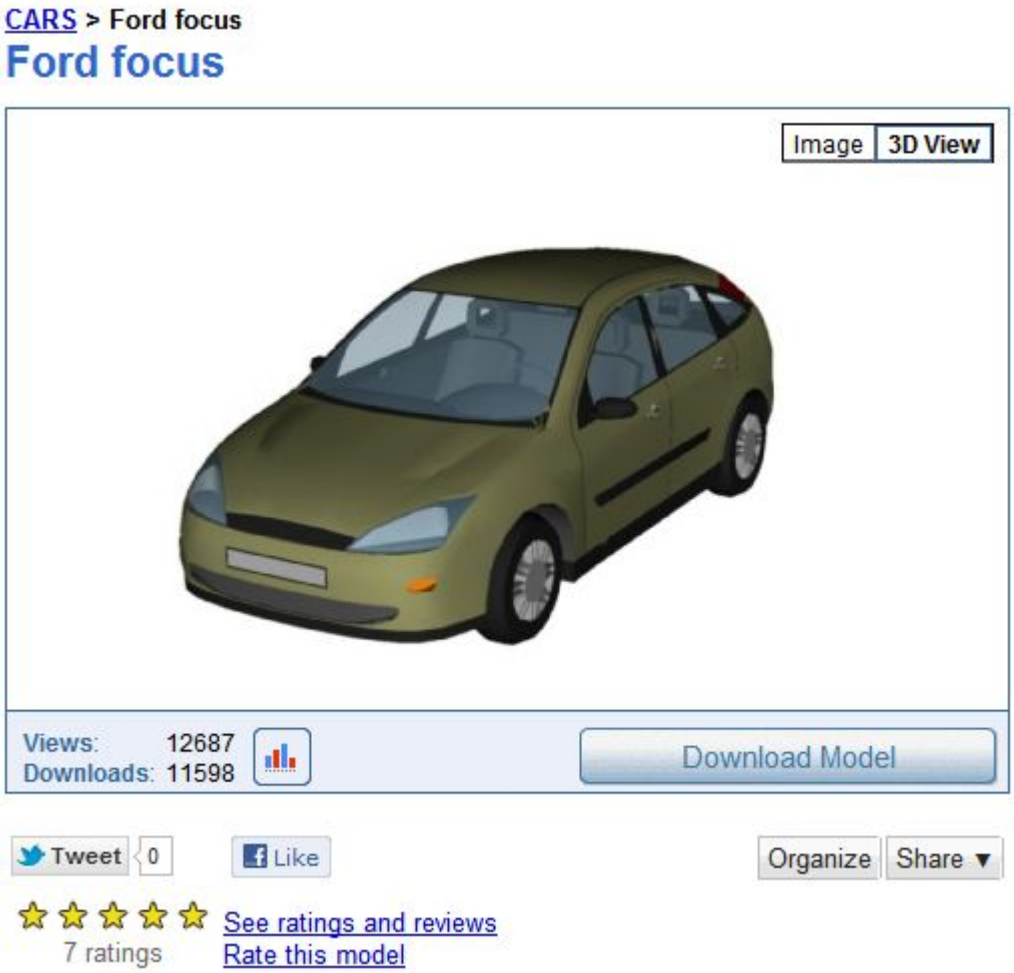
7. Start Google SketchUp, click **Get Models** button to access 3D Warehouse.



