The use of 3D geovisualisations for urban design: The case of informal settlement upgrading in South Africa

by

Victoria-Justine Rautenbach

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Philosophiae Doctor (Geoinformatics)

in the Faculty of Natural & Agricultural Sciences

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Die gebruik van 3D geovisualiserings vir stadsbeplanning: Die geval van opgradering van informele woongebiede in Suid-Afrika

deur

Victoria-Justine Rautenbach

Ingedien ter gedeeltelike vervulling van die vereistes vir die graad

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Universiteit van Pretoria

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I, Victoria-Justine Rautenbach declare that the thesis, which I hereby submit for the degree PhD Geoinformatics at the University of Pretoria, is my own work and has not previously been submitted by me for a degree at this or any other tertiary institution.

SIGNATURE: ……………………………………………

DATE: ………15/02/2017……………………………………

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Abstract

Title:	The use of 3D geovisualisations for urban design: The case of informal settlement upgrading in South Africa
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Informal settlements are a common occurrence in South African due to housing backlogs and shortage of housing subsidies, and are often located on disputed land. To improve in-situ circumstances of these communities, informal settlement upgrades and urban design is required. Spatial data and maps are essential throughout the entire upgrading and urban design process in order to understand the current environment, plan new developments and communicate planned developments. All stakeholders need to understand maps to ensure active participation in the urban design process. Previous research demonstrated that a large number of planning professionals in South Africa have a relatively low level of map literacy, which is considered to be inadequate for effective planning. Many researchers proclaimed that because 3D visualisations resemble the real environment more than traditional maps, and are more intuitive, therefore 3D geovisualisations are easier to interpret. The goal of this research is to investigate the use of 3D geovisualisations (specifically 3D city models) for urban design in informal settlement upgrading in South Africa. To achieve this goal, the following topics were investigated: modelling processes (manual and procedural); visual design (visual characteristics, visual complexity and visual variables); and cognition related to spatial tasks on 3D geovisualisations and comparable alternatives (i.e. topographic maps, aerial photographs, 2D maps) when performing basic map reading tasks. Procedural modelling was found to be a feasible alternative to time-consuming manual modelling and has the capabilities to produce high-quality models. When investigating the visual design, the visualisation characteristics of 3D models of informal settlements, and relevance of a subset of visual variables for urban design activities of informal settlement upgrades were assessed. The results were used to produce various maps and 3D geovisualisations that were presented in quantitative user studies and expert interviews. The results of four user studies and expert interviews contributed to understanding the impact of various levels of complexity in 3D city models and map literacy of future geoinformatics and planning professionals when using aerial photographs, 2D maps and 3D models. The research results could assist planners in designing suitable 3D models for use throughout the entire urban design process.

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Abstrak

Titel:	Die gebruik van 3D geovisualiserings vir stadsbeplanning: Die geval van opgradering van informele woongebiede in Suid-Afrika
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As gevolg van agterstande met behuising en ’n tekort aan behuisingsubsidies, is informele woongebiede ’n algemene verskynsel in Suid-Afrika en is dit dikwels op betwiste grond geleë. Om hierdie in-situ omstandighede van die gemeenskappe te verbeter, is daar opgradering en stedelike beplanning nodig. Ruimtelike data en kaarte is deurlopend noodsaaklik vir die volledige opgradering en stadsbeplanningproses om sodoende die huidige omgewing te verstaan, nuwe ontwikkelings te beplan en die beplande ontwikkelings te kommunikeer. Dit is noodsaaklik dat alle rolspelers kaarte verstaan om aktiewe deelname aan die stedelike beplanningsproses te verseker. Vorige navorsing het getoon dat ’n groot aantal professionele beplanners in Suid-Afrika ’n relatiewe lae vlak van kaartgeletterdheid het, wat beskou word as onvoldoende om doeltreffende beplanning te kan doen. Baie navorsers maak daarop aanspraak dat 3D geovisualiserings nader aan die werklike omgewing is en dat dit meer intuïtief en makliker as tradisionele kaarte vertolk kan word. Die doel van hierdie navorsing is om die gebruik van 3D geovisualiserings (meer spesifiek 3D stadsmodelle) te ondersoek om die ontwikkeling van stadsbeplanning in informele woongebiede in Suid-Afrika op te gradeer. Om hierdie doelwit te bereik, is die volgende onderwerpe nagevors: modelleringsprosesse (volgens handleidings en prosesse); visuele ontwerp (visuele eienskappe, visuele kompleksiteit en visuele veranderlikes); en die herkenning van verwante ruimtelike take op 3D geovisualiserings en vergelykbare alternatiewe (byvoorbeeld topografiese kaarte, lugfoto’s, 2D kaarte) wanneer basiese kaartlees take uitgevoer word. Prosedurele modellering is ’n haalbare alternatief teenoor tydrowende modellering volgens handleidings en dit het die moontlikhede om hoë kwaliteit modelle te lewer. By die ondersoek van visuele ontwerp is die visuele karaktereienskappe van 3D modelle van informele woongebiede en die relevantheid van ’n onderafdeling van visuele veranderlikes beoordeel/geassesseer vir ontwerpaktiwiteite by informele nedersettings. Die resultate is gebruik om verskillende kaarte en 3D geovisualiserings te skep wat in kwantitatiewe gebruikerstudies en in onderhoude met kenners aangebied is. Die resultate van vier gebruikerstudies en onderhoude met kenners, het bygedra om die impak te verstaan van verskillende moeilikheidsvlakke van 3D stadsmodelle en kaartgeletterdheid van toekomstige geoinformatika- en professionele beplanners

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wanneer lugfoto's, 2D kaarte en 3D modelle gebruik word. Die navorsingsresultate kan beplanners ondersteun om geskikte 3D modelle te ontwerp wat deurlopend in die stedelike beplanningsproses gebruik kan word.

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It takes a village to raise… a PhD. There are numerous people that have contributed to this thesis either directly or indirectly and I would like to use this opportunity to thank my village.

Firstly, I would like to thank my supervisor, Prof Serena Coetzee, without whom this research would not have been possible. I could not have asked for a better and more dedicated supervisor. I am eternally grateful for all the guidance and support you provided me, not only with my PhD research but also at work and in life. Thank you, for inspiring me to work harder and to never give up. It has been quite a journey and a great privilege to work with you.

Thank you to my co-supervisor, Dr Arzu Çöltekin. I started this PhD not knowing anything about empirical experiment design and now, after various publications on the topics, I can with confidence say I know the basics. Thank you for teaching and guiding me in this process. Without your knowledge and insight, I would not have been able complete this thesis. I appreciate all your insightful comments and encouragement throughout this process.

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Table of Contents

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List of Figures

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List of Tables

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Chapter 1. Introduction

1.1. Overview

A picture is worth ten thousand words – Chinese proverb

The general consensus is that a well-designed data visualisation can communicate data more effectively than text (Vessey, 1991; Speier, 2006; Yau, 2013). This has been proven in various fields, such as public engagement (Strekalova and Krieger, 2015), education (Vazquez and Chiang, 2014), and cartography (Smelcer and Carmel, 1997; Slocum *et al.*, 2009). Despite the general agreement on the effectiveness of visualisations in comparison to text, the visualisation community is still striving to understand what contributes to the efficiency and usability of a data visualisation (Borkin *et al.*, 2013). For example, the inclusion of human recognisable objects and colour can improve the memorability of a data visualisation (Borkin *et al.*, 2013; Yau, 2013). It appears unique visualisation types, such as pictorial or tree diagrams, usually have a greater impact (i.e. be more effective at communicating a specific message) than traditional methods, such as bar or pie charts (Borkin *et al.*, 2013). That being said, a data visualisation should be as intuitive as possible, because the aim is to increase the understandability of the underlying data, and the visualisation should not necessarily be treated as a creative outlet (Binx, 2016). These principles apply equally to maps and other geographic visualisations (also known as geovisualisations), as geovisualisations are designed with a specific audience and purpose in mind, and thus they are tools that must function for a goal.

Over the last decade, mapping technology has rapidly evolved and users can now display information on various platforms, such as web maps or virtual globes, and also combine the data with non-geographic visualisations, such as scatterplots or bar charts. These platforms and tools provide users with many possibilities to develop more complex and more realistic geovisualisations than ever before. Overall, geovisualisations allow users to interact with the data and extract information more easily than working with, for example, numbers, text or tables only. Furthermore, new geovisualisation technologies overcome some of the limitations of traditional printed maps, such as the static nature of the medium complications of updating information, lack of real-time feedback, and the difficulty in understanding static two-dimensional map elements (e.g. the level of abstraction or scale). However, new challenges may be introduced with interactive geovisualisations due to complexity and computer illiteracy, for example.

A popular geovisualisation is the three-dimensional (3D) city model: a realistic digital representation of spatial objects, structures and other phenomena within urban areas. The inclusion of 3D city models in mainstream applications, such as Google Earth[1] and Apple Maps[2] have contributed to their popularity and widespread use by the general public. City models are increasingly being produced by

[1] http://www.google.com/earth/
[2] http://www.apple.com/ios/maps/

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developed countries to be leveraged in various applications, such as urban design, environmental management and tourism (Engel and Döllner, 2012; Biljecki *et al.*, 2015). Biljecki *et al.* (2015) reviewed over a hundred applications of 3D city models in 29 use cases. They found that currently 3D city models are primarily used for visualisation of data, followed by analysis, such as estimation of solar irradiation or classification of building types (Biljecki *et al.*, 2015). On the other hand, the effectiveness of these 3D city models is still debated (Häberling, 2002; Döllner, Kolbe, *et al.*, 2006; Schobesberger and Patterson, 2008; Ross *et al.*, 2009; Bleisch *et al.*, 2010; Chen, 2011; Bleisch, 2012; Fisher-Gewirtzman, 2012; Xu and Coors, 2012; Thompson and Charlton, 2013; Dickmann and Dunker, 2014; Biljecki *et al.*, 2015; Rautenbach, Coetzee, *et al.*, 2015).

Urban planning or urban design is currently one of the main application fields that employs 3D city models (Gaborit and Howard, 2004; Kim and Bejleri, 2005; Donaldson-Selby *et al.*, 2007; Isikdag and Zlatanova, 2010; Biljecki *et al.*, 2015). Figure 1 illustrates the difference between urban planning (which focuses on a larger area, such as a city), and urban design (which is concentrated on a specific smaller area, such as a suburb). Urban design is the process of shaping the physical environment of cities, towns or villages, while considering human behaviour, aesthetics and functionality (Lynch, 1960; Kim and Bejleri, 2005). This process relies on constant communication and the exchange of information between the various stakeholders (e.g. decision makers, community members, and the wider public). Thus, urban design is often more of a negotiation between the designer and various stakeholders than a top-down design process where an expert makes all the decisions.

Figure 1. The figure illustrates the difference between urban planning and urban design. Source: Kathryn Arnold

The urban design process is essential for the redevelopment and upgrading of informal settlements in South Africa (South Africa Housing Development Agency, 2011). Informal settlements are unavoidable in South Africa as they occur due to historic planning biased during apartheid and the

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current housing backlog (Richards *et al.*, 2006). These settlements are occupied by the urban poor seeking a better life (Sliuzas, 2003; Huchzermeyer and Karam, 2006). Unfortunately, they end up living in temporary dwellings constructed from scrap material with little to no service delivery. Kostof (1993) stated that the informal settlement upgrading process starts immediately (i.e. the first dwelling is constructed on the land) and never truly ends. The community should thus be engaged in the process as an active stakeholder and the upgrading process should not be forced upon them (Abbott, 2003; Darkey and Visagie, 2013). Bolnick (2009) states that the problem of informal settlements will not be resolved if the inhabitants are passive beneficiaries waiting for external interventions to deliver solutions. The community needs to unite and determine their own future and propose possible solutions if they would like to rise above their situation (Steinitz, 2012).

The urban design process relies on a variety of information, ranging from descriptive text to visual information in both 2D and 3D (Kim and Bejleri, 2005). This is also true when designing in-situ upgrades for informal settlements. 2D Geovisualisations (e.g. classic printed maps) have proven in the past to be useful in making projects visible to the public, and aiding in managing the processes during the planning and implementation of various improvements (Appleton and Lovett, 2003; Tress and Tress, 2003; Chirowodza *et al.*, 2009; Paar and Rekittke, 2011). The first major use of 2D geovisualisations for planning of informal settlement upgrading was in 1983 in Belo Horizonte, Brazil (Abbott, 2003). Since then, 2D geovisualisations of spatial data have reportedly been successfully used in many cases of informal settlement upgrading (Abbott, 2003; Sliuzas, 2003; Chirowodza *et al.*, 2009; Paar and Rekittke, 2011). On the other hand, 3D geovisualisations have proved to be of use in various applications, such as facility management, planning or design, navigation and forecasting or simulations; but there is little or no precedent for using 3D in urban design of informal settlements. The question arises whether 3D geovisualisations can support and even benefit the urban design process, in the context of this thesis, specifically for upgrading of South African informal settlements.

1.2. Problem statement

Statistics South Africa reports that 13.1% of the South African population lived in an informal settlement in 2014 (Statistics South Africa, 2016). This is a slight decrease from the 13.6% in 2002. However, the percentage of individuals living in backyard informal dwellings is increasing and not represented in these statistics. In the Gauteng province, South Africa's economic hub, over 5% of the Gauteng population lives in informal dwellings. On average, 2.7 individuals live in a one-room informal dwelling in Gauteng. These individuals have been on the waiting list for governmental housing for over three years, and in extreme cases for more than 10 years. Even though the percentage of the population living in an informal settlement has decreased, the percentage of households that have access to basic services, such as running water and sanitation, has decreased dramatically. In 2014, only 45% of households had running water on the stand or premises (decreased from 54% in 2002) and 75% had access to a toilet (decreased from 86% in 2002) (Statistics South Africa, 2016). The South African National Development Plan (NDP) 2030 prioritised informal settlement upgrading (i.e.

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formalisation and proclamation of individual land parcels) as a key infrastructure investment and strategic objective (South Africa National Planning Commission, 2012).

Informal settlement upgrading requires a strong emphasis and focus on the community. Thus the scope of urban design in informal settlements usually goes beyond a single individual or discipline, and requires collaboration to understand the problem and potential solutions. The problems as well as potential solutions are commonly visualised on maps, and these visualisations are essential throughout the entire urban design process.

Thus, all the stakeholders (e.g. community members, local government and decision makers) need to be able to understand maps to ensure that they can actively participate in all phases of the process. However, this may not always be the case. Various researchers have stated that planning professionals in South Africa have a low level of functional map literacy (Engel, 2004; Clarke, 2007; Marais, 2007), which is inadequate for the effective design of informal settlement upgrades. In South Africa, mainly hard copy maps prepared in a geographic information system (GIS) have been used by planning professionals to interact and communicate with the various stakeholders (Abbott, 2003; Chirowodza *et al.*, 2009; Viljoen *et al.*, 2014). Therefore it is most likely that the 'map literacy' mentioned in the previous studies usually refers to such maps. Technological advances over the last decade have resulted in new methods of mapping and geovisualisation. The most popular of these new methods is undoubtedly the 3D model. 3D models been shown to be useful, or at least used, in various applications (Biljecki *et al.*, 2015). However, research on 3D geovisualisations has mainly focused on the technical aspects and development of 3D models mostly for densely populated urban areas, while the effectiveness of using 3D models is rarely investigated, and seemingly has never been studied for informal settlement upgrading. The research in this thesis fills this gap, and contributes to understanding the appropriate use of 3D models by investigating the use of 3D models throughout the urban design process for informal settlement upgrading.

1.3. Objectives

The goal of the research was to investigate whether the use of 3D geovisualisations as a new form of visual representation during the urban design process for informal settlement upgrading in South Africa would support the process, and if it would bring benefits.

The following are the secondary objectives of this research to achieve the main goal:

1. Understand the informal settlement upgrading process in South Africa; urban design and planning process; map reading and map literacy; visual variables; geovisualisation; and other related work based on a literature review of existing theory and related work.

2. Define the map reading tasks and associated maps required as input for planning informal settlement upgrading during the urban design process.

3. Evaluate the relevance of a subset of visual variables for 3D geovisualisations of South African informal settlement for urban design.

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4. Assess usefulness of various map designs (ranging from 2D to 3D geovisualisations) for urban designers, planning professionals and geoinformation specialists aimed at designing informal settlement upgrades in South Africa.

5. Based on all findings, draw conclusions for the development and use of 3D geovisualisations during the urban design process for informal settlement upgrading in South Africa.

1.4. Research approach

1.4.1. Overview

In this section, the approach followed for the research and writing of this thesis is explained. The main body of this thesis comprises a number of publications (Chapters 2–6 and Chapter 8). In Section 1.4.2 the publications are listed; in 1.4.3 they are related to a chapter in the thesis and their contribution to the research objectives (set out in Section 1.3) is explained; in 1.4.4 the research methodology is described. Additionally, in 1.6 an overview of all chapters is presented.

Note that the publications were included with minimal changes; thus references to '*we*' (referring to the authors of the specific publication) are used. Additionally, in the publications references to '*this paper*' are used, instead of '*this chapter*'.

1.4.2. Publications from this research

The following articles about this research were published in peer-reviewed journals:

Rautenbach, V., Bevis, Y., Coetzee, S. & Combrinck, C. (2015) Evaluating procedural modelling for 3D models of informal settlements in urban design activities. *South African Journal of Science,* 111(11/12), DOI: 10.17159/sajs.2015/20150100. Impact factor: 0,902.

Rautenbach, V., Coetzee, S. & Çöltekin, A. (2016) Development and evaluation of a specialized task taxonomy for spatial planning - A map literacy experiment with topographic maps. *ISPRS Journal of Photogrammetry and Remote Sensing*, In press. DOI: 10.1016/j.isprsjprs.2016.06.013. Impact factor: 4,188.

The following articles about this research were published in peer-reviewed conference proceedings:

Rautenbach, V., Coetzee, S. & Çöltekin, A. (2014) Towards evaluating the map literacy of planners in 2D maps and 3D models in South Africa. *AfricaGEO 2014 Conference Proceedings*. 1–3 July 2014, Cape Town, South Africa.

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Rautenbach, V., Coetzee, S. Schiewe, J. & Çöltekin, A. (2015) An Assessment of Visual Variables for the Cartographic Design of 3D Informal Settlement Models. *27th International Cartographic Conference*. 23–28 August 2015, Rio de Janeiro, Brazil.

Rautenbach, V., Çöltekin, A. & Coetzee, S (2015) Exploring the Impact of Visual Complexity Levels in 3D City Models on the Accuracy of Individuals' Orientation and Cognitive Maps, *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, Volume II-3/W5, 2015 ISPRS Geospatial Week 2015, 28 Sep–03 Oct 2015, La Grande Motte, France

The following non peer-reviewed publications were a result of this research:

Rautenbach, V., Coetzee, S. & Çöltekin, A. (2016) Investigating the use of 3D geovisualisations for urban design in informal settlement upgrading in South Africa. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences (ISPRS Archives),* Volume XLI-B2, 2016 XXIII ISPRS Congress, 12–19 July 2016, Prague, Czech Republic.

Table 1. Overview of the relationship between publications and the objectives

<table>
<tr><th>Ch</th><th>Publication title</th><th colspan="3">Objective(s)</th></tr>
<tr><td>2</td><td>Evaluating procedural modelling for 3D models of informal settlements in urban design activities</td><td colspan="2">Objective 5: Based on all findings, draw conclusions for the development and use of 3D geovisualisations during the urban design process for informal settlement upgrading in South Africa.</td><td rowspan="6">Objective 1: Understand the informal settlement upgrading process in South Africa, urban design and planning process, map reading and map literacy, visual variables, geovisualisation, and other related work based on a literature review of existing theory and related work.</td></tr>
<tr><td>3</td><td>An Assessment of Visual Variables for the Cartographic Design of 3D Informal Settlement Models</td><td colspan="2">Objective 3: Evaluate the relevance of a subset of visual variables for 3D geovisualisations of South African informal settlements for urban design.</td></tr>
<tr><td>4</td><td>Exploring the Impact of Visual Complexity Levels in 3D City Models on the Accuracy of Individuals' Orientation and Cognitive Maps</td><td></td><td rowspan="3">Objective 4: Assess usefulness of various map designs (ranging from 2D to 3D geovisualisations) for urban designers, planning professionals and geoinformation specialists aimed at planning informal settlement upgrades in South Africa.</td></tr>
<tr><td>5</td><td>Towards evaluating the map literacy of planners in 2D maps and 3D models in South Africa</td><td></td></tr>
<tr><td>6</td><td>Development and evaluation of a specialised task taxonomy for spatial planning - A map literacy experiment with topographic maps</td><td>Objective 2: Define the map reading tasks and associated maps required as input for planning informal settlement upgrading during the urban design process.</td></tr>
<tr><td>8</td><td>Investigating the use of 3D geovisualisations for urban design in informal settlement upgrading in South Africa</td><td colspan="2">Objective 5: Based on all findings, draw conclusions for the development and use of 3D geovisualisations during the urban design process for informal settlement upgrading in South Africa.</td></tr>
</table>

1.4.3. Relationship between publications, chapters and objectives

Each of the publications produced from this research (refer to Section 1.4.2) addresses one or more research objectives (refer to Table 1). In the remainder of this section, the relationship between the publications and the objectives is discussed in more detail. Figure 2 provides an overview of the topics presented in this thesis. This thesis investigates the usefulness of 3D geovisualisations for urban

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design, specifically of informal settlement upgrading in South Africa. The chapter is organised in order from the development (Chapter 2) and design (Chapters 2–4) to the cognition of 3D models (Chapters 5–7), and lastly drawing final conclusions (Chapters 8–9).