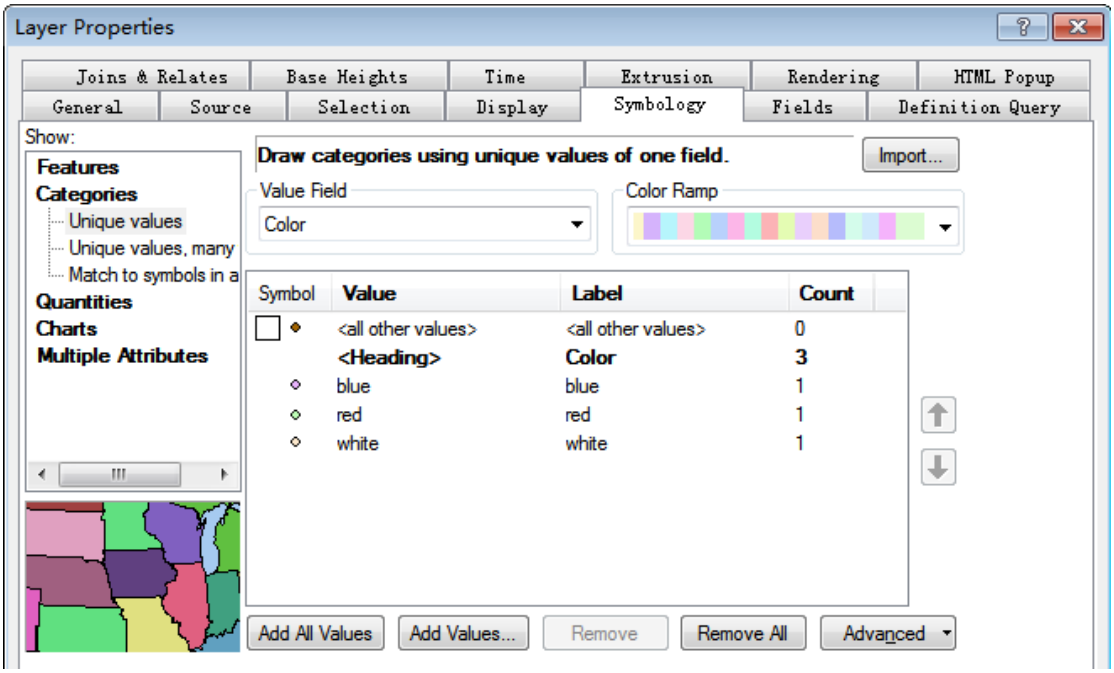
8. Type in 'ford focus gigi60' and see the return results. This is a Ford Focus car model uploaded by a user called gigi60. This care looks not bad so let's use it. You can also change the searching conditions to get wider range of selections.



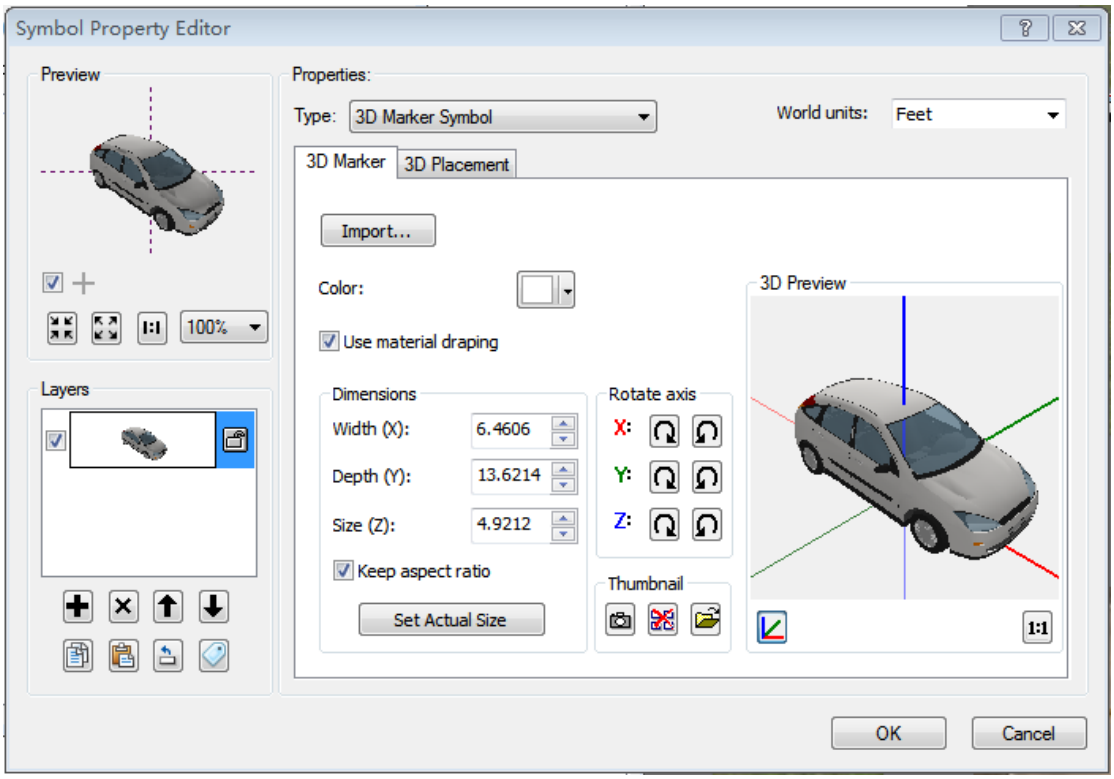
9. Click the title to see the details of this model. You can click **3D View** to see how the model will look like in a 3D environment.