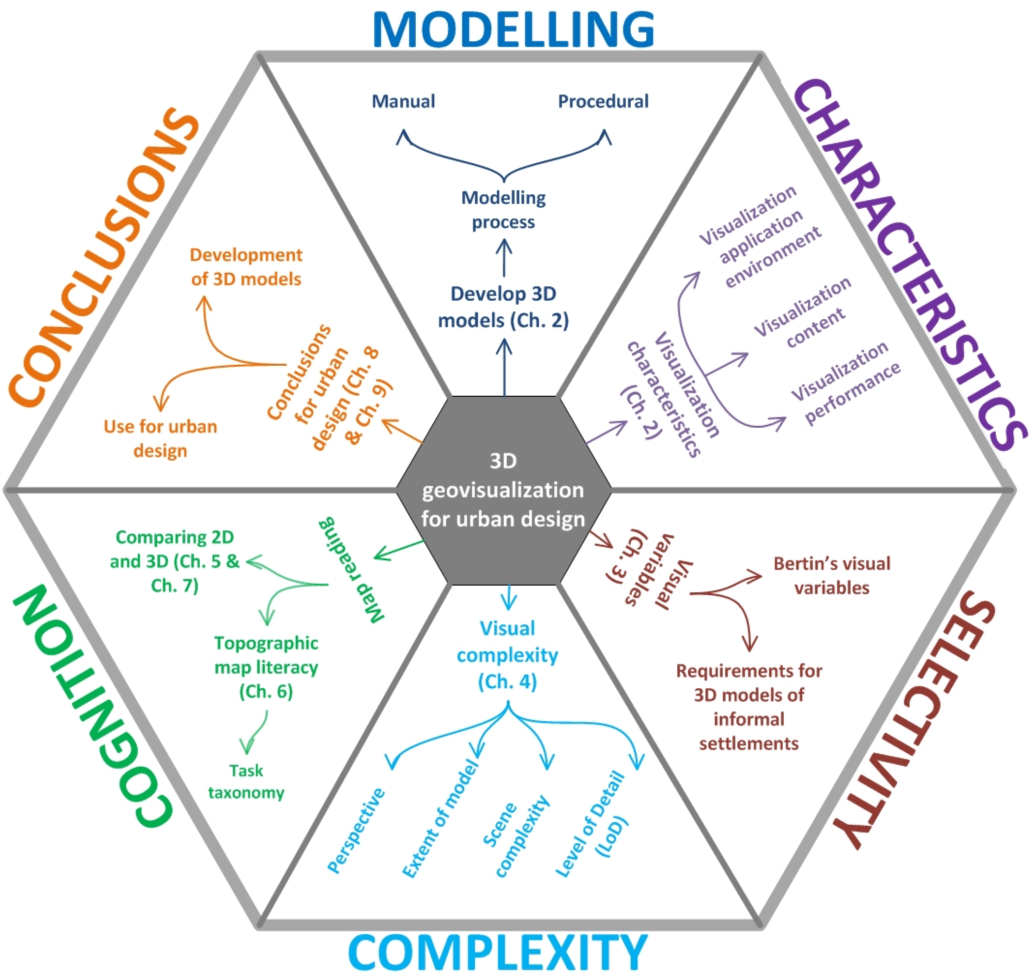

Figure 2. Overview of the topics presented in this thesis

Objective 1: Understand the informal settlement upgrading process in South Africa, urban design and planning process, map reading and map literacy, visual variables, geovisualisation and other related work based on a literature review of existing theory and related work

> The first objective has been an ongoing activity. The goal of the objective was mainly to gain a good understanding of the various topics involved and the latest research in this field. Chapters 2–6 and Chapter 8 all include a brief literature review relevant to the specific topic discussed in the chapter. Because each publication had to stand on its own, there may be some duplication in the background sections of these chapters. Additionally, all chapters (Chapters 2–8) include references to related work in the discussion of the results obtained. Table 2 provides an overview of the distribution of literature throughout the various chapters.

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Table 2. Overview of the distribution of literature throughout this thesis

Chapter *Topic*	Ch. 2	Ch. 3	Ch. 4	Ch. 5	Ch. 6	Ch. 7	Ch. 8
Informal settlement	x	x	x				x
Informal settlement upgrading	x	x	x				x
Urban design	x						x
Urban planning				x	x		
3D models	x	x	x	x			x
Level of Detail (LoD)	x		x				
Procedural modelling	x						
Visual variables		x					
Map reading or map literacy				x	x		x
Spatial cognition and empirical studies			x	x	x	x	
Related work	x	x	x	x	x	x	x

Objective 2: Define the map reading tasks and associated maps required as input for planning informal settlement upgrading during the urban design process

For this objective, a task taxonomy was created based on realistic map reading tasks that would generally be used in the urban design process. The task taxonomy defines tasks for map reading and can be used to evaluate an individual's map literacy. The map reading task taxonomy was compiled using expert knowledge and various sources, including the South African national geography curriculum. Currently, the taxonomy only considers tasks for topographic maps, other 2D maps and aerial photography. The taxonomy is presented in the journal paper entitled, *"Development and evaluation of a specialized task taxonomy for spatial planning - A map literacy experiment with topographic maps"* presented in Chapter 6.

Objective 3: Evaluate the relevance of a subset of visual variables for 3D geovisualisations of South African informal settlements for urban design

This topic started with an investigation into 3D symbology, about which very little is written or research done. During a research visit at HafenCity University Hamburg in Germany in 2014, the investigation narrowed down to focus on the appropriateness of visual variables for 3D informal settlement models for use during informal settlement upgrading in South Africa. This research resulted in a paper entitled, "*An Assessment of Visual Variables for the Cartographic Design of 3D Informal Settlement Models*" that was presented at to the 27th International Cartographic Conference to be held in Rio de Janeiro, Brazil, 23–28 August 2015 (refer to Chapter 3).

Objective 4: Assess usefulness of various map designs (ranging from 2D to 3D geovisualisations) for urban designers, planning professionals and geoinformation specialists aimed at designing informal settlement upgrades in South Africa

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An experiment was designed, implemented, and a study performed to evaluate the impact of level of detail in 3D city models on spatial cognition. The experiment was conducted on three groups of students (107 in total) from the University of Pretoria. The experiment was designed in such a way that it could be applicable to a number of application fields, including planning. The results for the experiment have been written up, and were accepted as a peer-reviewed conference presentation entitled, "*Exploring the Impact of Visual Complexity Levels in 3D City Models on the Accuracy of Individuals' Orientation and Cognitive Maps*" at the ISPRS geospatial week, 28 September–2 October 2015 in La Grande Motte, France (refer to Chapter 4).

To further achieve this objective, a series of additional user experiments were developed. Preliminary work on this topic, "*Towards evaluating the map literacy of planners in 2D maps and 3D models in South Africa"*, was accepted and presented at the AfricaGEO conference held in Cape Town, South Africa, 1–3 July 2014 (refer to Chapter 5). A follow-up user study was performed on 49 individuals, and a publication, entitled "*Development and evaluation of a specialized task taxonomy for spatial planning - A map literacy experiment with topographic maps*" was published in the *ISPRS Journal of Photogrammetry and Remote Sensing* in July 2016 (refer to Chapter 6). Lastly, a third user study compared the map literacy of individuals when interpreting aerial photographs, 2D maps and 3D models. The user study tested basic map reading skills, specifically symbol recognition and topography, using aerial photographs, 2D maps and 3D models of a typical South African informal settlement (refer to Chapter 7).

Objective 5: Based on all findings, draw conclusions for the development and use of 3D geovisualisations during the urban design process for informal settlement upgrading in South Africa

In collaboration with Dr Carin Combrinck (Department of Architecture, University of Pretoria), an article entitled, "*Evaluating procedural modelling for 3D models of informal settlements in urban design activities*" was published in December 2015 in the South African Journal of Science (refer to Chapter 2). The article provides insight into the use of procedural modelling, and the prioritisation of visualisation characteristics in 3D models used in urban design for informal settlement upgrading.

Throughout the various publications prepared from this research, conclusions on the use of 3D geovisualisations are presented. In the last two chapters (Chapter 8 and Chapter 9), these conclusions are combined and finalised for the effective use of 3D geovisualisations when designing informal settlement upgrades in South Africa. Chapter 8, entitled "*Investigating the use of 3D geovisualisations for urban design in informal settlement upgrading in South Africa*" was presented at the XXIII ISPRS Congress, 12–19 July 2016, Prague, Czech Republic.

1.4.4. Methodology

Empirical research methodology was used for this research. According to Olivier (2009), this methodology may be used to do exploratory research or to extend a theory. Empirical research

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methods were chosen, since this thesis has both exploratory components and hypothesis-driven components about the use of 3D geovisualisation for urban design of informal settlement upgrading in South Africa. The research is classified as exploratory, as this thesis aims to explore the topic by drawing on existing literature and conducting various user experiments in order to make a contribution to the current body of knowledge.

The primary method of this research was a series of user experiments, and the secondary method a literature survey.

The literature survey provides the required background into the disciplines of geoinformatics, cartography and urban design. This aids in understanding all aspects involved: informal settlement upgrading, urban design or urban planning process, map reading and map literacy, visual variables, geovisualisation and other related work. The literature survey not only contributed to the understanding, but also to the evolution of the aim of this research. For example, this research was originally focused on urban planning (refer to Chapters 5 and 6), and after extending the literature survey and informal discussion the aim was changed to focus on urban design (Chapters 2–4, and Chapters 7–9). From the literature survey and informal discussions, it was clear that informal settlement upgrading is considered to be more urban design than urban planning.

Secondly, a series of user experiments were designed to achieve objectives 2, 4 and 5 set out in Section 1.3. The research design for each user experiment is discussed in detail in the respective chapters (refer to Sections 4.4, 5.4, 6.4, 7.2.1, and 7.3.1). The first user experiment was exploratory, and it was designed and performed to understand the impact of various levels of complexity in 3D city models on the participants' orientation and cognitive maps (refer to Chapter 4). This was followed by three iterations of a user experiment to evaluate participants' map literacy when performing tasks on various geovisualisations. In the first iteration, another exploratory user study was implemented to evaluated basic map reading tasks (i.e. indicating cardinal directions, relative directions, and estimation of distance), which were performed on a 2D map, 3D non-realistic landscape and 3D model. To improve on the first iteration, a taxonomy of realistic map reading tasks was proposed. During the second iteration, the usefulness of the taxonomy was assessed by performing an empirical user experiments on map-literate participants solving a subset of tasks on a topographic map. For the last iteration a mixed-methods approach was used. A quantitative user study was designed to assess the participants' performance when completing tasks relating to symbol recognition and topography using aerial photographs, 2D maps and 3D models. This was supplemented by semi-structured expert interviews, which provided insight and a better understanding of how various geovisualisations are used in urban design projects, specifically for in-situ upgrading of informal settlements.

The results of the literature survey, theoretical studies on visual characteristics and visual variables, and the series of user experiments were combined to draw conclusions on the use of 3D geovisualisations for urban design when upgrading informal settlements in South Africa. The last step of the research was to write this thesis, which combines the author's understanding of the relevant

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theory, previous research and the results of the empirical user experiments and the resulting conclusions.

1.5. Contributions to scientific research

The main contributions of this research are summarised below:

3D models have the potential to be useful for urban design, specifically during the understanding and communication phase. New mapping tools and technologies are rapidly emerging. Nevertheless, in South Africa, physical models, paper maps and GIS are still the main tools used during urban design for collection, management, analyses and producing maps. This research investigated the appropriateness and effectiveness of using 3D geovisualisations in the urban design process and how this technology can be leveraged. The conclusions from this research can assist planning professionals, and geoinformatics specialists in designing suitable 3D models that can be used throughout all phases of the urban design process. Additionally, guidance for selecting aerial photography, 2D maps or 3D models is provided according to the specific tasks that are involved in the upgrading process (Section 8.6 and 9.2).

3D models are useful to gain stakeholder buy-in and communicate planned developments. 3D geovisualisations are eye-catching and this feature can definitely be exploited during the urban planning process. The results from this research suggest that the tools available for generating 3D models are currently not easy to use and individuals require some additional training to generate appropriate 3D models. The expert interviews confirmed that 3D models are useful to gain stakeholder buy-in. However, for other tasks during the urban design process individuals prefer maps and the use of 3D models should be considered carefully (Section 7.3).

Visual characteristics of informal settlements for urban design. When developing a 3D model for a South African informal settlement there are certain visual characteristics that are important for urban design activities. The importance of each visual characteristic for urban design is assessed, and this provides guidance to urban designers when developing a 3D model (refer to Section 2.5).

Procedural modelling is a viable alternative to manual modelling in the case of informal settlements. Manual modelling can be a time consuming and tedious task, especially when generating 3D models of informal settlements that tend to change often and without forewarning. Procedural modelling appears to be a suitable alternative for generating 3D models of an informal settlement for urban design, because it provides rapid results with necessary flexibility. (Sections 2.6 and 2.7).

Visual complexity is important to consider when designing a 3D model to be used for communication with various stakeholders. The results from one of the user studies suggest that level of detail (LoD), the extent of the model (scale), scene complexity (number, structure and density of objects), the camera angle (perspective), familiarity with the environment and training can influence

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individuals' cognitive map and orientation when using a 3D model. Due to the exploratory nature of the user experiments, these observations mainly serve as a basis to build hypotheses for the following studies (refer to Section 4.6)

Colour and texture are appropriate visual variables appropriate for 3D models. Bertin's (1983) theory of visual variables is an established approach to studying and improving a paper map's selectiveness when printed in black and white. Visual variables were never intended to be used for colour maps, and particularly not digital representations. In this thesis, the appropriateness of selected visual variables for urban design of informal settlement upgrading was investigated, specifically the selectiveness of objects. The results suggest that colour and texture can be used without modification. The other visual variables, such as position, might be considered in relation to the camera position rather than the object position (refer to Sections 3.6 and 3.7).

A specialised map reading task taxonomy for urban design is necessary for understanding the use of maps in the urban design process. In this thesis, a map reading task taxonomy, specifically for the spatial planning domain, is proposed. The taxonomy was compiled from various literature sources, curricula and also expert knowledge. The taxonomy is divided into six levels (i.e. level1: recognise symbology; level2: orientation; level3: locate; level4: measure or estimate; level5: calculate or explain; and level5: extract knowledge), increasing in complexity from level to level. The taxonomy can be used to evaluate an individual's level of map literacy. If an individual is able to complete all the tasks associated with level1 to level4, he/she is considered to be functionally map literate (refer to Sections 6.3 and 6.6)

Conclusions are relevant to other application fields, such as resource management or solar energy planning. The results presented in this thesis are specific for urban design of informal settlements in South Africa. However, the results can be useful in various other application fields that rely on visualisation, such as regional planning or resource management, or in other countries where urban design for informal settlements might have similar characteristic (refer to Section 9.2)

1.6. Overview of the chapters in this dissertation

This research spans three disciplines: Cartography, Geoinformatics and Urban Design. The design and development of geovisualisations, cartographic design, map reading and the map reading task taxonomy relate to cartography and geoinformatics. The urban design or urban planning process, and informal settlement upgrading are urban design concepts covered in the research.

The remaining chapters of this thesis are structured as described below. For Chapters 2–6 and 8, the respective objectives addressed in each chapter are listed in brackets; refer to Section 1.4.3 for a more detailed description.

Chapter 2 – Evaluating procedural modelling for 3D models of informal settlements in urban design activities. An evaluation of the suitability of using procedural modelling for urban design

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activities in informal settlements is given in this chapter. The visualisation characteristics of 3D models of informal settlements are described and the importance of each characteristic in urban design activities for informal settlement upgrades is theoretically assessed. The visualisation characteristics and their assessment provide guidelines for the development of 3D informal settlement models. *[Objective 1 and Objective 5]*

Chapter 3 – An assessment of visual variables for the cartographic design of 3D informal settlement models. The relevance of a subset of visual variables for planning informal settlement upgrades in 3D geovisualisations, and specifically how these variables contribute to the selectiveness of objects are discussed. Visual variables are important to consider when designing 3D models, and this chapter contributes to the discussion regarding the relevance of visual variables for designing 3D geovisualisations. *[Objective 1 and Objective 3]*

Chapter 4 – Exploring the impact of visual complexity levels in 3D city models on the accuracy of individuals' orientation and cognitive maps. The results from an exploratory user experiment designed to contribute to understanding the impact of various levels of complexity (mainly based on LoD) in 3D city models, specifically on the participants' orientation and cognitive maps are described in this chapter. An accurate cognitive map is essential for individuals when using a 3D model for urban design. The results from this chapter contribute to the development of better-suited 3D models for urban design. *[Objective 1 and Objective 4]*

Chapter 5 – Towards evaluating the map literacy of planners in 2D maps and 3D models in South Africa. The experiment presented in this chapter, is the first iteration of experiments regarding the usefulness of various geovisualisations for urban design tasks. The preliminary results of experiments to evaluate map literacy of planners in 2D maps and 3D models in South Africa are presented. The preliminary results contribute to the development of a conceptual design of an experiment to evaluate map literacy of users with 2D maps and 3D models as presented in the following chapters. Lastly, this chapter provides input to the user study design that was used in Chapter 7 *[Objective 1 and Objective 4]*

Chapter 6 – Development and evaluation of a specialised task taxonomy for spatial planning - A map literacy experiment with topographic maps. Firstly, a taxonomy of map reading tasks typically executed during the planning process is presented. The taxonomy defines six levels of tasks increasing in difficulty and complexity. Thereafter, results from an empirical experiment with map-literate participants solving selected tasks (subset vary between level1 and level4) with a topographic map are presented. The results suggest that the proposed taxonomy is a good reference for evaluating functional map literacy. *[Objective 1, Objective 2 and Objective 4]*

Chapter 7 – Evaluating the usefulness of aerial photographs, 2D maps and 3D models for urban design. The results from two user studies (i.e. controlled and distributed) and semi-structured expert interviews are presented. The aim of user studies and expert interviews was to evaluate the usefulness

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of 3D models when performing tasks relating to symbol recognition and topography using aerial photographs, 2D maps and 3D models. *[Objective 1 and Objective 4]*

Chapter 8 – Discussion of results. The results obtained from the various user experiments are discussed. Furthermore, recommendations for the design and use of 3D geovisualisations for the urban design of informal settlement upgrading are provided. *[Objective 1 and Objective 5]*

Chapter 9 – Conclusion. The most significant results obtained from this research and future research topics are discussed. In this chapter, the conclusions for the design and use of 3D geovisualisations are presented. *[Objective 5]*

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Chapter 2. Evaluating procedural modelling for 3D models of informal settlements in urban design activities

This chapter was published in the South African Journal of Science in 2015, as a peer-reviewed research paper by Rautenbach, V., Bevis, Y., Coetzee, S., and Combrinck, C. under the same title.

Contribution: Y.B. developed the 3D model and procedural modelling process as part of her postgraduate studies under the supervision of V.R. and S.C.; V.R. refined the visualisation characteristics as part of her PhD research under the supervision of S.C.; C.C. provided urban design input; V.R. and S.C. wrote the majority of the article; and the evaluation of the visualisation characteristics was done jointly by the four authors.

2.1. Abstract

Three-dimensional (3D) modelling and visualisation is one of the fastest growing application fields in geographic information science. 3D city models are being researched extensively for a variety of purposes and in various domains, including urban design, disaster management, education and computer gaming. These models typically depict urban business districts (downtown) or suburban residential areas. Despite informal settlements being a prevailing feature of many cities in developing countries, 3D models of informal settlements are virtually non-existent. 3D models of informal settlements could be useful in various ways, e.g. to gather information about the current environment in the informal settlements, to design upgrades, to communicate these and to educate inhabitants about environmental challenges. In this article, we described the development of a 3D model of the Slovo Park informal settlement in the City of Johannesburg Metropolitan Municipality, South Africa. Instead of using time-consuming traditional manual methods, we followed the procedural modelling technique. Visualisation characteristics of 3D models of informal settlements were described and the importance of each characteristic in urban design activities for informal settlement upgrades was assessed. Next, the visualisation characteristics of the Slovo Park model were evaluated. The results of the evaluation showed that the 3D model produced by the procedural modelling technique is suitable for urban design activities in informal settlements. The visualisation characteristics and their assessment are also useful as guidelines for developing 3D models of informal settlements. In future, we plan to empirically test the use of such 3D models in urban design projects in informal settlements.

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2.2. Introduction

The promise of work and a better life attracts thousands of South Africans to the country's major cities. However, various factors such as the housing backlog and shortage of housing subsidies forces hopefuls to live in informal housing or shack settlements (Richards *et al.*, 2006). Informal settlements in South Africa continue to regularly make news headlines because of lack of adequate housing and service delivery. The National Planning Commission (NPC) produces annual reports providing some insight into the magnitude of the problem: in 2013, 7.6% of the South African population (3-4 million people) lived in informal settlements (South Africa National Planning Commission, 2013).

The South African government is party to the United Nations Millennium Development Goals (MDG) that aim to significantly improve the lives of at least 100 million inhabitants by the year 2020 (MDG 7, target 4) (United Nations, 2011). As a result, the government is obligated to assist the inhabitants of informal settlements or slums to improve their living conditions. In response to the MDG, the National Housing Code by the Department of Human Settlements proposes a process for the upgrading of informal settlements (South Africa Department of Human Settlements, 2009). The South African Housing Programme was described in Part 3 this Code and aimed to improve the lives of 2.2 million households living in informal settlements by 2014. Additionally, the South African National Development Plan (NDP) identified informal settlement upgrading or relocation as one of its main objectives (South Africa National Planning Commission, 2012): by 2030 all informal settlements located on suitable land should be upgraded, or else relocated to suitable land.

To achieve the objectives set out by the MDG and NDP, urban design of informal settlement upgrades, such as the construction of a community hall, taxi rank, health clinic or playground, needs to consider both humans and the natural environment. Urban design is concerned with shaping the physical environment of cities, towns and villages, while considering human behaviour, aesthetics and functionality (Lynch, 1960; Kim and Bejleri, 2005). Similarly in urban planning, the human is the central component in the process. However, urban planners focus on designing and planning large areas for future use, e.g. new infrastructure (Rautenbach *et al.*, 2014), while urban design is more focused on enhancing the current environment. An important component of urban design in a democratic society is involving and communicating planned changes to various stakeholders. Geovisualisation of spatial data is a powerful tool in this communication. Over the years, spatial data have been represented in various formats ranging from two-dimensional (2D) maps, three-dimensional (3D) physical scale models, to 3D digital representations. Recently, 3D geovisualisations have grown in popularity, partly through the availability of applications such as Google Earth (https://www.google.com/earth/) or NASA World Wind (http://worldwind.arc.nasa.gov/java/).

Three-dimensional (3D) models are increasingly being used in urban design applications (Cartwright *et al.*, 2005; Cartwright *et al.*, 2005; Wergles and Muhar, 2009; Gröger and Plümer, 2012). 3D models can present information that could not previously be visualised in 2D maps and designs. In response to these benefits, most large German municipalities provide level of detail (LoD) 2 models of their municipal areas and in some cases LoD3 models of their city centres. Many of the German states aim

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to provide LoD2 models of all their urban areas by 2016. Other European cities, such as Monaco, Geneva, Zurich and Leeuwarden, use 3D city models as a means of representing and exchanging data, similarly in Asia (Gröger and Plümer, 2012).

Numerous studies have been conducted on various aspects of 3D city models, but these are limited to urban environments (i.e. city centres). 3D models of cities are used in various application fields, such as urban planning, disaster management, computer games, entertainment and education (Parish and Müller, 2001; Gröger and Plümer, 2012). 3D models of informal settlements could also be used in these application fields, however research on their use is limited to exploratory studies in a few countries (Buehler, 2014) and to our knowledge has not been done in South Africa .