10. Click **Download Model** and **Yes** for the pop-up message. It might take a few seconds depending on the complexity of model details. The downloaded model is following the mouse cursor at the moment, so click anywhere in SketchUp to drop the model.
11. **File** → **Export** → **3D Model**, save the model into the texture folder you created before. You need to choose **COLLADA** file (*.dae) as the correct format. We can differentiate cars based on their colors so name it *car_white*. Save it to *skpmodels* folder in geovis folder.
12. Follow 3.7~3.11, find a red car and a blue car, export and save them as COLLADA files to *skpmodels* folder. If you can't find any appropriate cars, you can use the two models *car_blue* and *car_red* saved in the folder.
13. Right click *vehicle* → **Properties** → **Symbology**. Choose **Categories** → **Unique values**, use 'Type' as **Value Field**, then click **Add All Values** button.



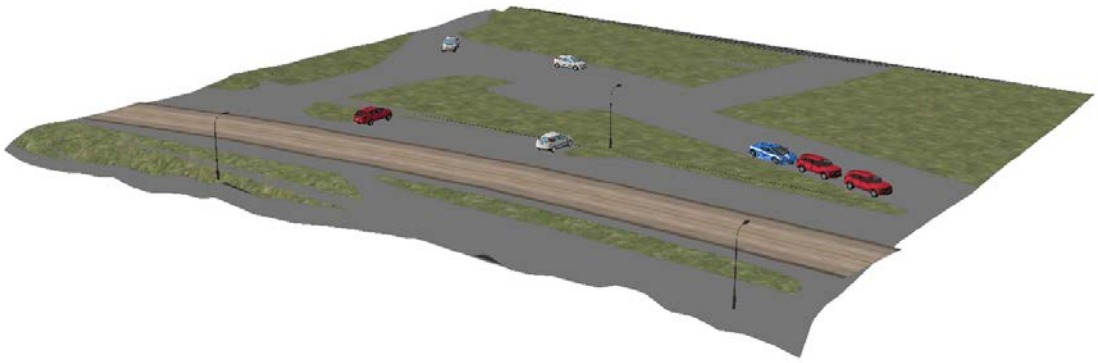
14. Double click the point before white and enter **Symbol Selector**, click **Edit Symbol**, and choose **3D Marker Symbol**. In the pop-up window, go to *skpmodels* folder, find *car_white* and **Open**. It might take a few seconds to load the model depending on the complexity of model details.



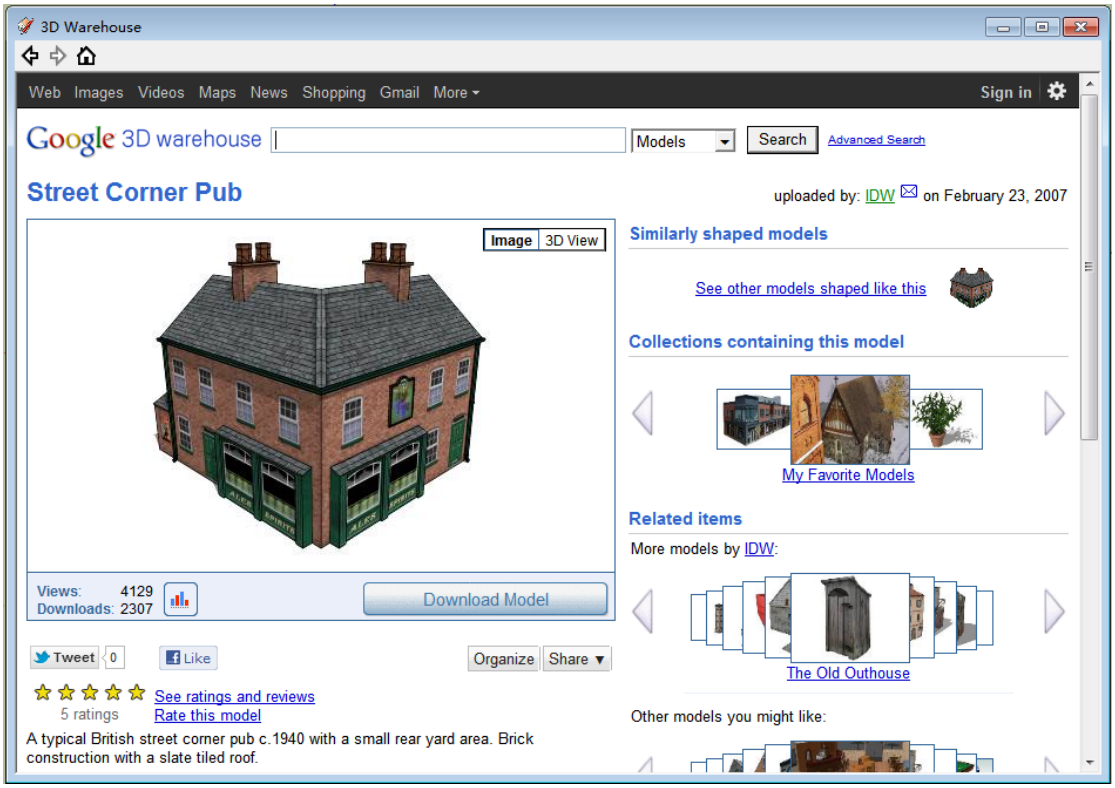
15. **OK** and **OK** again to go back to **Symbol Selector**.
16. Following the same procedures, you can symbolize the other two cars using the

models you have downloaded.

17. Click **Apply** and **OK**. You will see all the cars appearing in the scene. You will need to change the *Size* and *Angle* in order to display them correctly. **You might want to make sure the cars are all in a sensible size compared with other features (e.g. street lamps) in the scene.**



18. Open 3D warehouse, type in 'street corner pub' and click the search button. Select the first return result – Street Corner Pub uploaded by user IDW.

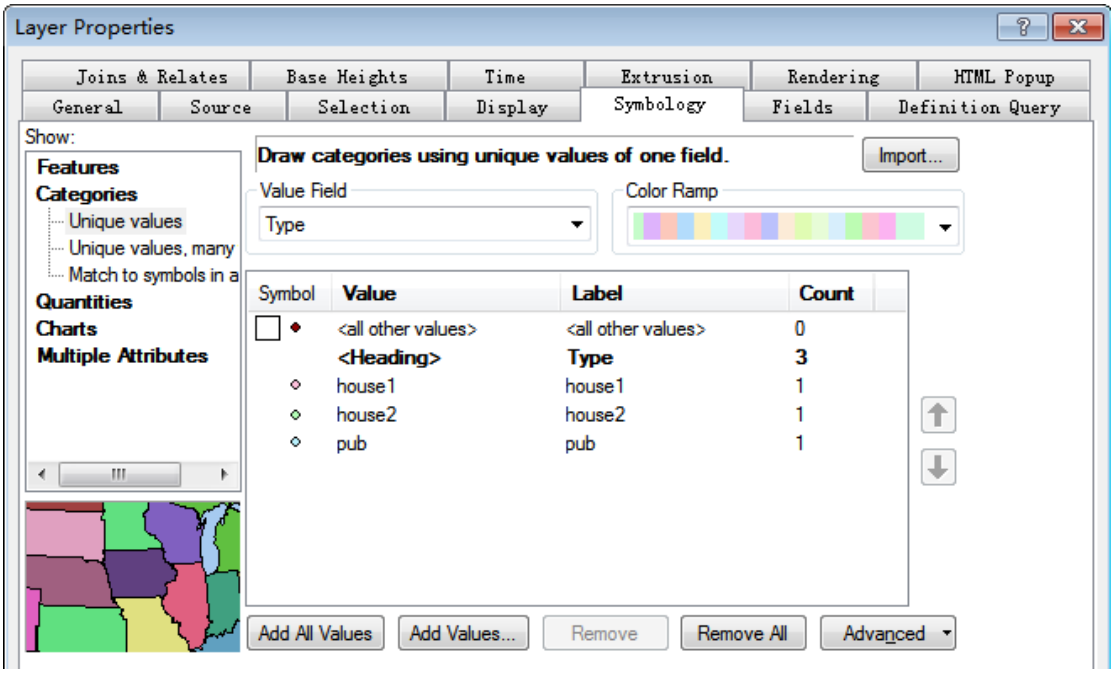


19. **Download Model** and add into SketchUp. View the model.