Modelling large 3D cities manually requires an enormous amount of labour (Müller *et al.*, 2006), making this approach expensive. Owing to financial constraints and the dynamic nature of informal settlements this approach is not feasible for South African informal settlements. Procedural modelling is a form of automatic generation that has been suggested as an alternative to traditional manual methods for creating 3D models. Algorithms are used sequentially to generate 3D objects in order to generate mass 3D models (Ganster and Klein, 2007; Ilčík *et al.*, 2010). Through procedural modelling an intricate object is created by iteratively applying a rule to each resulting component of the object (Talton *et al.*, 2011). An additional benefit of procedural modelling is that it can be used to automatically prepare 3D models from spatial data (e.g. topography and terrain models) made available through the spatial data infrastructure of a city or country (Hjelmager *et al.*, 2008; Cooper *et al.*, 2014).

The goal of this article is to describe a procedural modelling process to generate a 3D model of an informal settlement in South Africa, and to evaluate the applicability of the resulting model in urban design activities. We adapted visualisation characteristics of 3D models of buildings in city planning for the specific requirements of urban design activities during informal settlement upgrades in South Africa. Then we assessed the importance of each characteristic for such activities. We developed a prototype 3D model of a part of Slovo Park, an informal settlement in Johannesburg, South Africa and evaluated its visualisation characteristics.

2.3. Study area: Slovo Park settlement

Slovo Park is an informal settlement situated roughly 10 km south of Soweto, in the City of Johannesburg Metropolitan Municipality, South Africa (see Figure 3). It is located adjacent to a large freeway and is surrounded by industrial factories. There are approximately 1100 stands in Slovo Park, laid out by the community (i.e. not officially surveyed). The local municipality provides only rudimentary services in the form of waste and sewerage collection, and communal taps. The residents do not have access to formal electricity (see Figure 4).

The 3D model described in this article is merely a proof of concept, and thus only a sub-section of the settlement was selected as the study area. The study area contains various types of human-made

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constructions, such as a community hall (central meeting place for the community), a *shebeen* (local term for a bar), and surrounding dwellings (typical shelters found in an informal settlement).

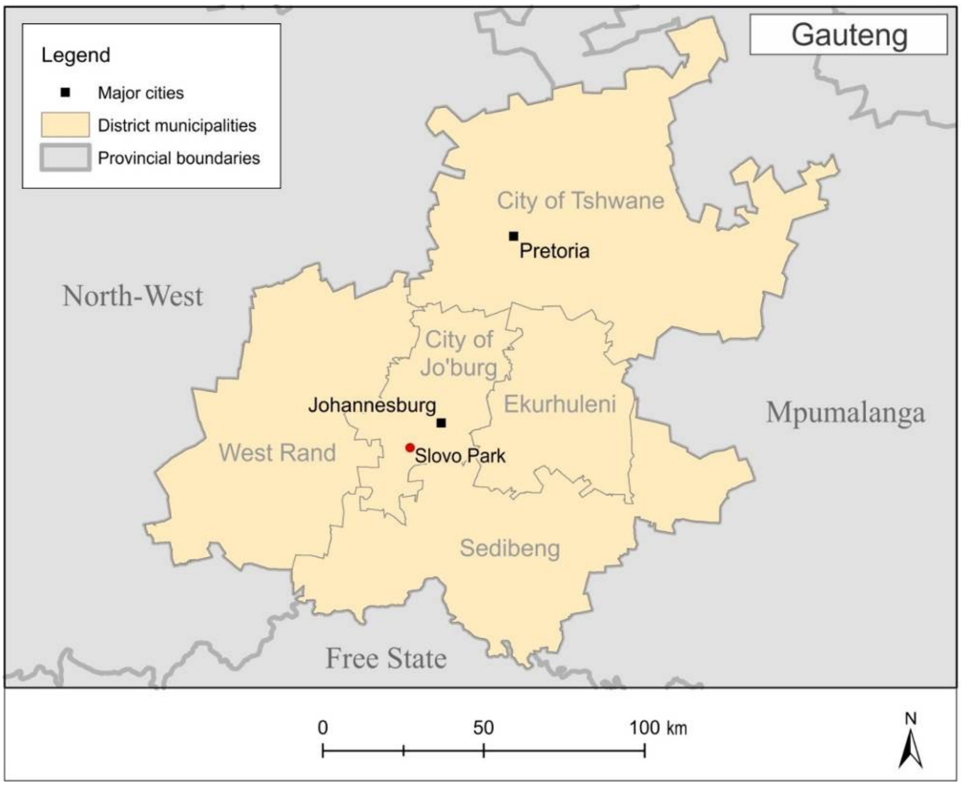

Figure 3. Location of Slovo Park within Gauteng, South Africa

a) Informal vendor b) Outside toilet and recycling for monetary gain

Figure 4. Photos depicting life in Slovo Park

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2.4. A procedural modelling process for informal settlements

2.4.1. Overview of the procedural modelling process

A procedural modelling process was developed as an alternative to manual modelling of informal settlements for planning upgrades. Procedural modelling iteratively applies algorithms and rules to an initial 2D shape that is afterwards replaced by a 3D object (Glass *et al.*, 2006; He *et al.*, 2012). Natural real world systems can be realistically replicated with procedural modelling as it utilises parameterisation that allows infinite variation in the generated model (Glass *et al.*, 2006; Smelik *et al.*, 2014). However identifying the correct parameters and values to generate a photorealistic model is not feasible.

Procedural modelling has proven to be successful for generating various models, such as urban environments, road networks, infrastructure, vegetation, and terrains (Fletcher *et al.*, 2010; Beneš *et al.*, 2011; Krecklau and Kobbelt, 2011; Smelik *et al.*, 2014). Urban modelling is a prominent reason for the popularity of procedural modelling, as cities are not only big, but also incredibly detailed (Watson *et al.*, 2008). With manual modelling, it would be too tedious and time consuming to generate realistic 3D models (Beneš *et al.*, 2011).

The procedural modelling process described in this article was derived from the visualisation pipeline and adapted for procedural modelling. The visualisation pipeline defines the process required to create visualisation from raw data (Upson *et al.*, 1989; Haber and McNabb, 1990; Jo Wood *et al.*, 2005). The basic visualisation pipeline consists of filtering, mapping and rendering (Upson *et al.*, 1989; Haber and McNabb, 1990). During the filtering phase, the data are converted and a subset of the data is selected. Thereafter, the data are transformed into geographic primitives during the mapping phase. Lastly, the geometric primitives are converted into realistic images, i.e. they are rendered. Our procedural modelling process is depicted in Figure 5.

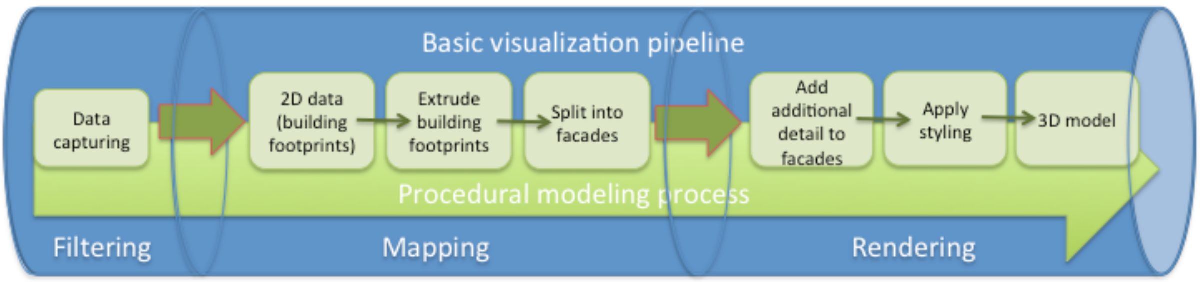

Figure 5. Overview of the procedural modelling process

2.4.2. Level of detail

3D objects can be characterised according to the level of detail (LoD) with which they represent objects in the real world. This LoD ultimately determines the model's applicability (Morton et al., 2012). One of the simplest reasons for using LoD in 3D models is to reduce the complexity of the geometry before rendering. Biljecki et al. (2013) suggested additional advantages for using LoD, e.g. to specify the level at which 3D data are captured, and for generalisation during rendering. Various approaches exist

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for specifying LoD for urban models. However, none of the approaches are without criticism. For example, some LoDs are considered too coarse and therefore hindering smooth transition between the levels (Biljecki et al., 2013). In this paper, the Open Geospatial Consortium (OGC) CityGML specification of LoD will be used (see

Figure 6) (Open Geospatial Consortium, 2008):

- *LoD0* is the 2.5D representation of the basic outline of objects, typically a flat polygon.
- *LoD1* is achieved when the volume of objects is modelled in a generalised fashion with the inclusion of vertical walls and flat roofs.
- *LoD2* builds on LoD1 with the addition of a roof structure, as well as the inclusion of texture or photography on surfaces and terrain.
- *LoD3* is an extension of LoD2 with the inclusion of openings, such as windows and doors, and by adding more detailed roof structures.
- In *LoD4* the interiors of buildings are added to the model.

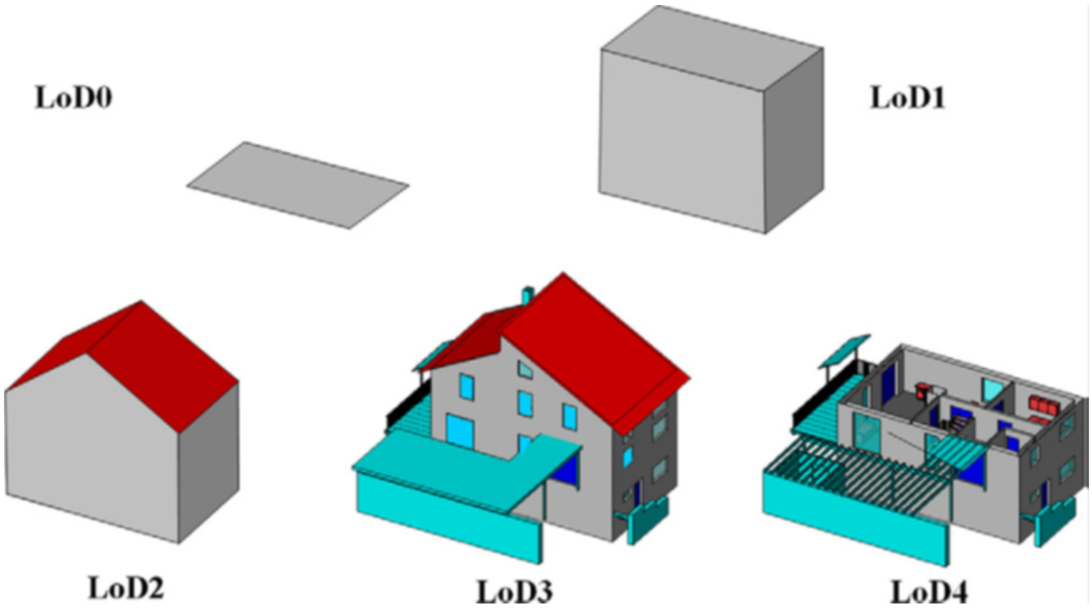

Figure 6. Levels of Detail (LoD) as specified by CityGML Source: Gröger and Plümer (2012)

2.4.3. Implementation of the procedural modelling process

During implementation, the steps identified in the section above on the procedural modelling process were refined and a detailed procedural modelling process was developed, depicted in Figure 7. The process was implemented in CityEngine (http://www.esri.com/software/cityengine) and CGA. After completion of a phase in the process, the resulting model can be related to a specific LoD. The prototype model of Slovo Park was modelled up to LoD3. The interiors of the informal structures (LoD4) were not considered, as these are deemed unnecessary for urban design.

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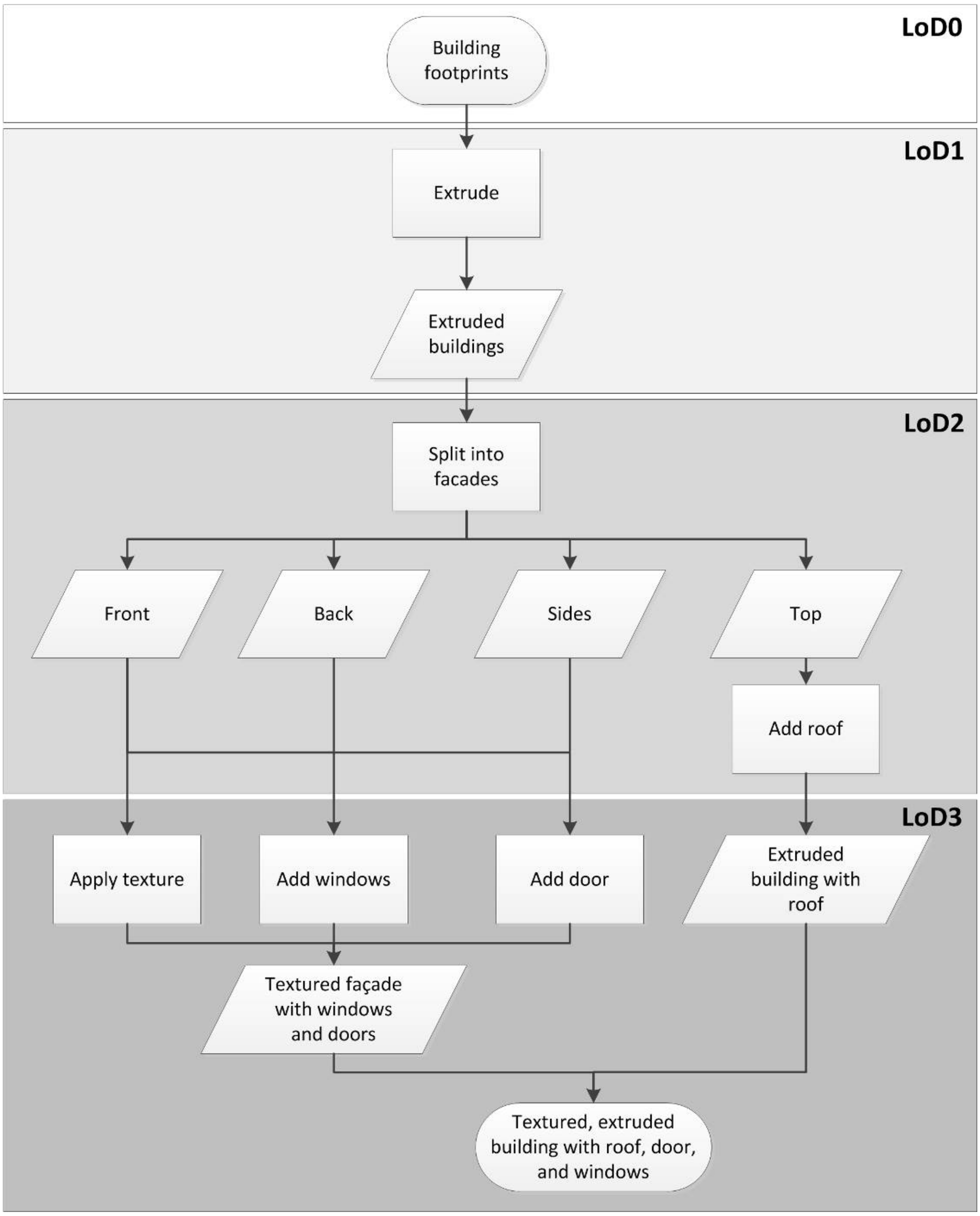

Figure 7. The detailed procedural modelling process

LoD0 is the most simplistic level; it consists of building footprints and terrain. Building footprints are commonly represented by 2D simple geometry. LoD1 was attained through the extrusion of the 2D building footprints into 3D cuboids. Each 2D geometry (or building footprint) in LoD0 was assigned a height value. The CGA *extrude* command was then executed to produce 3D geometric objects with the generalised volume and depth of the real world features. The dwellings were extruded to a height of 1.9 m, as this was observed to be the average height in the field. Figure 8a is an example of such a dwelling. In-situ measurements were taken of the community hall and the height of the structure was found to be approximately 2.3 m (see Figure 9a). The community hall was extruded accordingly.

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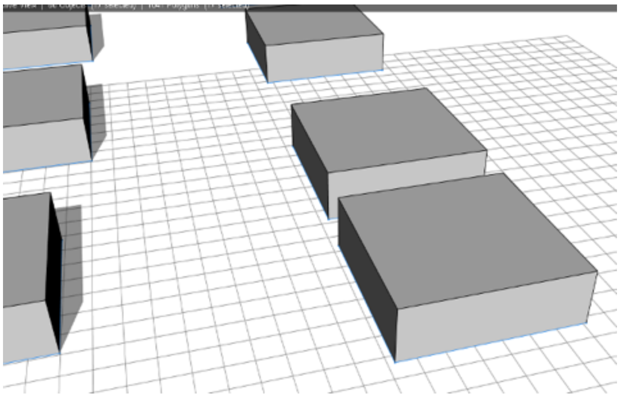
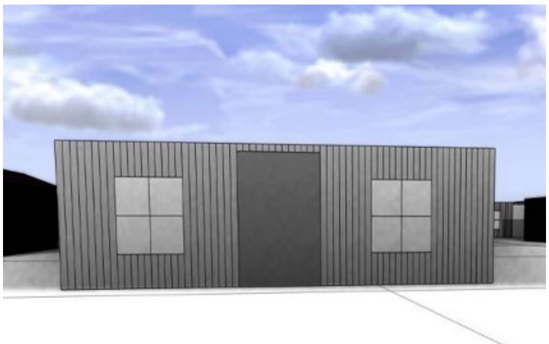
Procedural modelling allows users to extrude all of the building footprints simultaneously, compared to manual modelling which requires individual extrusion. With procedural modelling, structures can either be extruded to a predefined height, or a random height within a specified range. The result of the LoD0 to LoD1 transformation (i.e. the LoD1 model) is shown in Figure 8b and Figure 9b.

a) The generic informal dwelling



b) Informal dwelling modelled at LoD1



c) The front of an informal dwelling modelled at LoD3

d) The side of the informal dwelling modelled at LoD3

Figure 8. Results of modelling an informal dwelling

The 3D object at LoD2 starts to resemble its true form. An LoD2 model is attained when a roof is added to the LoD1 shape or object (Gröger and Plümer, 2012). Typically, roofs have a triangular shape, however, most structures in informal settlements have flat roofs. Gröger & Plümer (2012) argue that a horizontal roof is an attribute of a LoD1 model (refer to Figure 9b). To enable the modelling of more complex objects (at higher LoDs) using procedural techniques, the objects have to be separated into different components or objects, called facades. In our model we used the CityEngine *split* command to divide an object into facades. The following facades (or objects) were generated: front, back, sides and top. An advantage of procedural modelling is that these facades are now independent objects that can be modelled separately (e.g. different combinations of facades). Because there is an explicit top facade (the roof) after the execution of the split command, structures with flat roofs are now LoD2 objects. Semantic information (e.g. descriptive attributes) can be added to each of the facades so that complex analysis can be performed on the 3D model.

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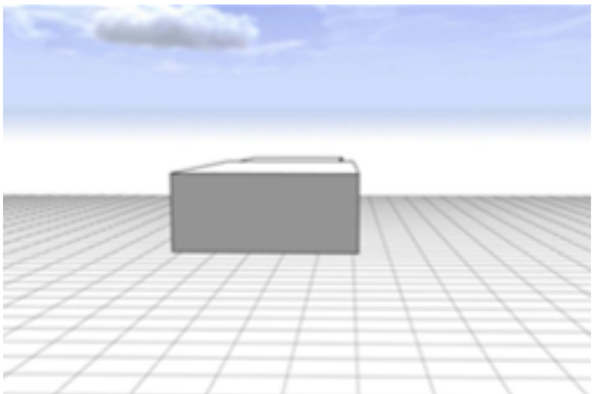
a) Front of the community hall



b) Community hall modelled at LoD1

c) Community hall modelled at LoD3

d) The side of the community hall modelled at LoD3

Figure 9. Results of modelling the community hall

LoD3 was achieved by adding windows and doors to the objects and by adding texture, resulting in a more complex geometric object that resembles the physical environment more closely. For the informal dwellings in our model, the front facade was split into seven sections, as depicted in Figure 10. Sections *S2* and *S6* in Figure 10 were divided into three sections, each along the y-axis so that two windows could be created in the wall. Each window was then split in half along the x- and y-axes to form burglar bars, a common feature in South Africa, even in informal settlements.

The informal structures are constructed mainly from corrugated iron. The corrugated iron was modelled recursively by splitting the front facade (excluding the windows and door) along the x-axis at an interval of 0.10 m. The remaining facades did not contain any windows and therefore only the corrugated iron was modelled for them.

The resulting 3D objects at LoD3 can be seen in Figure 8c and Figure 8d. The same recursive splitting technique was used to generate the texture of the community hall (Figure 9c and Figure 9d). The other objects in the 3D model, such as outside toilets and post boxes, were generated using similar techniques. The final results of the model can be seen in Figure 11.

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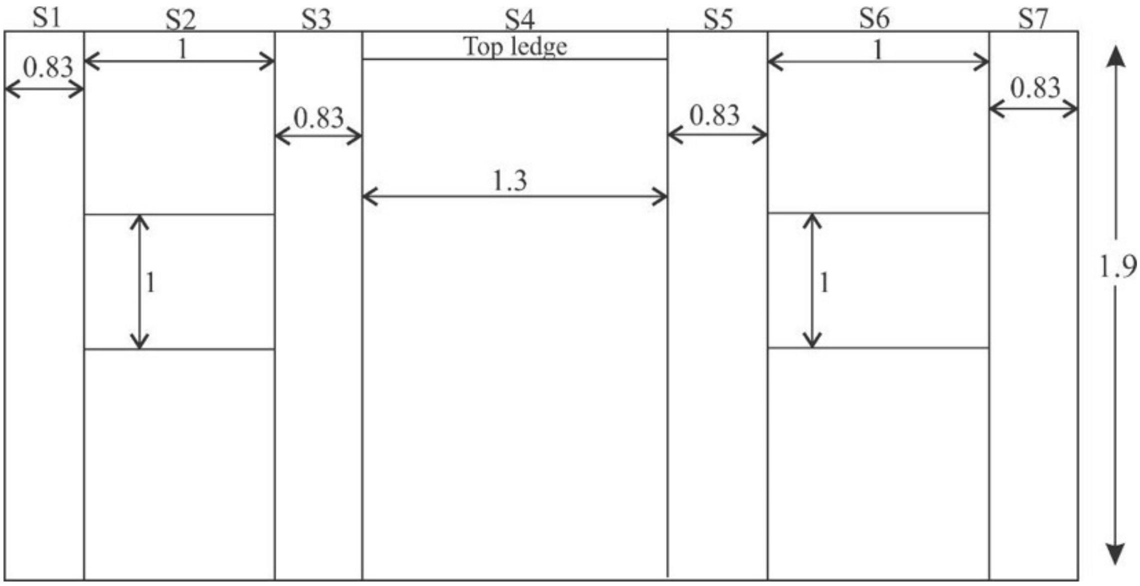

Figure 10. A preliminary plan of the informal structure (not drawn to scale)

Figure 11. A section of the Slovo Park informal settlement modelled at LoD3

2.5. Visualisation characteristics of 3D informal settlements models

Visualisation can support the urban design process at various stages, including the initial gathering of information about the environment; when designing or planning new developments; and for communicating the planned changes to stakeholders. In this section, we describe the visualisation characteristics of 3D models of informal settlements. The characteristics are adapted from those described by Dickmann and Dunker (2014) for 3D building models in urban planning. They defined three categories of characteristics: visualisation content; visualisation application environment and functionality; and visualisation performance. Drawing on discussions with experts, informal

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settlements inhabitants, as well our experience in urban design projects and informal settlement upgrades, the characteristics by Dickmann and Dunker (2014) were adapted for the use of 3D models of informal settlements in urban design (as opposed to urban planning) activities in South Africa.