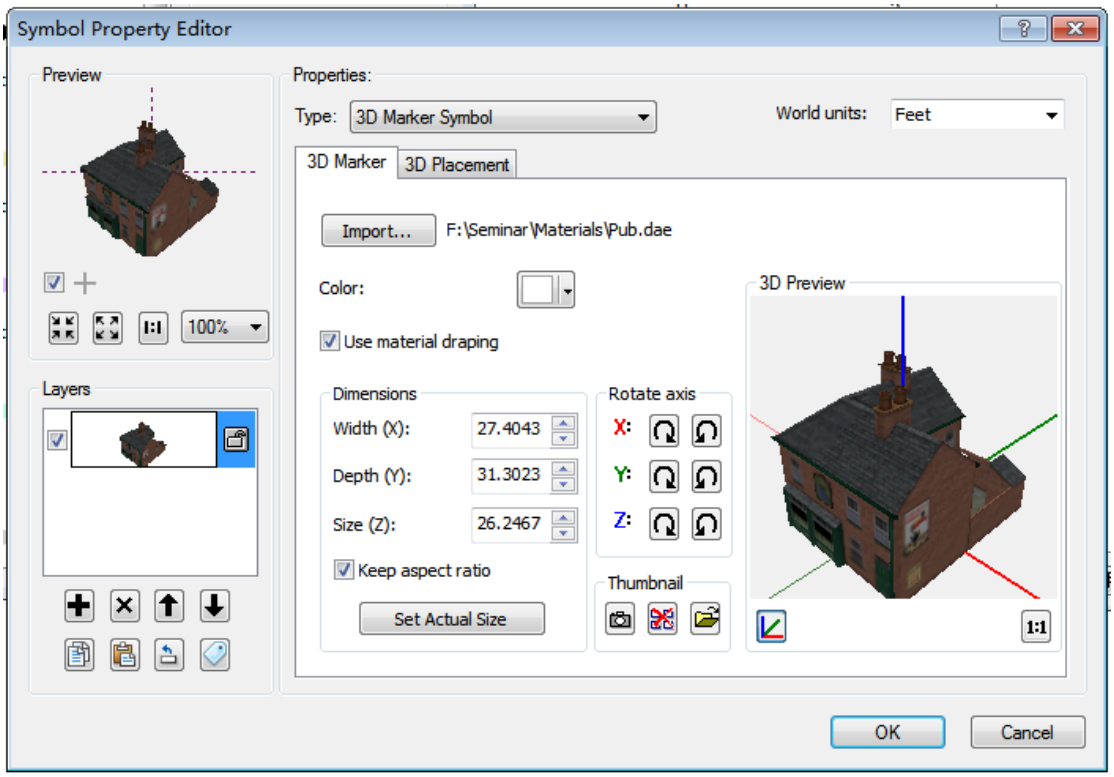
20. **File** → **Export** → **3D Model**, save the model as COLLADA file to skpmodels

folder with the name *pub*.

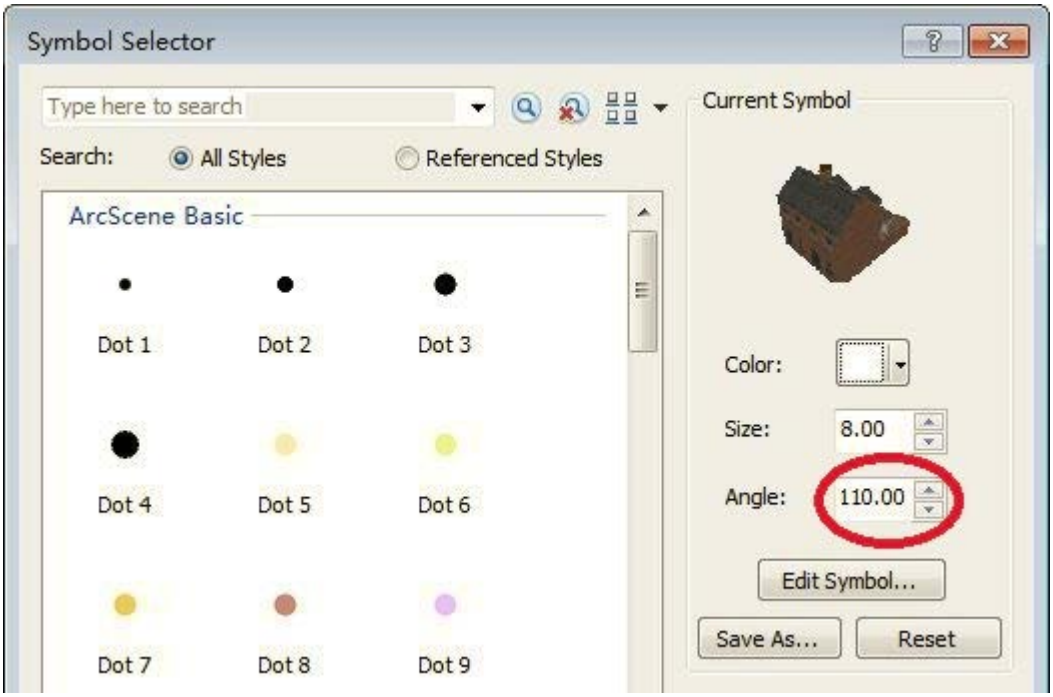
21. Right click *building* → **Properties** → **Symbology**. Choose **Categories** → **Unique values**, use 'Type' as **Value Field**, then click **Add All Values** button.



22. Double click the point before pub and enter **Symbol Selector**, click **Edit Symbol**, choose **3D Marker Symbol**. In the pop-up window, find *pub.dae* from skpmodels folder and **Open**.



23. Click **OK** and **OK** again. Symbolize the other two buildings using another model downloaded from 3D warehouse. It's up to you to choose a house from the whole collection. However if you can't find any appropriate one, you can use *house.dae* saved in the folder.
24. You will need to change **Angle** for the models separately in order to make the building facing the right direction.



25. Find a tree and symbolize following the same steps. If you can't find any appropriate one, you can use the model saved in the folder. It's also up to you if you feel interested to add a few more features.
26. Finally you should get a scene similar to the following one

27. Add the water level layer *level_4* into current scene.
28. Right click *level_4* → **Base Heights** and change **Layer offset** to 4.
29. Find texture **WaterPlain0012_2_S.bmp** from *geovis* folder and use it to symbolize water.

30. **Save** the document.

So far we have successfully create a simple flood scenario in ArcScene. It is not the best 3D flood scenario that could be created, but it contains those essential elements of a flood event, and it manages to display the likely inundation happened in this small place.

Now open area.xxx from geovis folder, explore the whole scene. You will find that

this 3D map contains a lot more elements than what we have done. You might have noticed that due to the existence of these elements (i.e. 3D models), the rendering load for ArcScene has been increased. When you are viewing the scene, try to answer the following questions:

How many different types of vehicles are there in the scene?

Among all the buildings, can you find one with a Guinness poster?

What is the height of the road lamp, can you measure it?

At SLR 2, can you tell the height of coastal embankment?

At SLR 3, how many houses will be flooded?

At SLR 4, how many cars will be flooded?

Section 4. Comparing different visualisations

Do you like the flooding scenario you have just created? To create a same flood scenario, there are actually many different ways. The following pictures present some other ways to tell the same story. Compare these different visualisations and think about critically:

Are they communicating the same information differently?