Table 3. Visualisation characteristics for 3D models of informal settlements in South Africa

Category	Characteristic	Origin	Description
1. Visualisation content	1.1. Level of detail (LoD)	Adopted	Distinct levels according to which 3D models can be generated. The level specifies object complexity and granularity regarding geometric representation and thematic differentiation.
	1.2. Size or extent of the model	Adopted	The area or extent of the model is the physical land covered by the model. Smaller models focus on the area of interest, while larger models 'see the bigger picture'. For example, in informal settlements a larger area is required to see how a community is or can be integrated into the surrounding area.
	1.3. Facade and/or texture	Adopted	The outward appearance of the object. The desired appearance can be achieved using textures (imported from photographs or custom textures using graphic editors) or it is modelled using a combination of geometry and colour.
	1.4. Terrain model	Adapted	The representation of elevation information (the bare ground) without any details about objects on the surface. A terrain model represents the physical characteristics of the natural features in an area, i.e. landform. The terrain provides import information for landscape design and flood drainage in an informal settlement.
	1.5. Topography	Adapted	Commonly known as the physical lay of the land. The earth's surface features, such as relief, terrain, vegetation and any features created in the landscape by human endeavours. Topographical information thus provides import information about the surface in an informal settlement, e.g. natural or human-made barriers.
	1.6. Vegetation	Adapted	The total plant cover of an area, comprising one or more plant species. Vegetation may be considered as landmarks in some cases, e.g. three abnormally tall trees in a specific area could be considered a landmark.
	1.7. Human-made structure	Additional	A human-made structure is any building or dwelling constructed by humans. In informal settlements a wide variety of materials are used, including bricks, wood, corrugated iron and even road signs. Some of these could be classified as landmarks, street furniture or service delivery infrastructure, or could form part of the movement network (e.g. taxi rank).
	1.8. Landmark	Additional	A landmark is a notable object (stands out from its surroundings) used as a point of reference when orientating oneself within an environment, e.g. taxi ranks, cemeteries or playgrounds.
	1.9. Street furniture	Adapted	Street furniture generally refers to pieces of equipment located along a thoroughfare for various purposes, e.g. light poles or road signs. In this case, we use the term to refer to any objects along a thoroughfare that are deemed necessary in the 3D model.
	1.10. Movement network	Additional	A movement network is defined broadly as the public right-of-way network, accommodating land-based movement by a range of movement modes (CSIR Building and Construction Technology, 2003). It is the combination of the traditional road layout and footpaths within a settlement. The

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Category	Characteristic	Origin	Description
			movement network provides an indication of the accessibility of the informal settlement, as well as the accessibility of locations within the settlement.
	1.11. Service delivery infrastructure	Additional	In informal settlements where households do not have running water, water distribution points at various points in the settlement are a common feature. These water distribution points are often just a single tap. Informal electricity connections are also a common feature of informal settlements.
2. Visualisation application environment and functionality	2.1. Model navigation	Adopted	The ability to traverse or move around in the virtual environment. Movement through the model is either user-directed or predefined by the designer of the model.
	2.2. Perspective	Adapted	A perspective, such as the pedestrian perspective or bird's eye view, refers to the specific viewpoint or camera position from which the model is observed.
	2.3. Shading and illumination	Adopted	Shading and illumination add to the realism of the virtual environment, and can also be used to do certain analysis within the model.
	2.4. Measurement tools	Adopted	Allows the user or viewer to determine the length, area or height of an object.
3. Visualisation performance	3.1. Time cost	Adopted	The time and effort required for developing the 3D model; to determine this a cost-benefit assessment may be required.
	3.2. Application performance	Adopted	Refers to the real-time visualisation performance of the application rendering the 3D model.

First, we expanded the visualisation content category by including human-made structures, landmarks, the movement network and service delivery infrastructure. We split vegetation and street furniture into two distinct characteristics. While vegetation in urban areas tends to be cultivated and arranged in an orderly fashion (similar to street furniture), vegetation in informal settlements usually comprises remainders of natural vegetation and haphazardly distributed trees, shrubs and patches of grass. Therefore, it needed to be considered separately.

In the category of visualisation application environment and functionality we combined the pedestrian perspective and bird's eye view into a single characteristic. The remaining characteristics in this category and the visualisation performance category were adapted. Table 3 lists our proposed visualisation characteristics and their descriptions. Adopted characteristics are shaded in dark grey; characteristics adapted for informal settlements are shaded in light grey; and additional characteristics have a transparent background.

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Table 4. Assessment of the importance of each visualisation characteristic to stakeholders in urban design activities

Category	Characteristic	Minor contribution	Moderate contribution	Major contribution
1. Visualisation content	1.1. Level of detail			Informal Urban
	1.2. Size or extent of the model		Informal	Urban
	1.3. Facade and/or texture	Informal	Urban	
	1.4. Terrain model			Informal Urban
	1.5. Topography		Urban	Informal
	1.6. Vegetation	Informal	Urban	
	1.7. Man-made structure			Informal
	1.8. Landmarks		Informal	
	1.9. Street furniture	Informal	Urban	
	1.10. Movement network			Informal
	1.11. Service delivery infrastructure	Informal		
2. Application environment and functionality	2.1. Model navigation			Informal Urban
	2.2. Perspectives			Informal Urban±
	2.3. Shading and illumination	Urban	Informal	
	2.4. Measurement tools		Informal Urban	
3. Performance	3.1. Time			Informal Urban
	3.2. Application performance			Informal Urban

± *Moderate contribution by the pedestrian perspective; major contribution by the bird's eye view.*

Dickmann and Dunker (2014) concluded that the importance of visualisation characteristics varies among different users of 3D models of buildings in city planning. For example, LoD1 or LoD2 are sufficient for planning experts, but community members prefer more detail and textures. Based on their findings and our experience in urban design and informal settlement upgrade projects, each criteria identified in Table 3 was assigned an importance ranking, ranging from *no contribution* to *major contribution* (refer to Table 4). Contribution refers to our assessment of how important the specific visualisation characteristic is regarded by various stakeholders (e.g. settlement dwellers, planners and officials) when using the 3D model in urban design activities.

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2.6. Evaluation of the visualisation characteristics

For communicating planned upgrades, it is important that 3D models, specifically the area of interest, be generated at a high *LoD*, such as LoD3. The higher LoD creates a more realistic and relatable 3D model. If stakeholders can recognise aspects of the environment, they can more easily relate to the model. Consequently, they will have a better understanding of the effect that proposed upgrades may have on their daily lives and environment. The surrounding area is acceptable at a lower LoD. Similarly, a lower LoD is typically sufficient for planning experts when gathering information about the current environment before planning and designing upgrades.

Our research demonstrated that procedural modelling is a viable alternative for generating a 3D model of a typical South African informal settlement at LoD3 (refer to Figure 8 and Figure 9). Roofs, windows and doors were modelled procedurally through either adding geometry or splitting up existing geometry. Substantial initial preparation is required for procedural modelling, however, once the correct dimensions of the objects have been calculated, the procedural technique to model the objects is straightforward and can be repeatedly applied.

The *size or extent of the model* is determined by the planner, and influenced by upgrades where the integration of the area of interest with the surrounding community needs to be considered. However, we consider the size or extent less important for urban design activities, which tend to be localised, in comparison to regional or city planning which needs to consider a wider area. Procedural modelling provides an effortless method of populating the background (space beyond the area of interest) of a 3D model through the repetitive execution of the same procedures with different parameters. There is no limit on the size of the model that can be created with procedural modelling.

Facades and/or texture are less important in informal settlements (similar facades and textures on human-made structures) than in urban areas (more variety in building facades and textures) when collecting information about existing environment or designing upgrades. LoD3 provides sufficient detail about 3D objects to make a model suitable for communicating information about the existing informal settlement. Additional details could prove useful when it is important to communicate the specific facade or texture of a planned building. Detailed facades comprising irregular shapes are time--consuming and tedious to create with procedural modelling. However, once the facade details have been modelled, they can be flexibly combined into a variety of different facades. Various texture libraries are available online and these can be included in the models, as necessary.

A *model of the terrain* also provides useful information when considering integration. For example, it could allow the identification of possible natural barriers (e.g. a *donga,* hill or mountain) to integration into the surrounding area. However, a terrain model also aids in identifying physical risks to the settlement, such as the risk of landslides or flooding. Informal settlements often arise on land not suitable for development, so physical risks may be significant. Therefore, the terrain should always form part of the 3D model of an informal settlement. Aerial imagery draped over height maps can be used to depict various landforms. Such 'draping' is possible with procedural modelling. Terrain modelling, however, was not relevant in this particular study area (Slovo Park) as it is relatively flat.

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Topographical information adds the required detail resulting in a more realistic and relatable model. Topography may also provide reference points to the audience in the public participation process. When considering the integration of the settlement with the surrounding community, topographical information may point out how certain features separate the settlement from the surrounding area. For example, South African 1:50,000 topographic maps include prominent rock outcrops, mine dumps or excavations, graves and powerlines. Such information would already have been considered during planning in a developed urban area, but may significantly impact the location and distribution of planned upgrades in an informal settlement that arises spontaneously. Therefore, we consider this characteristic more important in informal settlements than in urban areas. Procedural modelling provides tools to automate the conversion of topographical information from vector data (e.g. in SHP files) into 3D objects.

Vegetation adds realism to the model, and in some cases, could act as a landmark. Vegetation is, however, a minor consideration when modelling an informal settlement because much of the vegetation is usually destroyed during the construction of the settlement. If a certain element of the vegetation is also a landmark (e.g. an unusually tall tree) then it should be included. In procedural modelling, vegetation is added to the model as an object and then manipulated procedurally. For example, the size of the tree can be increased or additional trees can be added recursively.

Informal settlements comprise *human-made structures,* mainly in the form of informal dwellings. Such dwellings are typically conglomerations of cuboids. Procedural modelling allows developers to generate large quantities of informal dwellings with a single command call in a simple script. More complex structures can also be generated, however, they may require initial preparation (similar to the process for higher LoDs). The human-made structures provide context to understand how planned upgrades relate to and impact on the current environment. For example, it could help inhabitants to understand how accessible a planned community hall, clinic or playground is to their own dwelling. Human-made structures are also considered by planning experts to ensure that the planned upgrades 'fit' with existing dwellings (e.g. avoid destruction of, or are in too close proximity to, dwellings).

Informal settlement dwellers place great value on certain *landmarks* within their community. These landmarks could be of social (e.g. community hall, *shebeen* or water distribution point) and/or cultural (e.g. cemetery or church) importance to them. It is important to include these landmarks in the model, as they provide context for the stakeholders.

As there typically is no *street furniture* in an informal settlement, its contribution to 3D informal settlement models is limited. It should only be included when referred to specifically and when included in planned upgrades.

The *movement and access network* needs to be considered when planning upgrades. For example, access to economic centres, education and health services should be taken into account. Informal settlement dwellers commonly do not own cars and often walk or take public transportation to their destinations. All aspects of the movement network, such as roads, taxi ranks and footpaths, need to

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be included. The movement network is important for determining how best to integrate the settlement into the surrounding community, and also to determine accessibility of a planned upgrade within the informal settlement itself. Existing streets can either be imported into the model (e.g. from a SHP file or spatial database) or grown algorithmically to align with existing buildings and terrain.

Service delivery infrastructure is of concern when the planned upgrades involve upgrades to the infrastructure, the construction of new infrastructure or if planned upgrades are close to existing infrastructure. Infrastructure objects, such as water meters, street lighting poles and electricity distribution boxes, are typically scarce or non-existent in informal settlements. However, it makes sense to at least consider 'other' types of service delivery objects, such as water distribution points and illegal connections to the electricity network (also known as *izinyoka*), as they often pose significant risks to inhabitants. In procedural modelling, 3D objects can be added from libraries (collections of objects that may be shared and reused). A South Africa-specific object library does not exist. Thus 3D objects resembling South African service delivery (e.g. *izinyoka*), vegetation (e.g. indigenous trees) and street furniture (e.g. road signs) had to be developed from scratch for this study.

The ability to explore or *navigate* through the 3D model is a significant consideration when selecting a visualisation application to plan the upgrades (planners) and to demonstrate the planned upgrades to stakeholders (officials and inhabitants). Although interoperability issues still exist, most applications can currently export 3D models into diverse formats for use in a variety of applications. An intuitive mechanism for moving within the model allows unskilled individuals to explore the model and thus better understand the planned upgrades. Alternatively, videos of different view paths through a 3D model allow users to experience specific parts of the model, for example, the area of interest. Such videos can be made available on the Internet for easy access by stakeholders.

Different *perspectives*, such as bird's eye view or the pedestrian perspective, allow the 3D model to be viewed from several angles or viewpoints. Different perspectives are important for officials and experts during the planning stage (e.g. to evaluate the impact of a large building) and for communicating upgrades (e.g. to understand the impact of a large building) to stakeholders.

Shading and illustration are common functionalities in most 3D modelling applications, allowing analyses to be performed, for example, to evaluate solar radiation availability. They are more important to planners than to the public and used, for example, to analyse the availability of solar radiation on the roofs of informal dwellings after construction of a double storey community hall. Owing to the increased use of solar energy in informal settlements, we consider this characteristic more important in 3D models of informal settlements than in 3D models of urban areas, and also more important in urban design than in urban planning.

The importance of *measuring tools* depends on the purpose of the 3D model (e.g. to communicate an initial proposal vs. the final plan). Measuring tools are generally more important during planning than during communication with stakeholders. Procedural modelling produces proportionally accurate models, as calculated dimensions are used to iteratively generate the objects in the model. Navigation,

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perspective, shading and illumination and measuring tools are tool-specific functionalities and are not relevant during the procedural modelling process.

Using procedural techniques for generating intricate 3D models, especially if they contain complex geometric details, is initially time consuming *(time cost)*, as it requires extensive planning and preparation. But once the initial model is generated, modifications can be made by adjusting parameters, commands and scripts. Large quantities of 3D objects can be generated with a single script. Procedural modelling makes it possible to prepare models with semi-realistic structures with minimal effort, and yet, the models contain enough detail for planning, analysis and communication during urban design activities. For financially constrained municipalities in South Africa, procedural modelling could be a cost-effective alternative to expensive manual modelling techniques. Initially, procedural modelling has a steep learning curve for users who are not familiar with scripting and the concepts of spatial data and 3D modelling. This needs to be considered when evaluating the return on investment from the use of procedural modelling.

Procedural modelling is performed using scripts that extrude and generate 3D objects from 2D geometries. The real-time *performance* of the visualisation application relies on the computer specification. The application must be able to handle large amounts of data and render high-quality 3D models in real-time. For the Slovo Park model, a standard desktop PC was sufficient.

2.7. Conclusion

In this article, we discussed the procedural modelling process followed to develop a 3D model of the Slovo Park informal settlement. The visualisation characteristics of the resulting model were evaluated for use in urban design activities in informal settlement upgrade projects in South Africa.

The description and assessment of visualisation characteristics indicated a number of unique challenges for the use of 3D informal settlement models in urban design activities. For example, visualisation content, such as human-made structures and the movement network, are considered important for informal settlement upgrades, but not for modelling typical city centres. On the other hand, facades and/or textures, vegetation and street furniture are less important in informal settlement models than in models of city centres. Increased use of solar energy in informal settlements raises the importance of shading in 3D models of informal settlements. The visualisation characteristics and their assessment in this article are also useful as guidelines for developing 3D models of informal settlements.

Procedural modelling was found to be a viable alternative to the traditional time-consuming manual modelling process for typical South African informal settlements. With procedural modelling, planners can produce cost-effective 3D models for planning and communication during urban design. Although procedural modelling requires initial preparation, once the groundwork is complete, high quantity and quality 3D objects can be generated in near real-time. The scripts can also be reused and customised

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to prepare models of more than one settlement. However, some challenges exist, such as the initial preparatory work, the steep learning curve and the lack of a 3D object library for South Africa.

This article described the frameworks for the development and evaluation of 3D informal settlement models in urban design activities during informal settlement upgrades. In future, we plan to design and perform user studies to empirically evaluate the use of 3D models during planning and communication of informal settlement upgrades in urban design projects. In addition, the development of a South Africa-specific 3D object library for procedural modelling of informal settlements needs to be explored.

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Chapter 3. An assessment of visual variables for the cartographic design of 3D informal settlement models

This chapter was presented as a peer-reviewed oral presentation at the 27th International Cartographic Conference (ICC) 23 to 28 August 2015 in Rio de Janeiro, Brazil, as a paper by Rautenbach, V., Coetzee, S., Schiewe, J., and Çöltekin, A. under the same title.

Contribution: V.R. identified the requirements for informal settlement upgrades and provided the first assessment of the appropriateness of the subset of visual variables, which was reviewed by the other three authors. V.R. wrote the majority of the paper under the guidance of S.C. and the final paper was jointly finalised by all four authors.

3.1. Abstract

Visual variables were originally proposed for hard copy maps printed in black and white by Bertin in the 1980s. However, we can now generate various digital geovisualisation products that are inherently different from printed maps, such as interactive 3D city models. Additional visual variables have been proposed for some of these new geovisualisations, but the discussion is still ongoing. In this paper, we contribute to this discussion by investigating the relevance of a subset of visual variables for planning informal settlement upgrades in 3D geovisualisations, and specifically how these variables contribute to the selectiveness of objects. The variables were systematically evaluated against specific requirements for planning upgrades which were compiled using expert knowledge. We observe that evaluated visual variables, except colour and texture, are not directly transferrable. Furthermore, we propose that; in an interactive 3D setting, visual variables position, orientation and motion should not be only considered in relation to the objects in a 3D environment, but also in relation to the camera, and the concept of Level of Detail (LoD) should replace shape. The results contribute towards building design principles of 3D informal settlement models for planning upgrades.

3.2. Introduction

Informal settlements (also known as squatter camps, shantytowns or slums) are densely populated illegal or unauthorised settlements characterised by rapid and unstructured expansion and improvised dwellings made from scrap material (Mason *et al.*, 1997; Huchzermeyer and Karam, 2006; City of Tshwane, 2012). The settlements are traditionally located along the borders of urban areas, close to the social and economic hubs. As informal settlements are considered to be illegal or unauthorised, they lack secure tenure, basic service delivery (e.g. access to water, electricity and waste removal)

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and infrastructure (e.g. roads and storm water drainage) (Sliuzas, 2003; Richards *et al.*, 2006; Paar and Rekittke, 2011; City of Tshwane, 2014). In South Africa, informal settlements arise due to biased planning, housing backlog and the search for work and a better quality of life (Richards *et al.*, 2006; City of Tshwane, 2014).

The South African government has prioritised the upgrading of informal settlements to ensure that all citizens have adequate housing and access to basic services (South Africa National Planning Commission, 2012). Planning informal settlement upgrading is part of the urban planning process and could integrate geovisualisation to *understand* the current environment, and to *communicate* planned developments. Maps and aerial photography have successfully been used in the past to gather information from the local community (Mason *et al.*, 1997; Sliuzas, 2003; Paar and Rekittke, 2011). However, recent research suggests that three-dimensional (3D) geovisualisations are a viable alternative for collecting and exploring information virtually. Especially when used in conjunction with site visits, 3D geovisualisations have successfully been utilised in other application fields, such as forensic science and anthropology (Gibson and Howard, 2000; Agosto *et al.*, 2008; Gruen, 2008; Koller *et al.*, 2009).

When using 3D informal settlement models for urban design, users should be able to extract information from the model, such as distance from a water distribution point or sunlight exposure for placement of solar geysers. This type of information can be visualised in 3D models using graphical aspects (in other words, visual variables) such as facade *colour*, *texture* or *size* of the object (Döllner, Baumann, *et al.*, 2006). Information needs to be simplified and abstracted when visualised using visual variables (Michael Wood *et al.*, 2005).

In this paper, our goal is to assess the relevance of a subset of visual variables for 3D geovisualisations of informal settlements for urban planning. The assessment is based on whether visual variables can be *selective* (see Table 6 for Bertin's definition of this term) in the context of visualising 3D informal settlements for the purposes of planning upgrades. The results will contribute towards obtaining design principles for 3D informal settlement models in the context of urban planning. The focus of this paper is on 3D models, i.e. accurate and mathematically correct 3D digital representations of an area (Chen, 2011); rather than 3D maps, i.e. a generalised representation of a specific area using symbolisation to illustrate physical features (Häberling *et al.*, 2008).

3.3. Visual variables

Bertin (1983) pioneered the concept of visual variables for designing data graphics for print on white paper under normal reading conditions, listing seven variables*: position, size, shape, value, colour, orientation* and *texture*. At the time, Bertin (1983) did not see the usefulness of dynamic maps and argued that motion would dominate the graphic and disturb the effectiveness of the cartographic message. However, through the years, visual variables were extended for interactive displays, most prominently by DiBase *et al.* (1992) and MacEachren (1995) who introduced six new visual variables:

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movement, duration, frequency, order, rate of change and synchronisation. Another decade later, Carpendale (2003) also argued that *motion* should be considered a visual variable for information visualisation on computational displays. Furthermore, Slocum *et al.* (2009) proposed *perspective height* which is important for 3D models. Information visualisation introduced *sketchiness* as a visual variable that has been found quite effective in visualising uncertainty (Boukhelifa *et al.*, 2012; Wood *et al.*, 2012). In a recent paper, Halik (2012) provides a complete chronological breakdown of static visual variables and identifies the following static visual variables that are most frequently used in literature: *size, shape, lightness/value, orientation, texture, location (position), hue, saturation/intensity* and *arrangement*.

Visual variables have been adapted successfully in various application fields, such as visualising interactive information, 3D cadastre and 3D maps, and evaluated (Köbben and Yaman, 1996; Fosse *et al.*, 2005; Döllner, Baumann, *et al.*, 2006; Heer and Robertson, 2007; Halik, 2012; Wang *et al.*, 2012; van Oosterom, 2013; Walker *et al.*, 2013; Brychtová and Coltekin, 2014).

Table 5 provides descriptions of the visual variables considered in this paper. Note that the term *mark* refers to points, lines, and areas (or polygons) in 2D maps, and for 3D models, Carpendale (2003) proposed surfaces and volumes as marks.

When choosing which visual variable to modify, it is important to understand how it will affect the user's ability to perform a specific task (Carpendale, 2003). Visual variable characteristics were developed to classify the variables according to their practicality (Halik, 2012). Table 6 provides an overview of the characteristics.