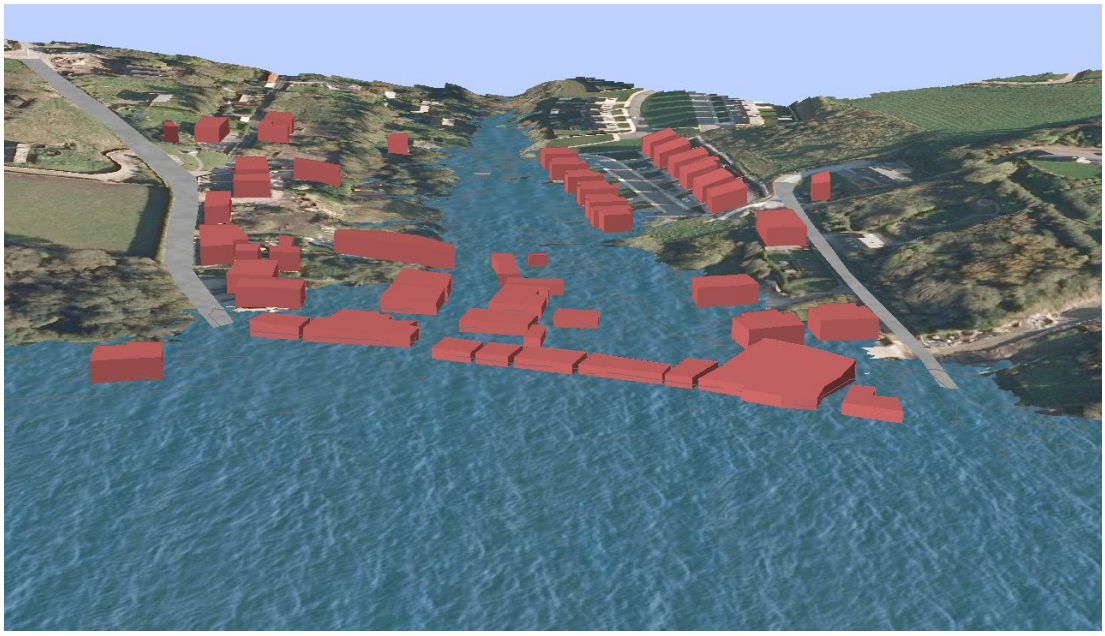
Do you prefer any specific type of mapping? Why?

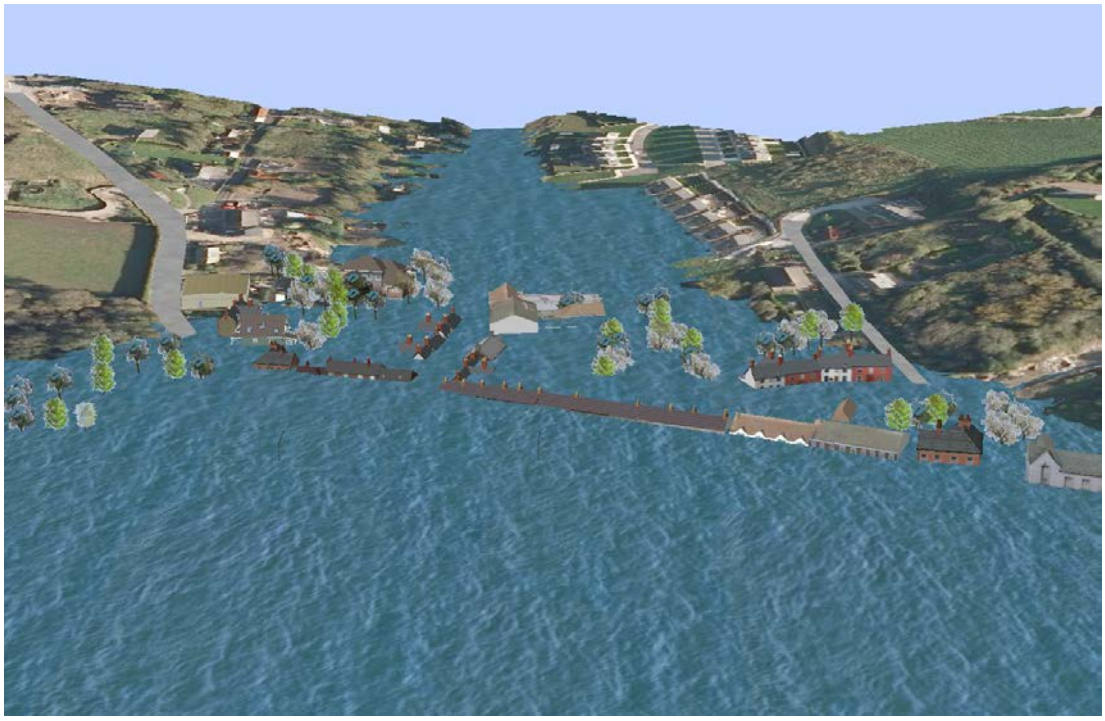
What are the adding values provided by them moving from 2D to 3D?