Table 5. Subset of visual variables considered in this paper (Häberling, 2002; Carpendale, 2003; Wang *et al.*, 2012)

Visual variable	Description
1. Position	Position is considered the most versatile visual variable and is important for representing geovisualisations (the exact position of objects in a geovisualisation). On a 2D computational display, two positional variables X and Y are used, and on a 3D display, three variables X, Y and Z.
2. Size	A mark's size can be changed in length, area or volume. However, when modifying the size of a mark, altering the meaning should be avoided.
3. Shape	Varying the outline, not the size, can change a mark's shape. The shape can be associated with a specific meaning (i.e. a red cross denotes a medical facility). The link between shape and meaning can be cultural, and is commonly stated on the legend of a map.
4. Value	A shift in the value of a mark is attained by changes in lightness or darkness (range of shades in grey).
5. Colour	Changing a mark's colour involves adjustments in the hue without affecting the value. On computational displays, changes in saturation and transparency are included in this visual variable.
6. Orientation	The orientation of a point has an infinite number of different orientations, and orientation of a line or area is altered by the angle of the pattern. In 3D environments, the orientation of the camera (viewing angle) is included.
7. Texture	This visual variable refers to grain, pattern and texture. With advancements in technology a wide variety of grains, patterns and textures are available to display characteristics of various materials.
8. Motion	Motion was impossible with printed graphics. With computational displays, motion is possible; however, this has not been researched comprehensively. Motion has various aspects to consider, such as direction, speed, flicker, frequency and rhythm.

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In addition to the visual variables listed in Table 5, various other aspects should be considered for interactive 3D models: e.g. *camera setting, lighting and illumination, shading and shadows,* and *atmospheric and environmental effects* (Häberling, 2002). However, these aspects are not considered in this paper, as they are beyond the scope of our case study. These variables are important to consider for a sense-of-place experience (e.g. virtual reality experiences, gaming) but for our urban planning context with a specific purpose (informal settlement upgrades in South Africa), we start with the most basic visual variables.

Table 6. Characteristics of visual variables (Bertin, 1983; Carpendale, 2003; Halik, 2012; Wang *et al.*, 2012)

Characteristics	Description
1. Selective	A visual variable is selective if a mark can be changed in only this variable and easily differentiated afterwards.
2. Associative	A visual variable is associative if several marks that are related can be grouped according to a change in only this visual variable.
3. Quantitative	A visual variable is quantitative if the relationship between two marks can be expressed as a numerical value.
4. Order	A visual variable is ordered if marks can be ordered and if changes in this visual variable express the ordering.

3.4. Upgrading informal settlements in South Africa as a use case

One of the main aims of the South African National Development Plan (NDP) is to improve the standard of living of all South Africans. The NDP highlights adequate housing, and access to clean water, sanitation and electricity as key elements for achieving a minimum standard of living (South Africa National Planning Commission, 2012). According to the Municipal Systems Act of 2000, each district municipality shall develop Integrated Development Plans (IDP) spanning five years. The IDP informs and guides all development activities within the region. The City of Tshwane IDP aims to provide *sustainable service infrastructure and human settlement management* (strategic objective 1), and as part of this outcome three aims to *develop quality infrastructure to support liveable communitie*s (City of Tshwane, 2013). For the financial year 2014/15, the City of Tshwane aims to formalise seven informal settlements; proclaim eight identified settlements; and, increase the number of households in informal settlements that have access to rudimentary water, sanitation and waste removal services.

Figure 12 presents an overview of the process to be followed when an informal settlement is upgraded. It also indicates the level of services available at each stage of upgrading. Geovisualisation can be useful to *understand* the initial or current situation (Level 1) and to *communicate* planned developments for subsequent levels.

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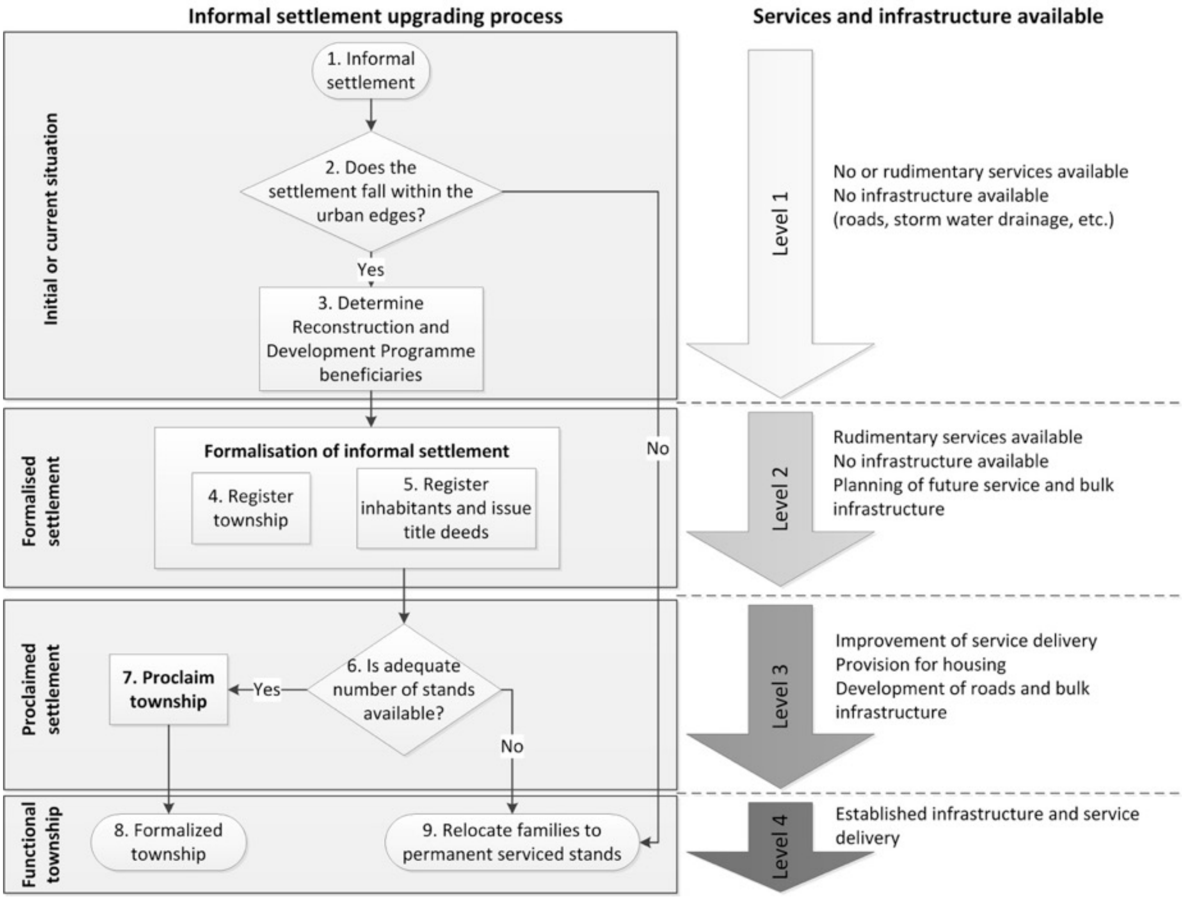

Figure 12. Informal settlement upgrading process

3.5. Requirements for 3D informal settlement models

In this context, formalisation refers to the legal processes required to create townships (township establishment) with formal service delivery through which residents obtain security of tenure. This normally includes the development of top structures, such as houses, through government-funded programmes. For the formalisation of an informal settlement, the principal planning task is identifying (or distinguishing) individual stands (also known as land parcels) and allocating addresses (including street names).

The following are key considerations when deciding to do in-situ upgrading or to relocate the settlement during formalisation (South Africa Housing Development Agency, 2011; City of Tshwane, 2012; City of Tshwane, 2014): *can the settlement be integrated into the adjacent communities? Is adequate access to the city and main economic hubs possible? Is the area of a stand large enough for the number of individuals, accommodating changing requirements over time, e.g. single to multiple households?*

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Therefore, the following are essential requirements for a 3D informal settlement model:

1. **Representation of the terrain of the stands**: Understanding the terrain of the environment is important for determining if the settlement is located on a suitable terrain. For example, harsh terrains like rocky or mountainous areas should be avoided.

2. **Representation of the boundaries of a stand**: The extents of stands in informal settlements are not well defined, as the area is typically very densely occupied. It is important that the stakeholders can identify the bounds of a stand in a 3D model. During the *formalisation of the informal settlement* (Figure 12) it is required to identify the boundaries of the stands and to determine if the stands satisfy predetermined specifications.

3. **Representation of spatial patterns among stands**: The spatial patterns among stands within an informal settlement and adjacent community are important to plan how the informal community can be integrated with the surrounding city for the *formalisation of the informal settlement*. The spatial patterns provide insight into the distribution of the stands in the settlement and can assist in planning upgrades to ensure lower density and improved infrastructure.

4. **Representation of spatial relationships between stands and other physical objects**: The relationship between the stands and other objects such as water tanks or footpaths is vital to answer some of the key considerations mentioned above.

5. **Representation of the impact of new infrastructure**: Service delivery infrastructure is important for enhancing the quality of life of the inhabitants. However, not always positively; e.g. high voltage electricity transmission lines would affect the height of new structures and nearby vegetation. Refer to the *functional township* in Figure 12.

6. **Display of additional information**: Information, such as addresses, is important in informal settlements for the *planning of future service delivery and bulk infrastructure* (refer to Figure 12 Level 2). Additional information, such as the size of a stand or distance from water distribution points, can be displayed on labels.

3.6. Evaluation of visual variables for the requirements of informal settlement upgrading

We evaluate the relevance of a subset of visual variables for interactive 3D informal settlement models considering only the selective characteristic as an exercise to systematically study the transferability of visual variables in this context. In this manuscript, “3D geovisualisation” refers to an abstraction of real world objects on 2D displays with 3D perspective views. The following visual variables are included in the study: *position, size, shape, value, colour, orientation, texture and motion* (Table 5 provides a short description of each variable). Note that for this exercise, we only considered expert users, and a non-exhaustive list of geovisualisation requirements. The requirements were collected

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through a literature review and expert knowledge, and only the primary requirements are discussed (refer to Section 3.5). The requirements consider 3D objects and text labels.

Table 7 provides a summary of our assessment (refer to Annex D. Selected examples of visual variables for cartographic design for examples of each visual variable). We phrased a question for each requirement and visual variable; for example, *can position be used to enhance the selectiveness of a stand's boundary?*

Table 7. Relevance of visual variables for the requirements of informal settlement upgrades (selective)

Requirement \ Visual variable	Position	Size	Shape	Value	Colour	Orientation	Texture	Motion
1. Representation of the terrain of the stands	No	Limited	No	Limited	Yes	Limited*	Yes	Limited
2. Representation of the boundaries of a stand	Limited*	No	Yes, but changes are rather in LoD than shape	Limited	Yes	Limited*	Yes	Yes
3. Representation of spatial patterns among stands	Limited*	Yes	Yes, but changes are rather in LoD than shape	Limited	Yes	Limited*	Yes	Yes
4. Representation of spatial relationships between stands and other physical objects	Limited*	Yes	Yes, but changes is rather in LoD than shape	Limited	Yes	Limited*	Yes	Yes
5. Representing the impact of new infrastructure	Limited*	Yes	Yes, but changes are rather in LoD than shape	Limited	Yes	Limited*	Yes	Yes
6. Display of additional information	Yes	Yes	No	Limited	Yes	Limited*	No	Yes

** Limited, only appropriate for the camera.*

Informal settlement upgrade planning requires accurate models, i.e. existing objects should be shown in their correct positions. This does not necessarily mean that the model shall be georeferenced, but that all objects representing existing features (e.g. shelters) and planned developments (e.g. tar roads or water distribution points) should be placed in their correct relative position. Thus **position** is not applicable as a visual variable for the requirements relating to objects, as changing the X, Y or Z positional parameter of the object will alter the accuracy of the model. However, the position of labels displaying additional information can be altered as needed to ensure that the information is optimally placed and legible.

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The position of the camera is applicable for all requirements as it can enhance the selectiveness of the desired objects. For example, by focusing on new developments, such as a (proposed) bridge to connect the settlement to the local community, when entering the 3D environment, we expect that the user will immediately notice them. However, changes in the camera position might alter or distort perspective. These distortions can make an object (e.g. a shelter) appear larger or leaning to one side (e.g. would make the shelter seem structurally unsound).

A change in **size** is not suitable for most requirements. For example, size is not suitable for representing the terrain or boundary as changes might alter the meaning. For example, the boundary of a stand cannot be extruded to make it more visible, as this extrusion would alter the meaning of the boundary (the boundary might be interpreted as a wall). However, altering the size of an object depending on the distance from a specific location or object (e.g. proportionally reducing the size of shelters according to the distance from a water distribution point) could be quite effective.

We found that **shape** was not appropriate for 3D models. Instead we propose *level of detail (LoD)* to be considered. Changing an object's physical shape may change the meaning of the object. For example, changing the shape of a shelter (generally a cuboid) to a sphere would not contribute to the informal settlement upgrading requirements. However, LoD is a method of modifying the shape of the objects in subtle ways by adding or removing detail, while keeping the global shape recognisable (Çöltekin and Reichenbacher, 2011). A high LoD is often associated with higher realism, and considered to be useful for showing new developments or upgrades in the environment by planners. Additional housing to be developed can be shown in a higher LoD. This would contribute to the selectiveness of the objects.

Modifying the colour **value** refers to changes in lightness or darkness, but was found to be of limited relevance for the requirements. Modern 3D models are generated in self-illuminating environments and typically there is no light source or shadow. Colour value would only be effective for certain views, such as static overviews. Self-illuminating environments pose a challenge because as the user navigates through the environment, the lightness of objects changes, and then value is not an optimal visual variable to employ for selectiveness. An example of changes in colour value could be for planning the addition of solar geysers; i.e. shelters with high sun exposure would appear lighter than those with a lower sun exposure.

Variations in colour, texture and LoD contribute to the realism of the 3D environment. Changes in **colour** and **texture** were found to be the most relevant visual variables for the requirements. Various colours or textures can be used to highlight certain aspects and to ensure selectiveness. However, selecting the optimal colour or texture for informal settlement upgrading remains an issue that needs to be investigated further.

Orientation was found not to be relevant for any requirement, as altering the orientation of an object in the 3D environment would change the meaning and accuracy of the model. However, changing the

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orientation of the camera to focus on the aspect that needs to be distinguished would potentially assist in the selectiveness of certain objects

The use of **motion** in 3D environments still needs further research, but motion is essentially the principal attention grabber of all visual variables. Carpendale (2003) stated that it is then fundamentally selective. However, spinning a house around in a city model might not be an optimal choice, but rather a flickering object would immediately get the attention of the user (used with caution). Thus motion was found to be relevant for all requirements. The motion of the camera can also be included, for example, the user's attention would be drawn to a specific development corridor. Motion should be cautiously used, and the viewer should be able to deactivate it at any time.

3.7. Conclusion

In this paper, we present results from an expert assessment of the relevance of a subset of visual variables for 3D interactive geovisualisations of informal settlements for urban planning. Our goal was to evaluate the selectiveness of the visual variables for specific geovisualisation requirements of planning upgrades in informal settlements.

Various researchers have expanded on Bertin's (1983) visual variables and there are many interesting suggestions for interactive displays. However, in the scope of this paper, we only considered the following variables: *position, size, shape, value, colour, orientation, texture and motion*.

Position in the traditional sense is not easily utilised as a visual variable, as we cannot move the physical position of a river, for example. However, *the position of the camera* is very important in a 3D environment as the placement may enhance the selectiveness or distort the perspective. Not only should the camera position be considered as an additional aspect of position as a visual variable, but also the *camera orientation* and *camera motion*. *Motion* is an integral part of interactive 3D geovisualisations, and can be of great use as an attention grabber. Nevertheless, motion can limit the visual variable *value*. Due to motion and self-illumination of environments, value needs to be used with care as dynamic light sources and self-illumination might influence how the value is displayed. As a result of this qualitative evaluation, *colour* and *texture* emerge as the most powerful variables, because these two were found to be appropriate for all requirements. Optimal colour and texture need to be further investigated. We suggest that *shape* is replaced with LoD, as it is commonly used in computer graphics to add or eliminate detail from 3D objects (Luebke, 2002). More detailed objects are considered to be more selective, as they (potentially) capture the attention of users more easily in an environment where most objects will have lower LoDs. The opposite would also apply – a lower LoD objects in a highly detailed environment.

In this study, we conducted a conceptual exercise by rethinking the visual variables for 3D in a very specific context of urban planning. We argue that such studies are useful in expanding the cartographic knowledge beyond its usual audience and application domains. With this manuscript, we

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provided new observations and suggestions which may be applicable for 3D geovisualisations in general. As next steps, we plan to evaluate the other characteristics (associative, quantitative and order) of visual variables, as well as additional visual variables to establish the most useful visual variables for 3D geovisualisations of informal settlements. Following this, we plan to evaluate the proposed visual variables with user studies to complete our top-down expert evaluation with empirical observations.

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Chapter 4. Exploring the impact of visual complexity levels in 3D city models on the accuracy of individuals' orientation and cognitive maps

This chapter was presented as a peer-reviewed oral presentation at the International Society for Photogrammetry and Remote Sensing (ISPRS) workshop 28 September - 3 October 2015 in La Grande Motte, France, as a paper by Rautenbach, V., Çöltekin, A. and Coetzee, S., under the same title.

Contribution: V.R. designed and conducted the experiment, under the guidance of S.C. The first draft of the paper was written by V.R. and S.C. and then revised by A.C. to improve the focus and structure of the paper.

4.1. Abstract

In this paper we report results from a qualitative user experiment (n=107) designed to contribute to understanding the impact of various levels of complexity (mainly based on levels of detail, i.e., LoD) in 3D city models, specifically on the participants' orientation and cognitive (mental) maps. The experiment consisted of a number of tasks motivated by spatial cognition theory where participants (among other things) were given orientation tasks, and in one case also produced sketches of a path they 'travelled' in a virtual environment. The experiments were conducted in groups, where individuals provided responses on an answer sheet. The preliminary results based on descriptive statistics and qualitative sketch analyses suggest that very little information (i.e., a low LoD model of a smaller area) might have a negative impact on the accuracy of cognitive maps constructed based on a virtual experience. Building an accurate cognitive map is an inherently desired effect of the visualisations in planning tasks; thus the findings are important for understanding how to develop better-suited 3D visualisations such as 3D city models. In this study, we specifically discuss the suitability of different levels of visual complexity for development planning (urban planning), one of the domains where 3D city models are most relevant.

4.2. Introduction

Developing countries are affected by numerous socioeconomic problems, such as poverty, poor social services, lack of infrastructure for human development, and serious resource depletion, often as a consequence of inadequate planning. Development planning (i.e., urban planning) is globally very important for sustainable progress in all these areas, and this is especially true in developing countries.

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Geographic visualisations are an essential component of such planning processes. For example, in our case study area (South Africa), two-dimensional (2D) maps are frequently used for development planning. However, in a recent study, Clarke (2007) documented that development planning professionals in South Africa have a low level of functional map literacy. This indicates that the planners were not able to effectively read these abstract 2D maps, which, in turn, negatively impacted critical planning processes. Therefore, Clarke (2007) suggested that alternative new visualisations (which may suffer less from this lack of map literacy) should be investigated for development planning.

The Internet and other related technologies brought about many new methods of geovisualisation and data exploration, such as virtual globes (e.g., Google Earth, NASA World Wind), interactive online maps (e.g., Google Maps and OpenStreetMap), 3D virtual city models (Morton *et al.*, 2012) and many others. Similarly, cities have been represented in various formats, e.g., 2D maps, 3D physical scale models, and various 3D digital representations (Morton *et al.*, 2012). The popularity of 3D city models and their applications is rapidly increasing (van Lammeren *et al.*, 2005; Glander *et al.*, 2009; Wen *et al.*, 2010; Gröger and Plümer, 2012; Pasewaldt *et al.*, 2012). These 3D city models have been reported to be successful for development planning by various experts (Isikdag and Zlatanova, 2010; Wu *et al.*, 2010; Chen, 2011; Wu *et al.*, 2013).

3D city models are also essential components of a spatial data infrastructure (SDI) because of their function as integration platforms for geospatial data (Hildebrandt and Döllner, 2009). However, while traditional cartography offers various (mainly theory based) design principles for two-dimensional (2D) maps, there seems to be considerably less theory for three-dimensional (3D) visualisations (Rautenbach, Coetzee, *et al.*, 2015). Additionally, there are very few empirical user tests to demonstrate for which tasks 3D visualisations may be a good fit (Boér *et al.*, 2013) and in our case study area (South Africa) the application of 3D models for development planning has been initiated but not yet empirically tested (Rautenbach *et al.*, 2014). Regardless of which domain or user group is targeted, user-centred thinking is important in visualisation design. Especially in interactive computer-generated virtual environments the human user is allowed to be an active participant, rather than an inactive observer (Henry, 1992). The illusion virtual environments create is compelling, especially with stereoscopic visualisations, but also with otherwise large screen realistic displays because they provide the participant with a sense of presence (the illusion of truly being within this environment). Virtual environments have been used in many domains ranging from medicine to psychology and from spatial cognition to urban planning because they provide us with the aforementioned sense of presence. We can immerse ourselves in the experience of an environment by moving around within it, inspecting it from above, watching a movie, studying a map, or listening to a verbal description of it (Pazzaglia and De Beni, 2006). Similarly to being in the 'real world', when we encounter a new virtual environment, our mind immediately starts to build a cognitive map (also known as a mental map) of this new space. A cognitive map is a map-like mental construct that stores spatial knowledge in memory that can be mentally inspected (Tversky, 1993). These cognitive maps serve as a survival mechanism that allows us to navigate in unfamiliar territory (Lynch, 1960; Henry, 1992).

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This paper presents results from a qualitative/observational user experiment to evaluate the influence of the visual complexity of 3D models on an individual's orientation and cognitive map after being exposed to unfamiliar virtual environments in a walkthrough. The results contribute to hypothesis building for future experiments.

4.3. Background

4.3.1. Measuring the orientation ability and cognitive maps

Spatial cognition deals with the acquisition, organisation, utilisation, and application of knowledge about phenomena in the physical world (Bodine, 2006); thus it is intertwined with processes of thinking, reasoning, memory, abstraction, problem solving, perception, sensation, belief, and language (Burgess, 2008). With this in mind, Tversky (1993) argued that the cognitive map is rather a cognitive collage. The knowledge we collect about unfamiliar environments is unquestionably rich and complex. This so-called cognitive collage contains spatial memories, e.g., routes previously taken, things we have seen, heard or read about, and information about the weather, to name a few. Many of these spatial memories have a 3D component as we experience the world in a "first person view". Therefore, 3D spatial memory is important in our everyday life. For example, the ability to navigate from one point to another within a shopping centre requires 3D processing in the brain (Vidal and Berthoz, 2005). Due to the richness of spatial memories, Lynch (1960) found that it is almost impossible to be truly lost within a city. However, even if we are never "truly lost", a moment of disorientation can lead to severe anxiety, depending on the personality traits, or induced by the contextual circumstances (Cubukcu, 2011). A better understanding of our spatial experiences, e.g., through a study of how we form cognitive maps, might be a key approach in (eventually) addressing some of these anxieties. Canter (1977) suggested obtaining people's cognitive maps by asking them to sketch a plan. This is an information-rich method, since it includes the sizes of the individual spaces, their location relative to each other, and specific details or landmarks. However, sketching can be challenging for some: the participant is required to convert a 3D cognitive map into a 2D plan. This 3D-to-2D conversion (perspective transformation) may be difficult for some individuals. In other words, even though they might have a perfect 3D cognitive map, transforming it into a 2D plan on paper could be challenging.

To address the shortcomings about 2D-3D perspective transformation, Okabe *et al.*, (1986) utilised an indirect method for measuring the accuracy of cognitive maps and eliminating errors present in sketches. This method is known as the "point-in-the-direction" technique. With this method, participants move within an environment and at an explicit point they are asked to point in the direction of a specific object or place that was previously passed. The object or place (target) would no longer be in sight, and the participants would need to rely on their cognitive map for the location of the target. To add another level of complexity, the participants can also be asked to estimate the straight line distance (as the crow flies) from their current location to a specified target (Okabe *et al.*, 1986; Henry, 1992). While both point-in-the-direction and distance estimation allow collecting information related to cognitive maps, overall these methods allow less information to be derived in comparison to sketches.

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4.3.2. Levels of detail

To guide modelling and visualisation decisions of a "walkthrough" experience in a virtual environment, it is important to understand which level of detail (LoD) facilitates construction of an accurate cognitive map. Arguably the most common approach to manage the LoD of a 3D model (which is the foundation of all virtual environments) is controlling the number of polygons that construct an object. For example, "distance to the viewer" is among the most established spatial criteria, i.e., a 3D object's complexity (number of polygons) is intentionally decreased as it moves further away from the camera or viewer. In city models, LoD is a standardised concept for defining levels of complexity when representing geographic objects (Biljecki *et al.*, 2013). These standardised LoD definitions are used in 3D modelling as a mechanism for describing product specifications (and to facilitate the acquisition process) and as a step for generalisation.

In the experiment described in this paper, the Open Geospatial Consortium (OGC) CityGML definition of LoD is used. The CityGML standard differentiates five consecutive LoDs for urban models with increasing complexity and granularity regarding both their geometric representation and their thematic differentiation (Open Geospatial Consortium, 2008). The LoDs are defined ranging from level 0 to 4:

- LoD0 – regional, landscape: This is the coarsest level. It is essentially a two and a half dimensional (2.5D) digital terrain model that can be draped with aerial imagery to create a more realistic view.
- LoD1 – city, region: Level one consists of well-known block models comprising prismatic buildings with no (or flat) roofs.
- LoD2 – city districts, projects: This level adds differentiated roof structures and thematically discrete surfaces.
- LoD3 – architectural models (outside), landmarks: Level three denotes architectural models with detailed wall and roof structures, balconies and bays, to name a few. At this level, the outside architecture of the buildings should be consistent with the real world object. In addition, detailed vegetation and transportation objects are components of a LoD3 model.
- LoD4 – architectural models (interior): Level four adds interior detail to the model, such as number of rooms, interior doors, stairs and furniture to the building.

The CityGML LoD definition has been criticised (Fan and Meng, 2012; Biljecki *et al.*, 2013); however this definition is currently the only one that is standardised by either the International Organization for Standardization (ISO) or the Open Geospatial Consortium (OGC) and will be used as the main differentiator between the various levels of visual complexities used in this experiment.

4.3.3. Related work

Pazzaglia and Taylor (2007) studied the effect of spatial perspectives and wayfinding instructions on the navigational accuracy and speed of participants. Fifty-four undergraduate students were taught an

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urban route either while watching a moving dot on a map (survey perspective, i.e., aerial or top view), or following an avatar through a virtual navigation (route perspective, i.e., first person or street view). Results suggest that the route perspective is “more functional to navigation” while survey perspective provides a more complete environmental representation (Pazzaglia and Taylor, 2007). In a similar study, Hund and Minarik (2006) asked participants to navigate through a city model using landmarks (e.g., turn towards the church on Stead Ave) or cardinal (e.g., go north on Stead Ave) directions. They concluded that participants who were given cardinal directions completed the tasks faster and more precisely than the landmark directions group, though these results should be interpreted carefully as there may be cultural differences in utilising cardinal directions.

In another study conceptually similar to ours, Cubukcu (2011) reports the effect of visual detail in virtual environments on participants’ spatial performance when they estimate direction and distance (straight line and walking distances), and produce a sketch. In the experiment, 49 participants were exposed to a small virtual environment generated with low (portrayed with four colours) and high (using textures) visual detail. The authors did not observe a significant effect on spatial performance based on the tested high or low visual detailed environments, suggesting that for certain tasks and user groups, a low-detail visualisation may suffice (Cubukcu, 2011). While Cubukcu (2011) did not observe a difference between the two levels of detail for the tasks she tested, some studies suggest that visualising too much detail can impair memory in some tasks (Borkin *et al.*, 2011). Conversely, this memory-related finding does not seem to apply in all cases. For example, Cockburn (2004) investigated the effect that 2D and 3D have on spatial memory where letters and flags were presented to the participants in 2D and in 3D. This study demonstrated that letters were recalled more easily than flags because the participants can rely on mnemonics, but 3D made did not impair or improve the effectiveness of spatial memory for this task.

4.4. Methodology

A qualitative user experiment was conducted in this study where tasks were delivered in a classroom, supported by answer sheets. The goal was to observe the impact of various visual complexity levels and the training effect on the accuracy of a participant’s orientation and cognitive map.

4.4.1. Participants

107 undergraduate students (51 males, 56 females) participated in the study. The majority of the students were from the Science Faculty. Other students were from the Education, Engineering, Built Environment and Information Technology Faculties. Refer to Figure 13 for a detailed breakdown of degree programs. The participant age varied from 18 to 25 years, with an average age of 20 years. This student population was targeted purposefully as we consider them future professionals (and community members) in the domain of interest (development planning). The experiment was repeated with three groups of students (44, 25 and 38) on three different days.

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4.4.2. Study design and materials

The study was designed to observe the impact of different levels of visual complexities and the effect of training on the accuracy of the participants' orientation and cognitive maps. The visual complexity can be defined based on various computational and human factors (Schnur *et al.*, 2010). In this study, it was defined with reference to different CityGML-related LoDs (LoD1, LoD2 and LoD3), the extent of the area covered, the number, structure and density of objects, number and type of landmarks and the camera angle in the virtual environments. For simplicity, we will refer to different levels as Visual Complexity 1 (VC1), VC2 and VC3.

The number, structure and density of objects as well as the extent of the area of interest, varied over the three models (see Table 9). The structure of the VC1 model was simplistic (consisting of basic geometric objects) and covered a small area (Figure 14). The VC2 was a model of Alexanderplatz, spread over a larger area with prominent landmarks of different heights and form, such as the Berliner Fernsehturm and the Berliner Dom (Figure 15). The VC2 model covered the largest area, 1,403 km^2. The VC3 was a model of Ettenheim, a compact town with unobtrusive landmarks but more detailed building representations and street furniture (Figure 16). The VC3 model covered an area of 0.795 km^2.

Table 8. Visual complexity levels in this experiment

	VC1 (abstract)	VC2 (Berlin)	VC3 (Ettenheim)
Level of detail (LoD)	LoD1	LoD2	LoD3
Number of objects	6	Around 100	Around 100
Extent of area of interest	--	1,403 km^2	0,795 km^2
Density of objects	Low	Medium	High (smaller area)
Structure of objects (variation and landmarks)	Limited variation	Moderate variation	Some variation (less than VC2)

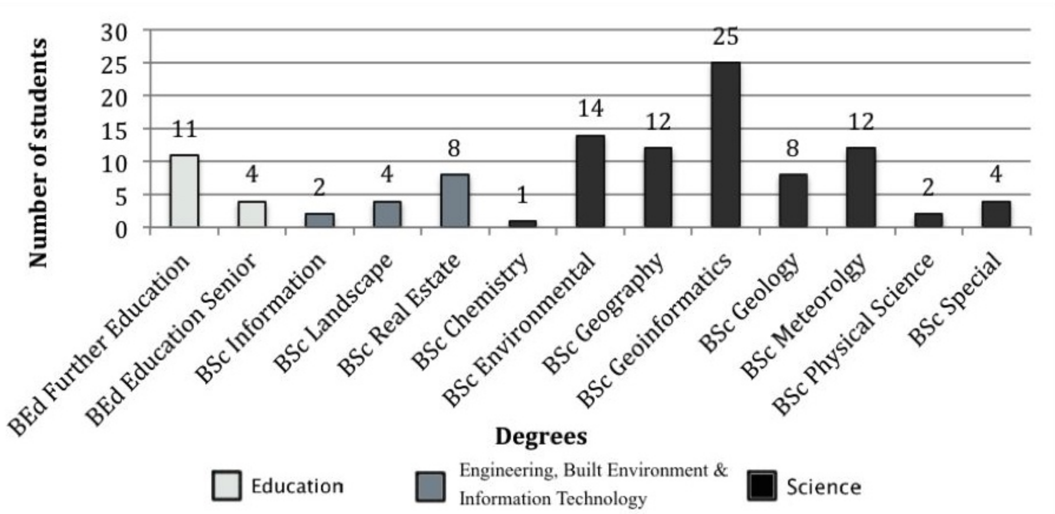

Figure 13. Degree programs participants are enrolled in

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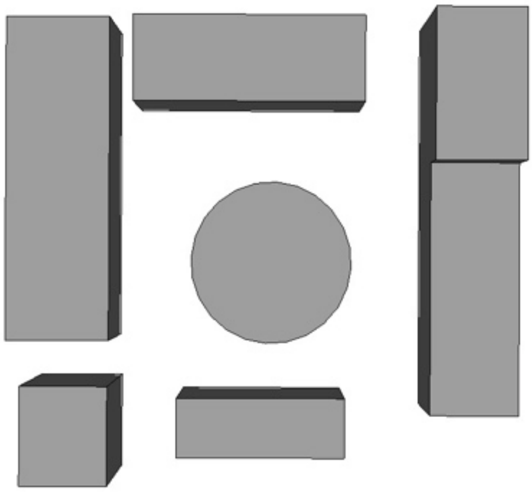

Figure 14. Top view of the VC1 model

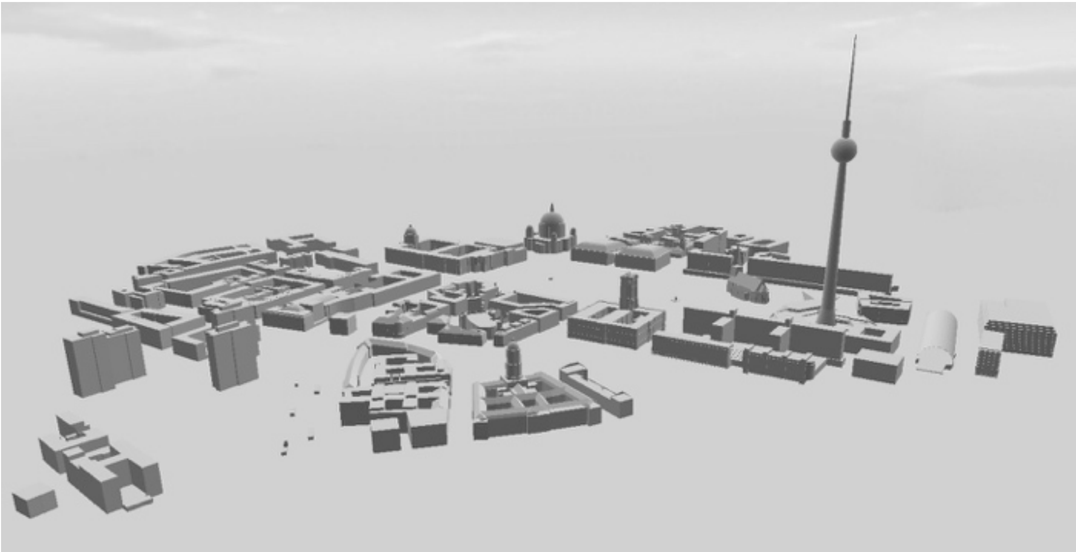

Figure 15. The VC2 model: Oblique view of the Alexanderplatz, Berlin in Germany. Source: CityGML

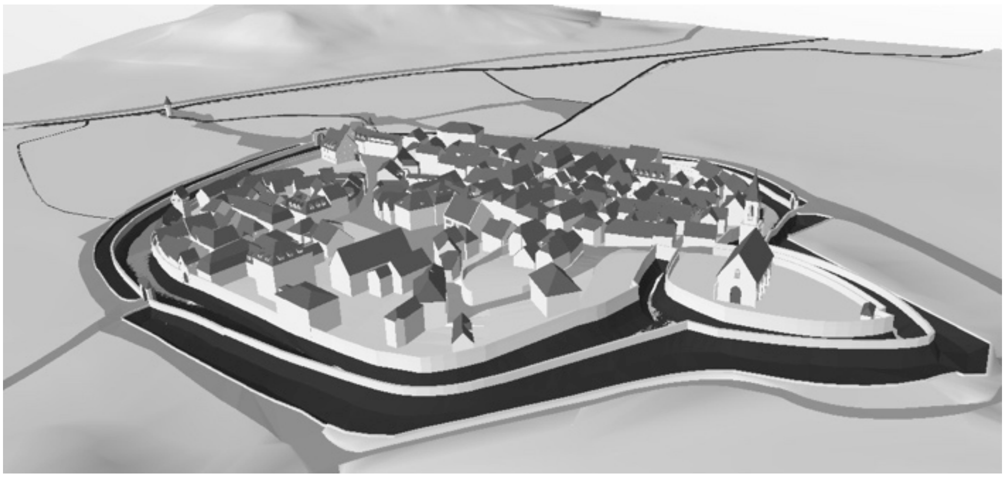

Figure 16. The VC3 model: Oblique view of Ettenheim, Germany. Source: CityGML

The VC1 model was an artificial model created in Trimble SketchUp (http://www.sketchup.com/), consisting of six basic geometric objects that represent buildings in LoD1. Five of the objects in the

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model had the same height, while the sixth object was a composite building and had two distinctly different heights (on the right in Figure 14). The VC2 and VC3 models were obtained from the CityGML project website (http://www.citygml.org/). Note that while Figure 14, Figure 15 and Figure 16 show screenshots, during the experiment, the visualisations were dynamic, i.e., pre-recorded videos of about one minute of each model were shown to participants. The first two videos were presented from a pedestrian perspective and the third from a 45 degree bird's eye view to observe participant behaviour under various conditions.

4.4.3. Procedure and tasks

The experiment consisted of three interactive question and answer sessions (similar to focus groups), including the video presentation of the three visualisations, and the sketch production. Each participant received an answer sheet. The instructor presented questions one-by-one and asked the participants to write down their answers on the sheet before proceeding with the next question. The experiment consisted of six parts. For simplicity, we refer to them as Task1 to Task6. **Task1** and **Task2** gathered basic demographic data (e.g., age, gender, expertise, experience with computer games and similar) and the participants' self-assessment of their spatial abilities. Responses were provided by participants on printed answer sheets. The remainder of the session was structured as follows:

- In **Task3**, the participants were asked to indicate the direction of two well-known buildings on campus while sitting in a lecture hall. The main campus was their home campus; thus it was a familiar environment. They were all facing the same direction and were asked to indicate the direction of two buildings (e.g., to the left when facing the front of the lecture hall) from their memory on the provided diagram (illustrated in Figure 17).
- In **Task4**, the participants were shown a short video clip where the camera traversed through a virtual environment consisting of six basic geometric objects or buildings in the VC1 model (refer to Figure 14). Afterwards, the participants were requested to draw a 2D sketch map of the environment depicted in the video. This task was based on Canter's (1977) method to evaluate a person's cognitive map, and their ability to convert a 3D cognitive map into a 2D map.
- For **Tasks 5 and 6**, two videos were used; one for VC2 and another for VC3. Before the video was started, the moderator indicated and verbally described three landmarks (prominent features) visible in the overview of each virtual environment. A short walkthrough of the environment from a pedestrian perspective for Task5 and a fly through from a 45 degree bird's eye view (approximately 5 m above the surface) for Task6 followed. At two predefined points in the video, the video was stopped and the participants were requested to indicate the direction of one of the landmarks from the current (virtual) location, using the diagram (Figure 17). This task was prepared on the basis of the Okabe *et al*. (1986) "point in a direction" method.

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	Front	
Left		Right
	Behind	

Figure 17. The diagram for marking the directions for Tasks 3, 5 and 6. Each zone corresponds to an area of approximately 45°

The participants had no prior knowledge of the artificial city and the two real cities used in the study, and the videos were presented once only. The visual complexity for the tasks increased not only in LoD, but also varied in number, structure and density of the objects, and extent of the area of interest (refer to Section 4.4.2 for detailed discussion of the differences).

4.5. Results and discussion

Results of Task1 (demographic information) are reported in *Section 4.4.1 Participants*. Responses to Task2 indicate that the majority of participants do not interact daily with video games or computer simulations (less than 30% of the participants reported daily interaction with video games or computer simulations). Additionally, in Task2 (self-reported spatial ability), participants were asked to rate their sense of direction between 1 (extremely poor) and 5 (excellent). 42% of the participants rated themselves at a 4; that is, just below excellent (refer to Figure 18). They were also asked to rate the frequency of their disorientation. 39% of the participants rated themselves at a 3 which is the equivalent of being disoriented often (refer to Figure 18). When these results are compared, it can be seen that most participants feel that they have a good sense of direction, but paradoxically, they also feel disoriented frequently.

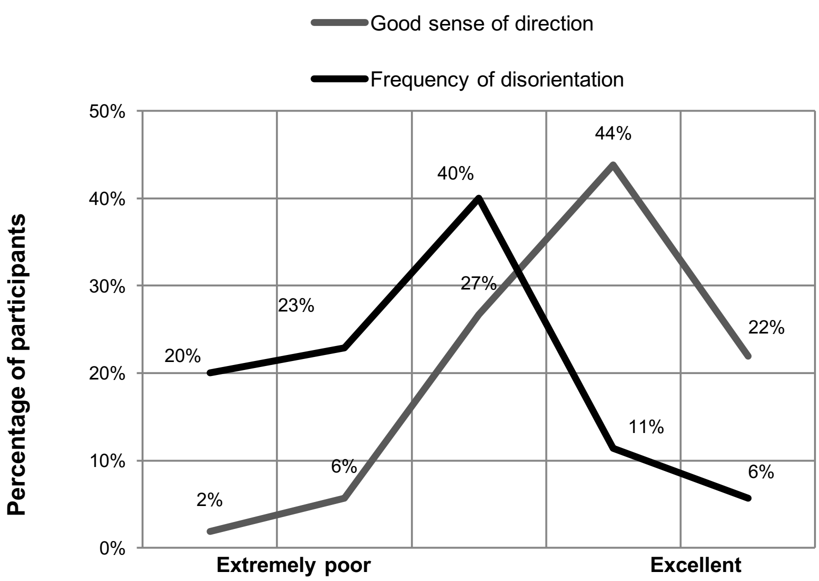

Figure 18. Graph depicting the participants' sense of direction and their frequency of disorientation

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Table 9 provides an overview of the different factors and visual complexities in Tasks 3 to 6. Task3 is included for reference, even though it is not a 3D model but the 'real world'. We believe it provides a more reliable indication of participants' sense of direction than the self-reported measure.

Table 9. Overview of the study

Factors \ Tasks	Task3: Real world (campus)	Task4: VC1 model (artificial)	Task5: VC2 model (Berlin)	Task6: VC3 model (Ettenheim)
Complexity	n/a	VC1	VC2	VC3
Familiarity	High	None	None	None
Perspective	Pedestrian	Pedestrian	Pedestrian	Oblique (45°)
Tasks	Orientation	Sketch	Orientation	Orientation
Training*	None	None	Medium	Most

**Training refers training received prior to the experiment and also during, considering the learning effect for example.*

As detailed in *Section 4.4.3 Procedure and Tasks*, for Tasks 3, 5 and 6 participants were asked an *orientation* question, where they marked the direction of an object that was not visible in the scene (for Task3, two campus buildings in relation to their current position, for Tasks 5 and 6, virtual landmarks in relation to their current virtual position). Only one of the blocks would apply (i.e., there was only one correct answer) and the 45 degree zone provided a large buffer. Note that this type of task is considered easier than the 3D to 2D transformation used in Task4 (Okabe *et al.*, 1986; Henry, 1992). Slightly less than half of the participants identified the direction accurately (47%) in Task3 where they had to rely on their cognitive map of the university campus (familiar to all participants) when asked to point to a building with its name. This can most likely be attributed to the participants having overall poor spatial orientation ability (despite their optimistic self-assessment, see Figure 18), especially since the majority were also not able to perform the other tasks successfully. Two individuals were identified who performed poorly in Task3, but performed all subsequent tasks correctly. These individuals may not pay attention to their daily surroundings in the 'real world', but when instructed, they appear to perform well (refer to Figure 19). The group setting of the experiment was another factor that could have contributed to the low performance, as the participants might not have given their full attention during the experiment. Kirasic *et al.* (1984) also suggested that if the participants frequently visit or walk by a specific landmark, they might not be able to recall the landmark's location or direction to the landmark. Seventy-five percent of participants that correctly performed Task3 were also able to perform Task6 accurately.