Which of them do you think would be most effective for communicating:

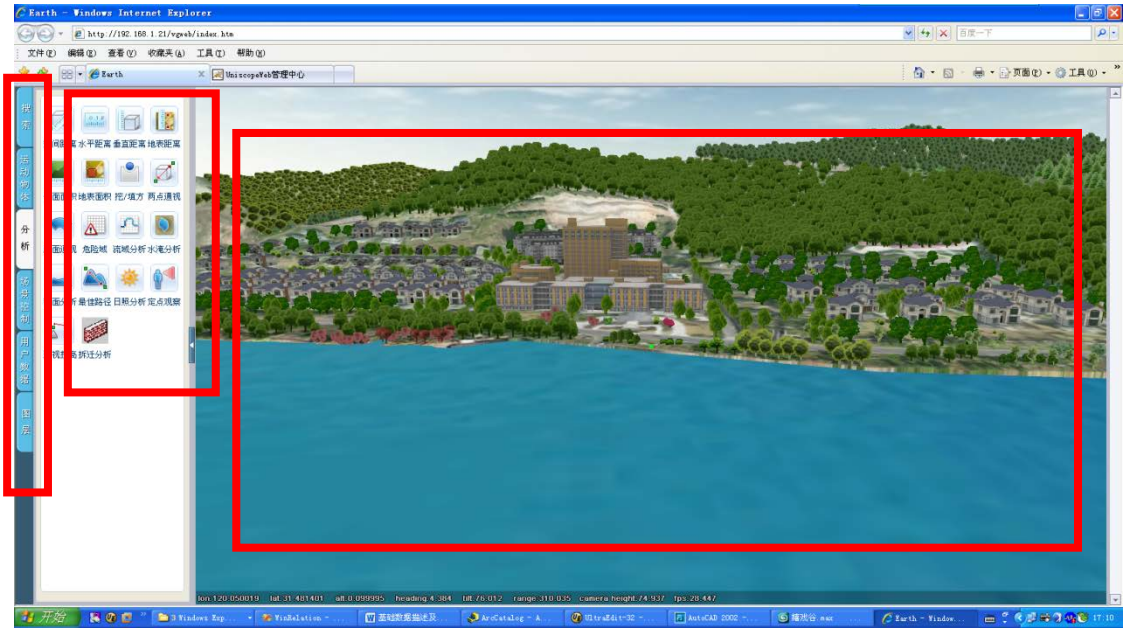
i. **scientific or technical information about flood-risk, causes and consequences to decision-makers**
ii. **scientific or technical information about flood-risk, causes and consequences to potentially affected stakeholders**
iii. **citizen/stakeholder concerns about flood-risk, causes and consequences to decision-makers**
iv. **citizen/stakeholder concerns about flood-risk, causes and consequences to scientists and technical experts**

Whitegate
An Geata Bá
Barrack St





系统操作主要说明如下：



本系统的界面从左至右分为三个主要区域：标签区，功能区和显示区。

标签区的主要功能包括

可以寻找 POI 的空间和属性信息，分析功能，帮助

可以进行场景动态游走，可以选择步行和车行两种方式

用于设置场景的相关参数

用于切换各图层，设置图层显示优先级

功能区提供了一些常用的空间分析工具，具体如下:

空间距离 用于测量三维空间中两点的直线距离。鼠标左键单击选择起始点，移

动到终点后单击。

水平距离用于测量平面两点直线距离，方法同上

垂直距离用于测量空间中垂直的高度，方法同上

地表距离用于测量地表上两点距离，考虑地表的起伏变化，方法同上

平面面积用于计算场景中某平面面积。鼠标左键单击开始，依次单击目标点行程几何面片，双击左键自动封闭平面

两点通视用于判断空间中两点是否可使，考虑地形和地物遮挡因素。鼠标单击第一点，再次单击第二点，系统生成连接线，绿色表示通视，红色表示不通视。

请在操作系统的过程寻找一下几个问题的答案：

（如果在操作过程中遇到问题，请呼叫我们寻求指导）

1. 在整个场景中一共有多少建筑物？

   _____

2. 远端的住宅楼 A 栋中一共有多少楼层？

   _____

3. 国际会议中心的高度是多少？

_____

4. 在水位多高的时候，场景前方的主干道会被淹没？

_____

5. 在水位多高的时候，会议中心的附楼会受到水淹影响？

_____

6. 从别墅 6B 前往会议中心门前广场的距离是多少？

_____

谢谢您的合作！

在实际使用过程中如果遇到问题，请随时联系常州市测绘院。