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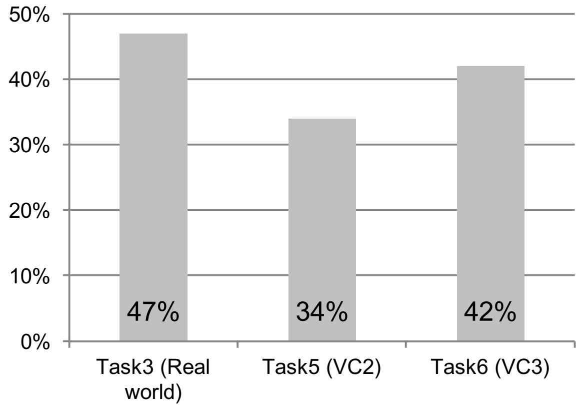

Figure 19. Percentage of accurate responses for Tasks 3, 5 and 6

In Task4, the participants were asked to draw a 2D map (sketch) of the environment (plan view) that they viewed in the video. Based on an analysis of three elements (layout, circle and height) on the sketches, responses were divided into the five sketch categories listed below (refer to Figure 20). A sketch that includes the layout, the circle and the height difference is regarded as correct. We categorized the sketches that participants produced based on the following criteria:

- Layout + Circle + Height: Layout correct, circle present and height differentiation indicated
- Layout + Circle: Layout correct, including the circle, but height differentiation not indicated
- Layout + Height: Layout correct, but circle not present, height differentiation correctly indicated
- Layout: Layout correct, but circle not present and height differentiation not indicated
- No resemblance at all: none of the elements are present in the sketch

Drawing the sketch was a challenging task, as it required a mental transformation (3D to 2D). As a result, as can be seen in Figure 9, the majority of participants were not able to accurately produce the sketch (Figure 20a shows the accurate configuration). Only a staggering 10% of participants were able to include the layout, circle and height differentiation. Thirty-four percent of participants produced the correct layout, but did not include the circle and change of height. This type of transformation task is a common task that many map readers, and more specifically planners, need to regularly perform (Ozawa and Seltzer, 1999). We believe the limited amount of visual detail and absence of highly distinctive characteristics in the VC1 model made this task even more difficult.

The participants were expected to have relatively good spatial abilities, as they are studying in fields that would require good spatial skills. However, in this study, it appears that, overall, the orientation tasks were challenging for the participants, even in a familiar 'real world' environment (with a success rate of only 47%). Orientation capability deteriorated in the subsequent task in an unfamiliar virtual environment with VC2 (34%). An overall improvement in the next task (42%) despite increasing complexity (VC3) suggests that training may be helpful. Nonetheless, the latter did not equal the success rate of the 'real world' task with the familiar campus buildings. In this study we did not observe any correlation between the participants' performance and their frequency of interaction with video

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games and computer simulations. However, an interesting observation was that the participants significantly overestimated their own spatial abilities: Sixty-four percent of the participants rated their sense of direction as above average (refer to Figure 18). However, at most only 47% of participants were capable of completing a task successfully (refer to Figure 19 and Figure 20). These results are further demonstrated with the low success rates in the sketch task, where the majority of the participants were unable to reproduce an accurate sketch of the virtual environment showing the essential elements of the layout, circle and height.

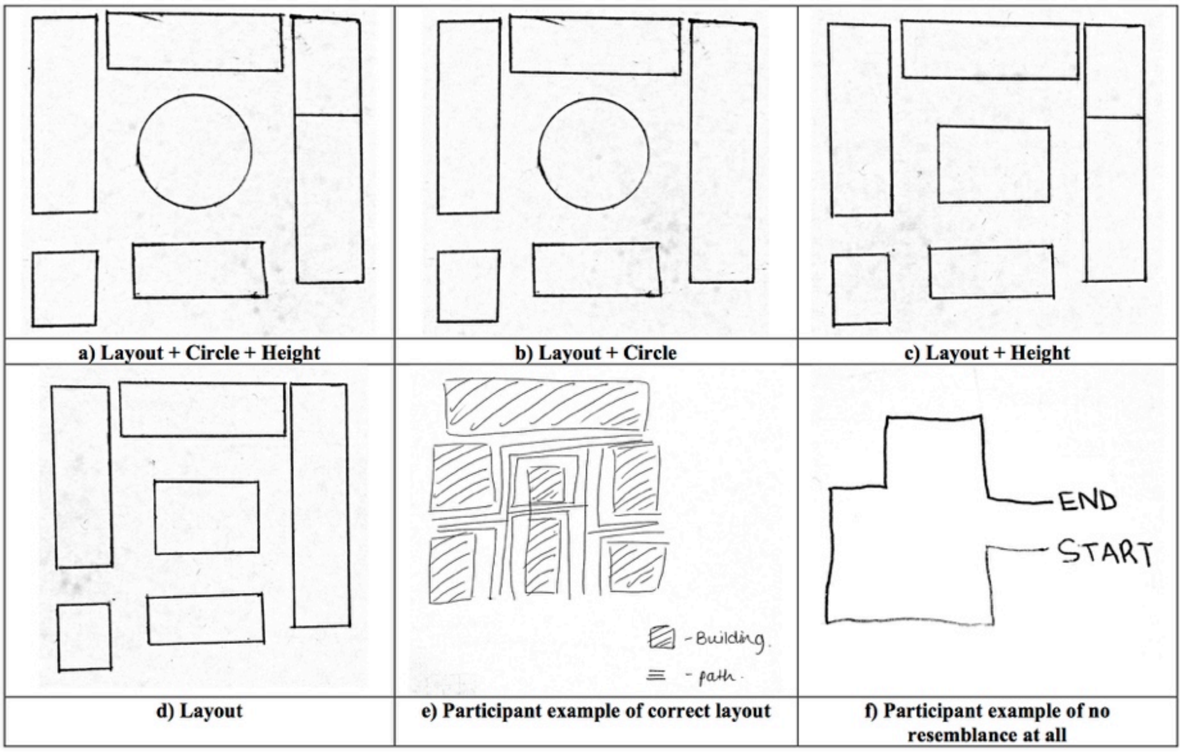

Figure 20. Examples of the different categories for the sketch (Task4)

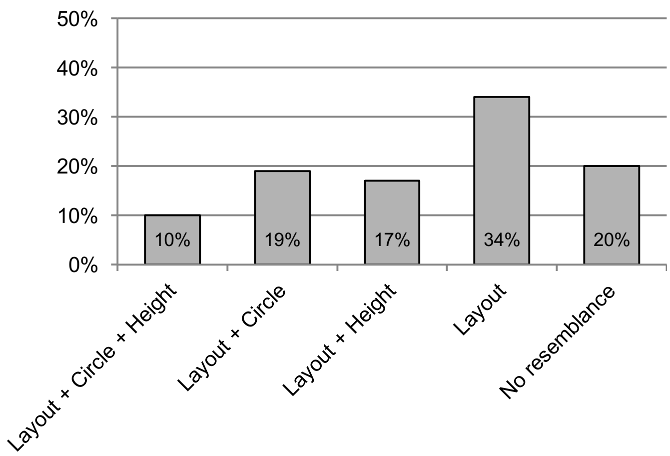

Figure 21. Percentage of sketches per category for Task4 (sketching VC1)

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To reiterate the interpretation of our analysis a little more in depth; Task3 tested the participants' general spatial orientation using their spatial knowledge of the university campus. Only 47% of participants were capable of correctly indicating the direction of a well-known building on campus. When exposed to the VC2 model (Task5, Alexanderplatz) and VC3 model (Task6, Ettenheim), the percentage of correct responses dropped to 34% and 42% respectively. A likely reason for the lower number of correct responses is the familiarity, or rather lack thereof, as mentioned earlier. Another reason could be that the verbal descriptions of landmarks were not as unambiguous as the buildings' names (which participants already knew) used in Task3. A third reason could be that participants were distracted or not paying attention when the verbal descriptions were provided. While controlled studies are needed to pin down the precise cause of the observed effect, based on this qualitative study, we can report that inappropriately designed 3D models do affect the performance when using or interpreting the model for orientation (pointing task) and recall (sketch task).

4.6. Conclusion

To summarise, the aim of the qualitative experiment presented in this article was performed to better understand the effect of visual complexity levels in 3D city models on orientation and cognitive maps of individuals. Ultimately, the results will contribute to the hypotheses development for a series of controlled experiments to study the effect of visual complexity. The results of these experiments will contribute to the development of recommendations on the design and use of 3D models for development planning, building on the work of other researchers, such as Häberling (2005; 2008), Döllner (2014; 2006) and Pasewaldt (2012). By understanding the effect of visual complexity in 3D urban models, we can better design and employ these models to ensure that all stakeholders (including individuals with various levels of map literacy) are able to extract the required information for effective decision making.

Our primary goal was to observe the effect that three different visualisations with varying levels of complexities have on the accuracy of the cognitive map when individuals are exposed to unfamiliar environments. The effect we observe is clear, however, the qualitative nature of this experiment does not allow us to determine the precise causes. All varied factors may have contributed to the observed effect to some degree, including a lower LoD and other design choices, such as the extent of the model (scale), scene complexity (number, structure and density of objects), the camera angle (perspective), familiarity, as well as training and the clarity of verbal instructions (building name in campus vs. a description of a building in the virtual representation). With the increasing popularity of 3D city models, it is important to understand the effect of design choices on people's cognitive maps. When creating 3D city models for development planning, it is important to understand how to design these models. Literature suggests that inappropriately designed 3D models can cause anxiety, disorientation, frustration and stress that would affect performance when using or interpreting the model (Cubukcu, 2011).

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The methods used in this study are qualitative (it should be viewed similarly as focus groups) where we collected *indications* from the participants under conditions that were not strictly controlled. On the other hand, from the perspective of controlled studies, the methodology used in this study introduces various limitations. Primarily, it is important to note that between the compared visualisations, multiple factors were varied. Additionally, the increased complexity and size of the areas with each visual complexity level might have been too large. It is difficult to find a single area that would be appropriate for different visual complexity levels unless we use entirely artificial environments. Such approaches exist, and we will follow them also in the future for the sake of *experimental control*; however, we clearly lose some *ecological validity* as we move away from visualisations of real environments in which multiple things vary at the same time. This is a known trade-off in experimental science. Furthermore, the sample population (participants) was restricted to university students, most of them studying in geography-related domains. Despite the staggeringly low success rates over all conditions we tested; this group's success may be "better" than the general population. In other words, they may be a self-selected group with higher-than-average spatial abilities and some of them had some exposure to video games and computer simulations. Additionally the two measurements (orientation task and sketch task) were not used in all tasks due to time restrictions; results could be enhanced if they had been measured for all conditions.

Further research should investigate the user experience with 3D city models from various aspects, such as colour schemes, light sources and different traversal techniques. In the next steps, we aim to test for individual factors (i.e., we will vary one factor at a time) to better identify the causes of the observed effect, which will complement this experiment and address the limitations otherwise identified in this paper.

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Chapter 5. Towards evaluating the map literacy of planners in 2D maps and 3D models in South Africa

This chapter was presented as a peer-reviewed oral presentation at the 2014 AfricaGEO conference 1 - 3 July 2014 in Cape Town, South Africa, as a paper by Rautenbach, V., Coetzee, S., and Çöltekin, A. under the same title.

Contribution: The preliminary user study presented in the paper was designed by V.R. under the guidance of S.C., and then conducted by V.R. The conceptual design of the proposed user study was developed by V.R. and A.C. The paper was jointly written by all three authors.

5.1. Abstract

South Africa is faced with numerous socioeconomic problems, such as poverty and resource depletion. Sustainable planning is of great importance to ensure that the necessary resources are available for future generations. However, research has suggested that South African planners do not have the necessary level of map literacy and that new geovisualisations may be required. The goal of this paper is to present preliminary results of comparative experiments to evaluate map literacy of planners in 2D maps and 3D models in South Africa. In these experiments, participants performed equally well when exposed to 2D maps and 3D models. These preliminary results were used to inform the conceptual design of an experiment to evaluate map literacy of users with 2D maps and 3D models. The new experiment was developed using a mixed factorial design and aims to address the challenges identified in the preliminary results. The implementation and execution of the new experiment design will contribute to understanding the strengths and limitations of 3D geovisualisation for planning in South Africa. Results will inform guidelines for the appropriate use of these non-traditional technologies for development planning.

5.2. Introduction

Planning encompasses all the activities involved in deciding what to do, how to do it, when to do it, and who is to do it (Koontz *et al.*, 1984). Planning can be seen as the actions that bridge the present and future. Argawala (1983) and Kotze & van Wyk (1986) define planning as a multidisciplinary field in which the future is anticipated, and accordingly, a number of tasks are developed to attain the desired future environment. The human is the central component in the planning process. However, planners need to consider the environment that the human lives in to ensure that the delicate balance between humans and the environment is maintained for future generations. Planning activities can

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take place in numerous forms ranging from strategic planning to impact evaluation. Typically, planners do not make the final decisions themselves; their duty is to provide decision makers with all the required information to make an informed decision.

Communication is a major aspect/task in the planning domain, and needs to occur between all stakeholders. Geospatial information provides an opportunity to planners to graphically communicate with decision makers and other stakeholders, such as citizens. However, these graphical representations are always supplemented with textual descriptions (Spatial Planning and Land Use Management Act, 2013). The graphical representation has the goal of simplifying the technical aspects, and assisting non-technical stakeholders in understanding the information presented by the planners.

Graphical representations, however, are not accessible to everyone as they require a certain level of *graphical literacy*. Literacy in its most simplistic form is defined as the ability to read and write. Literacy, thus, is the capacity to recognise, reproduce, and manipulate the conversions of text (Clarke, 2007). Similarly, related to graphical literacy, the term *map literacy* suggests that we can recognise, reproduce and manipulate spatial (possibly as well as temporal and attribute) information using maps or other forms of geographic visualisations. Bayram (2007) defines digital map literacy as the skills and abilities that enable users of computer maps, and other related digital information to extract relevant information for their purposes. The use of digital maps as a learning tool has increased, and users need to have a certain level of competence so that they can use this technology for problem solving.

As a form of digital maps, virtual cities and 3D city models have grown in popularity recently, especially with the launch of applications such as Google Earth. Over the years, cities have been represented in various formats ranging from 2D maps, 3D physical scale models, to the digital representation in 3D city models (Morton *et al.*, 2012). The importance of 3D city models and their applications seems to be also rapidly increasing (Gröger and Plümer, 2012; Semmo *et al.*, 2012). 3D city models have also been identified as an essential component of a spatial data infrastructure (SDI) due of their capability to act effectively as integration platforms for various spatial data (Hildebrandt and Döllner, 2009). Reportedly, 3D city models have been successfully used to communicate new planning developments in public participation projects (Isikdag and Zlatanova, 2010; Wu *et al.*, 2010; Chen, 2011). However, to our knowledge, the application of 3D models for development planning has not yet been tested in South Africa.

In South Africa, presently only 2D maps have been used in the public sector to communicate development plans (Unanimous, 2013). Testing these 2D maps, Engel (2004) and Clarke (2007) found that professionals in South Africa (in development planning) have a low level of map literacy which they considered inadequate for effective development planning. Clarke (2007) suggested that new visual representations should be investigated for communicating development plans.

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The goal of this paper is to present preliminary results of a user experiment to evaluate the relevant aspects of digital map literacy in 2D maps and 3D models for planning. The preliminary results contribute to the development of a follow-up experiment for evaluating map literacy of users with 2D maps and 3D models. The map literacy evaluation will serve as input to the development of guidelines for the use of 3D models in spatial planning in South Africa. This research is relevant in the context of South Africa's National Development Plan (South Africa National Planning Commission, 2012) which emphasises the need for instruments and capabilities needed for the effective spatial governance of development.

5.3. Background

5.3.1. Map literacy

A number of map reading skills are required to understand and interpret a map. Board (1978) defined three main groups of map reading actions, namely: navigation, measurement and visualisation. Board list of tasks require to perform these actions are quite extensive, and in total there are 27 tasks. Morrison (1978) refined Board's classification by simplifying the tasks and created four groups of basic map reading tasks. The groups are shown in Table 10. He suggested that these complex map reading tasks can be broken down into elementary tasks, and that we use a combination of these elementary tasks to complete an action.

Table 10. Main map reading tasks (Morrison, 1978)

Pre-map reading tasks	Detection, discrimination and recognition tasks	Estimation tasks	Attitudes on map style
Obtaining, unfolding etc.	Search	Count	Pleasantness
Orientating	Locate	Compare or contrast	Preference
	Identify	Measurement	
	Delimit	Direct estimation	
	Verify	Indirect estimation	

5.3.2. Planning process

Developing countries are faced with numerous socioeconomic problems. These problems are best tackled with geospatial thinking, thus map reading is an integral part of development planning. Development planning is of great importance for the sustainable development of developing countries (Nahas and Washington, 2013). The development of the South African Spatial Data Infrastructure (SASDI) is essential for development planning in the country, as an SDI facilitates access to and exchange of geographic information within all sectors and levels of society (Hjelmager *et al.*, 2008). In South Africa, the planning processes and invoked actions through these processes vary between different individuals and organisations. Despite this variation, Clarke (2007) suggested the following phases for the development planning process in South Africa: identification of development need, planning goals and objectives, data collection and analysis, identify alternative courses of action, appraise and select course of action, conduct pilot project or feasibility study, implementation, and monitoring and evaluation. This process only deals with high level phases, and a more detailed process should be investigated.

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Geographic information systems (GIS) have been shown in the past to be useful in making projects visible to the public, and aiding in managing the processes during the planning and implementation of various improvements (Chirowodza *et al.*, 2009; Paar and Rekittke, 2011). GIS is a useful tool in community participation projects and has been referred to as participatory GIS and community-integrated GIS (Abbott, 2003; Sliuzas, 2003; Chirowodza *et al.*, 2009). A key objective of using participatory GIS in planning is to empower the community, through providing them with information about the community that can be used to support negotiations with the local authorities (Abbott, 2003).

Related to governing and information systems, Choo (1998) developed a model, called *knowing organisation* that links the sense making process with knowledge creating, and decision making. He suggests that sense making (information interpretation) leads to knowledge creation (information conversion), and then to decision making (information processing), this ultimately leads to organisational action. The process of planning can be linked to the knowing organisation model. Planners and other stakeholders, such as planning professionals and citizens, go through these phases (information interpretation to information processing) during the planning and decision-making process. However, the use of inappropriate geovisualisations can have a negative effect on this process.

5.4. Methodology

5.4.1. Overview

The methods used during the experiment were a combination of a focus group and questionnaire. The participants were students from the University of Pretoria. The questionnaire allowed the students to keep their anonymity while making a contribution. A focus group comprises six to ten individuals guided by a moderator. Typically qualitative data is generated as the raised topics are discussed by the participants in the presence of a moderator and a note-taker (Kitzinger, 1995; Morgan, 1997; Courage and Baxter, 2004). The group discussion can stimulate new ideas, or encourage participants to talk about challenges or frustrations about discussion points that, for example, might not be raised during individual interviews. A questionnaire is a set of questions for obtaining statistically useful or personal information from individuals and thus can be used for collecting quantitative, as well as qualitative data (Martin, 2007).

5.4.2. Study design

A within-subject participant assignment was used, meaning that all participants were assigned the same questions (Martin, 2007). Within-subject assignment has a number of advantages, such as fewer participants are required, and statistical inference can be made through "*repeated measures*". However, there are also disadvantages to this method, for example, the learning effect can be an

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impediment. The learning effect is present if participants' behaviour is affected by exposure to earlier levels of the manipulated variable (independent variable) (Martin, 2007).

An independent variable is an element/variable that is manipulated during the experiment (Martin, 2007). The purpose of any experiment is to determine the effect of the independent variable on behaviour. The change in behaviour due to the independent variable is measured according to dependent variables. The dependent variable relies on the participant's behaviour.

In our experiment the independent variable was *the type of geovisualisation*, namely, 2D maps, 3D non-photorealistic landscapes and 3D realistic city models (e.g. Figure 22, Figure 23 and Figure 24). The main dependent variable we measured was *accuracy*. The experiment consisted of three parts: 1) map orientation, 2) relative direction between two points on the map, and 3) distance estimation (direct estimation). The experiment was limited to these aspects of map literacy (refer to Section 5.3) in order to limit the experiment length to less than 30 minutes.

Each task was repeated with the following type of stimuli: 2D map, 3D non-photorealistic landscape, and a 3D model (see section 5.4.2). For the map orientation tasks, participants were asked to indicate a certain cardinal direction (e.g. north, west) for a specific map or model. The relative direction tasks required the participants to specify the direction between two points (for example, the direction to traverse from point A to point B). For the final task the participants needed to estimate the distance between two points.

5.4.3. Materials

This section describes the maps and models used for the experiment. The 2D maps were 1:50 000 topographic maps from the South African National Map Series, and other custom made maps. The maps were developed with the aid of a cartographer, and the orientation of the maps was purposefully changed, so that north is not up (refer to Figure 22 for an example).

The Ordnance Survey Minecraft[3] landscape model of Great Britain was used as the 3D non-photorealistic landscape (Ordnance Survey, 2013). The model consists of 22 billion blocks that cover over 220 000 square kilometres of mainland Great Britain. The model depicts the land cover of Great Britain, such as forest, and built-up areas, on a 3D terrain constructed out of Minecraft blocks (refer to Figure 23). The Philadelphia redevelopment 3D model was used for the 3D realistic city models. The model was developed using Esri CityEngine,[4] and the model is freely available for download (Esri, 2012).

[3] https://minecraft.net/
[4] http://www.esri.com/software/cityengine

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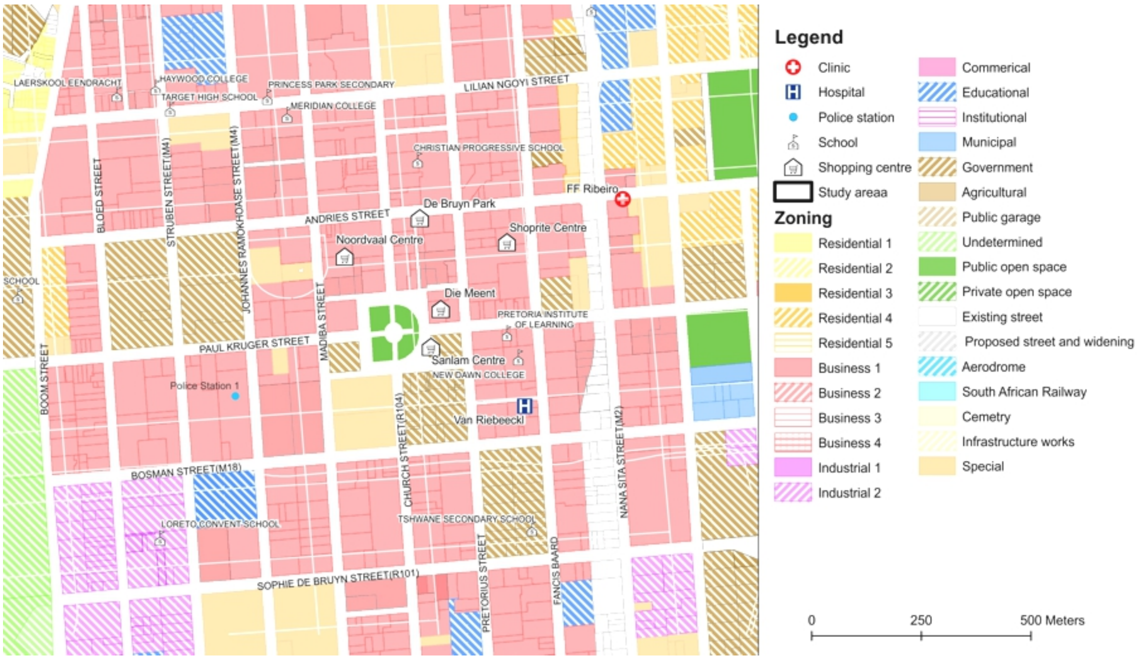

Figure 22. Land use map of central Pretoria, South Africa

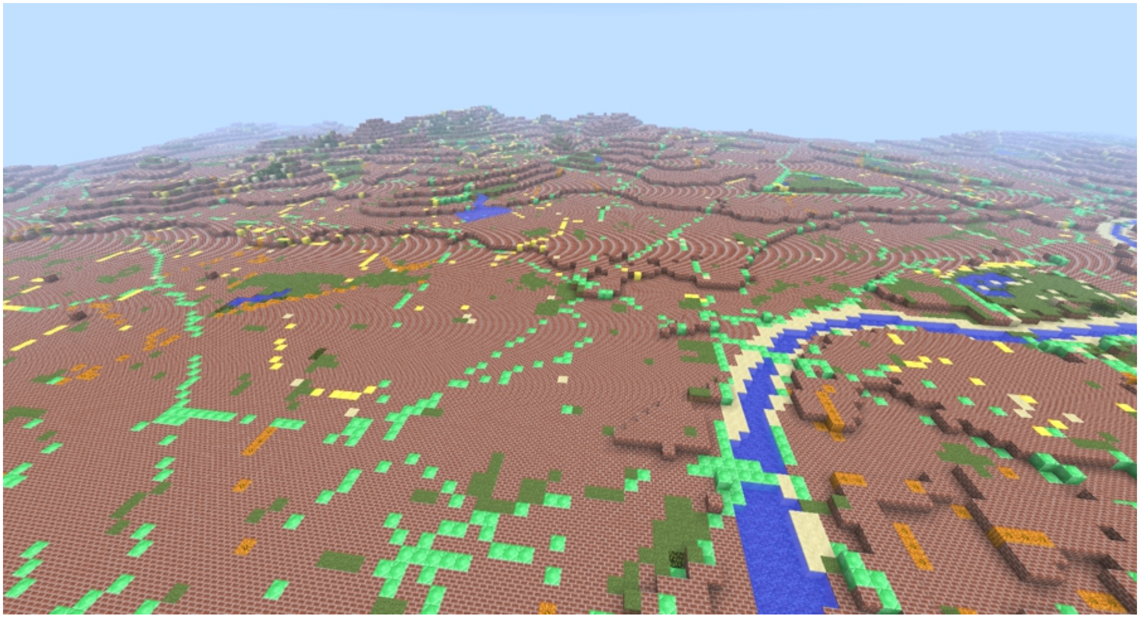

Figure 23. Minecraft model of London, United Kingdom. Courtesy of Ordnance Survey (2013)

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Figure 24. 3D model of Philadelphia, United States of America. Courtesy of Esri (2012)

5.5. Results and discussion

In this section the preliminary results of the experiment are presented and discussed. Twenty-one University of Pretoria undergraduate students (10 males, 11 females) participated. Besides the pragmatic reasons (convenience of travel etc.), students were invited to the experiment as they represent potential future professionals and community members. The participants were from a variety of degrees in the Faculty of Natural Sciences. The participant age varied between 18 and 29 years, with an average age of 21 years.

The participants were asked to rate their sense of orientation, map reading skills, and distance estimation skills on a scale from 1 (not good) to 5 (excellent). On average between 50% and 60 % of the participants rated their skill at above average (refer to Figure 25).

For all tasks, the participants were exposed to six maps and models (two for each type of stimuli). The results are summarised in Figure 26 and Figure 27. For Task 1 (cardinal direction) and Task 2 (relative direction), more than 90% of the participants indicated the correct cardinal direction despite the lack of conventional North reference (maps were purposefully disoriented away from the conventional North representation). For Task 3 (distance estimation) the basic statistical information was calculated, such as the average and standard deviation. We will not provide inferential statistical analysis at this stage as we consider these descriptive statistics indicative enough to discuss the preliminary results and build the next steps.

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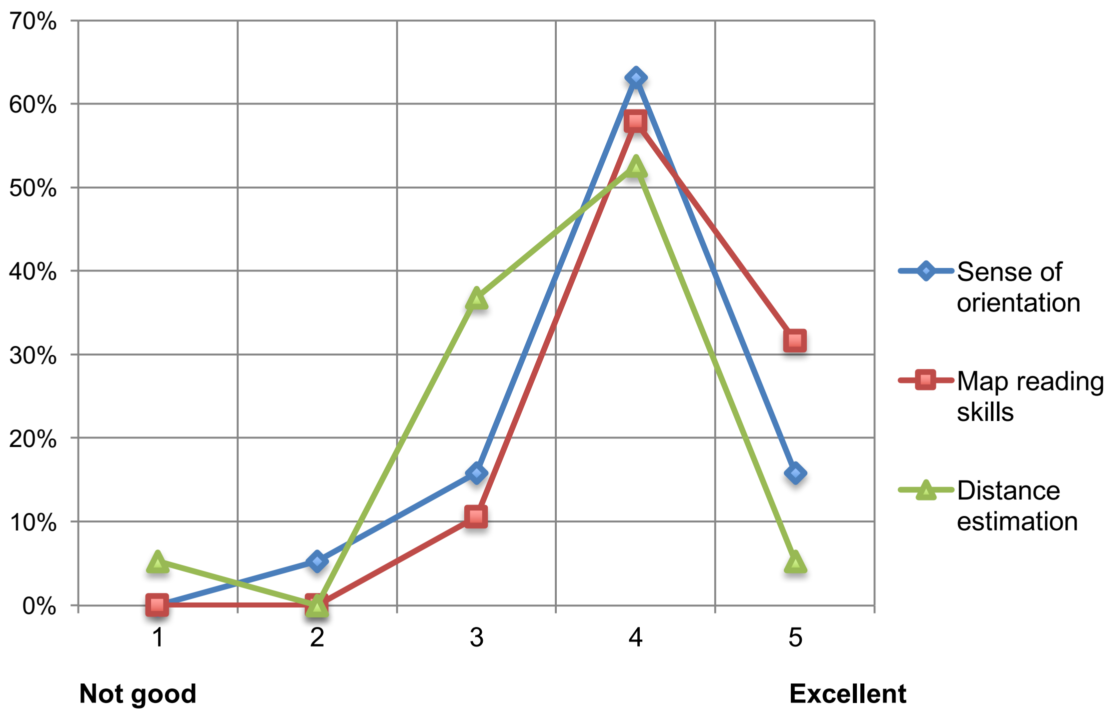

Figure 25. Participants' self-evaluated map reading skills

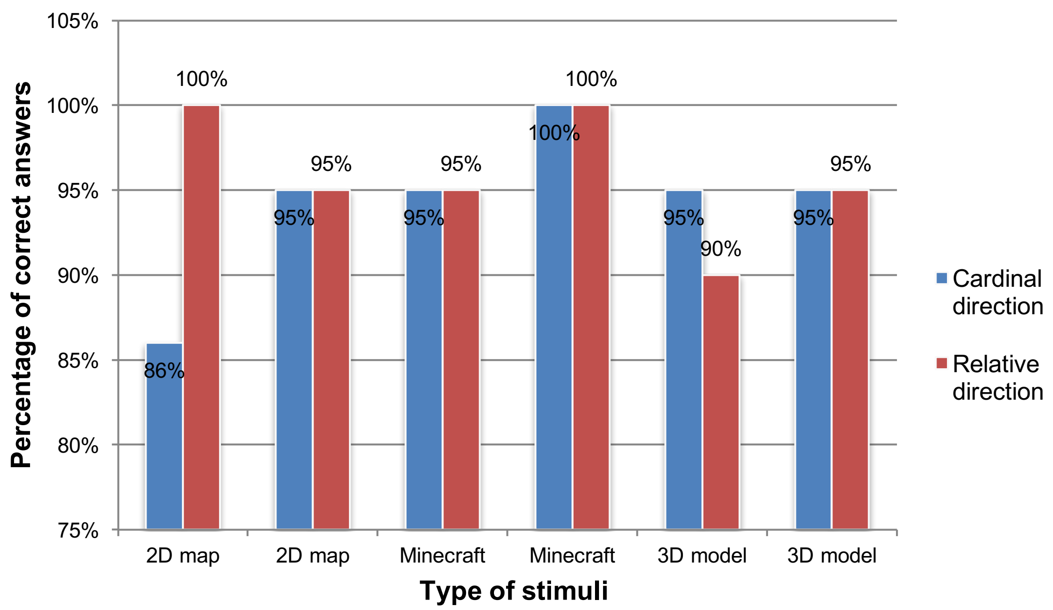

Figure 26. Correct answers for Task 1 (cardinal direction) and Task 2 (relative direction)

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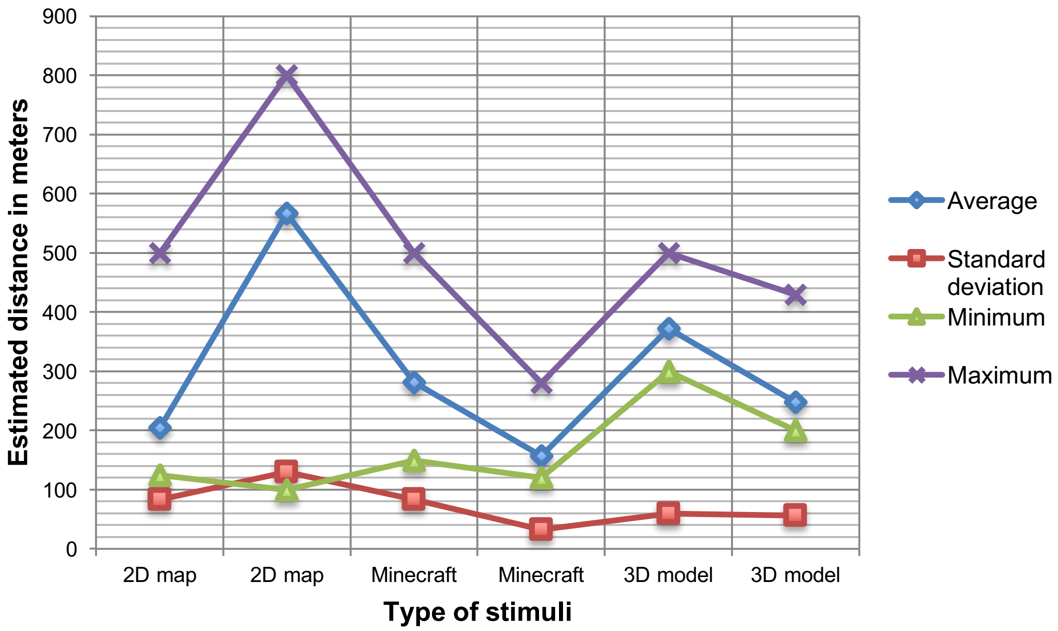

Figure 27. Basic statistical breakdown of Task 3 (distance estimation)

When the results of Task 2 (relative direction) and Task 3 (distance estimation) are compared to the participants' declaration of their map reading skills and sense of orientation, there is a clear correlation between their actual skills and perceived skills. The east and west cardinal directions were confused and swapped by a few participants. This problem did not occur with north and south. For Task 3 (distance estimation), the participants performed better with the Minecraft and 3D stimuli. The difference between the highest and lowest estimated values was smaller here, and the participants were more accurate.

The main problem encountered when conducting the "focus group" experiment was that some participants fell behind with the verbal instructions, and then consulted their peers which influenced the results (note that this is a known problem with focus groups). Most participants felt that tasks were easier to perform with the 2D maps, however the results showed that the participants were more accurate with the Minecraft and 3D models. This was most probably due to the learning effect which is a disadvantage of the within-subject assignment, especially if the stimuli order is not randomised. Retrospectively, another design issue in this experiment has been that the stimuli were from very different areas and scales. For example, the 2D maps were all from well-known South African areas, whereas the more challenging 3D non-photorealistic landscapes and 3D realistic city models were of unfamiliar areas abroad. While we acknowledge the shortcomings in this preliminary experiment, we have gained valuable insight various aspects of user testing as well as our research subject.

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5.6. Conceptual design for map literacy experiment

In this section, based on the hypotheses we derived in the preliminary experiment, a conceptual design for evaluating map literacy in 2D maps and 3D models of planners in South Africa are presented. The results presented in Section 5.5 provided valuable input into the design of the experiment.

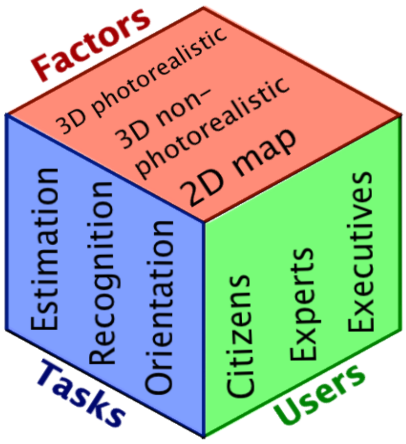

Figure 28. Map literacy factorial design matrix

The revised design was developed using factorial design. Montgomery (2009) describes factorial design as a method of replicating an experiment as to investigate all possible combinations of the different levels of the independent variable. Factorial design is commonly represented as a matrix (Martin, 2007). The factorial design matrix for the map literacy experiments described above is depicted in Figure 28. The independent variable in revised experiment will remain the type of geovisualisation: 2D maps, 3D non-photorealistic landscapes and 3D realistic city models. However, the study will use multiple dependent variables. The dependent variables will be accuracy, performance speed and the participant's confidence.

Participant assignment will be within-subject where all participants are exposed to every level of the independent variable. Each participant will be asked to perform a number of tasks on each level of the independent variable. Similarly to the preliminary experiment, the tasks are grouped into the categories *orientation*, *recognition* and *estimation*. The other aspects, such as symbology, will be covered in the future experiments.

The original experiment relied on the basic statistical analysis to make inferences. In the conceptual design, however, information about the participants' background, formal and informal training, and an additional pre-task to evaluate the participants' spatial ability will be captured. This will contribute to a more complete picture of the participants' performance. For this pre-task a standard spatial ability test will be used, such as the Santa Barbara solids test or Vandenberg mental rotation test. These tests evaluate the participants' spatial thinking skills which are essential to science, technology, engineering, and mathematics (STEM) professions (Cohen and Hegarty, 2012). Spatial thinking skills allow us to manipulate mental representations of objects real or imagined.

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As shown in the factorial design matrix (Figure 28) three main user groups in South Africa will be targeted: citizens, experts or professionals and executives. Citizens would be any person with no or little cartographic experience. For the experts and professionals group, current and future experts and professionals in geographic information science (GISc) and spatial planners will be targeted. Lastly, the executives will be from GISc and spatial planning (participants from this last group are anticipated to be the most difficult to find due to time constraints). In all user groups mentioned, males and female participants will be recruited in a balanced manner. The age range of the participants will most likely be between 20 and 60.

Another change is that the experiment will be presented to the participants in a survey format using LimeSurvey[5]. This will eliminate the possibility of participants falling behind, and speaking to one another during the experiment. The 3D non-photorealistic landscapes (Minecraft of Great Britain), and 3D realistic city models (of Philadelphia) will be used for this revised experiment. However, the 2D maps will be replaced with maps of the same scale and area as that of the 3D non-photorealistic landscapes and 3D realistic city models, in order to introduce more experimental control and to ensure as much as possible that the different stimuli and levels of detail can be compared.

5.7. Conclusion

In this paper we present results from a preliminary experiment to evaluate map literacy of users with 2D maps and 3D models. We used these preliminary results to achieve our goal of designing an experiment that can be used to further evaluate planners' map literacy of 2D maps, 3D non-photorealistic landscapes and 3D models in South Africa. Our preliminary results suggest that the revised experiments can effectively evaluate map literacy with 2D maps and 3D models.

More specifically, our preliminary results indicate that it is possible to perform basic map reading tasks on 3D non-photorealistic landscapes and 3D models. Most participants felt that the tasks were easier with 2D maps. However, the results depicted that participants are just as capable and accurate when using 3D non-traditional geovisualisations despite the fact that these were from unfamiliar or foreign areas. The application of these geovisualisations in planning is becoming more popular, and their relevance and effectiveness for planning in South Africa needs to be further evaluated.

In future work, we plan to implement the conceptual experiment design, and evaluate the map literacy of the three groups of participants identified (citizens, experts and executives). The design only covers selected aspects of map literacy, the other aspects will be evaluated in follow-up experiments. A correlation between the tasks evaluated, and the process a planner follows needs to be investigated as well.

[5] http://www.limesurvey.org/en/

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Chapter 6. Development and evaluation of a specialised task taxonomy for spatial planning – A map literacy experiment with topographic maps

This chapter was publication in the ISPRS Journal of Photogrammetry and Remote Sensing in 2016, as a peer-reviewed research paper by Rautenbach, V., Coetzee, S., and Çöltekin, A. under the same title.

Contribution: The proposed task taxonomy was developed by V.R. under the guidance of S.C. and A.C. The user study was designed jointly by all three authors, and conducted by V.R. The data was analysed by V.R., with direction from A.C. The paper was jointly written by all three authors.

6.1. Abstract

Topographic maps are among the most commonly used map types, however, their complex and information-rich designs depicting natural, human-made and cultural features make them difficult to read. Regardless of their complexity, spatial planners make extensive use of topographic maps in their work. On the other hand, various studies suggest that map literacy among the development planning professionals in South Africa is not very high. The widespread use of topographic maps combined with the low levels of map literacy presents challenges for effective development planning. In this paper we address some of these challenges by developing a specialised task taxonomy based on systematically assessed map literacy levels; and conducting an empirical experiment with topographic maps to evaluate our task taxonomy. In such empirical studies, if non-realistic tasks are used, the results of map literacy tests may be skewed. Furthermore, experience and familiarity with the studied map type play a role in map literacy. There is thus a need to develop map literacy tests aimed at planners specifically. We developed a taxonomy of realistic map reading tasks typically executed during the planning process. The taxonomy defines six levels tasks of increasing difficulty and complexity, ranging from recognising symbols to extracting knowledge. We hypothesised that competence in the first four levels indicates functional map literacy. In this paper, we present results from an empirical experiment with 49 map-literate participants solving a subset of tasks from the first four levels of the taxonomy with a topographic map. Our findings suggest that the proposed taxonomy is a good reference for evaluating topographic map literacy. Participants solved the tasks on all four levels as expected and we therefore conclude that the experiment based on the first four levels of the taxonomy successfully determined the functional map literacy of the participants. We plan to continue the study for the remaining levels, repeat the experiments with a group of map-illiterate participants to confirm that the taxonomy can also be used to determine map illiteracy.

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6.2. Introduction

Topographic maps do not only depict relief, but also natural, human-made and cultural features and provide an accurate and comprehensive graphic record of locations. Topographic maps are used extensively, for example, by soldiers for battle planning, by engineers when designing and planning roads, by geologists and surveyors for fieldwork planning and by spatial planners when developing plans for cities or regions (Innes, 1998). Due to the graphically rich nature of topographic maps, they are considered difficult to read and understand (Chang *et al.*, 1985). The abundance of symbols and colours used in topographic maps could be challenging, but a comprehensive, well-designed legend can assist. According to Chang *et al.* (1985), the ability to form a 3D mental image of the terrain is considered to be the most challenging aspect when working with topographic maps. The map-reader needs to either interpret contour lines or deduce heights from spot heights.

Map reading is taught in school in many countries, specifically in primary and secondary education (Board, 1981). However, map reading is a complex task (Board, 1981; Rayner, 1996). In fact, Rayner (1996) reviewed various studies and concluded that *most* adults are map illiterate and unable to complete basic map-use tasks. More recently, many more empirical studies highlighted the complexity of map reading tasks; even perceptual tasks that require no expertise, such as size of the symbols or colour discrimination, can hinder map reading severely (Clarke, 2003; Kent and Cheng, 2008; Brychtová and Coltekin, 2014; Brychtová and Coltekin, 2015; Brychtová and Çöltekin, 2016). Ooms *et al.* (2016) raised the question whether the increased accessibility of maps with the introduction of new technology and tools, such as Google Maps, has affected map literacy of individuals. They found that secondary education pupils (between the ages of 11 and 18 years) were able to mostly successfully complete various map reading tasks at different levels of difficulty. This was especially true for older pupils and those currently enrolled for geography. However, the Ordnance Survey (2015) carried out a survey asking 2000 individuals which traditional skills they thought were in danger of dying out, and map reading was in the top spot. The reason provided was the increased reliance on technology, such as GPSs (Bachmann, 2015; Ordnance Survey, 2015). Bachmann (2015) suggests introducing activities into curricula that would alter a student's perception that GPSs and maps are perfect representations of the world. While it might be difficult for many people, map reading is necessary for many everyday tasks as well as professional use, e.g., topographic maps contain essential information for spatial planning and decision making. Planners formulate plans for optimal land management and development in cities and wider regions. For this they rely on topographic maps (among various other data sources): from gathering information to communicating planned developments. Thus, map literacy is an essential skill for planning professionals. Surprisingly, however, Engel (2004) and Clarke (2007) found that map literacy levels among those involved in development planning in South Africa were simply inadequate. This mismatch naturally presents challenges for effective development planning and indicates a need for reforming the university curricula for educating planners and others who might conduct spatial analysis tasks related to planning.

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Board and Taylor (1977) suggested that map reading experiments for adults rarely used 'realistic' map reading tasks, and that this might skew the results. It also appears that experience plays a major role in reading topographic maps, as experienced individuals are more efficient and effective in interpreting contours and visualisation of terrain, among other spatial tasks (Chang *et al.*, 1985; Kent and Cheng, 2008; Rinner and Ferber, 2005). A strong correlation has been reported between self-reported familiarity and experience with topographic maps and participants' performance with them in map reading tasks (Chang *et al.*, 1985).

Map literacy tests designed specifically for planners simply do not appear to exist. Such tests could be used to evaluate map literacy and to initiate remedial actions, where necessary. In this article, we propose a map reading task taxonomy that is specifically relevant for the spatial planning domain. The map reading tasks in the taxonomy were derived from the tasks that are generally used in the planning process. Furthermore, we present results from a user experiment where map-literate participants used a subset of the tasks in the proposed taxonomy, and we measured their map reading performance. We worked with map-literate participants as a validation mechanism (i.e. we expected them to be successful with the tasks we prepared), and we chose a topographic map for the experiment, as topographic maps are commonly used by planners to gain a general overview of the environment, including terrain. The remainder of the paper is structured as follows: Section 6.3 presents the map reading task taxonomy; in Section 6.4 the study design is described; results are presented in Section 6.5; and in Section 6.6 the results are discussed and conclusions are provided.

6.3. Map reading task taxonomy for planning

Various researchers have identified and proposed map reading tasks for the evaluation of map literacy. For example, in 1990, Saku (1990) identified the following tasks involved in map reading: reading, analysing and interpreting geographic data. These tasks were extended by Keates (1996), as he justifiably discriminates between identifying and interpreting map symbols: the symbol has to be identified initially, only thereafter interpreted, and lastly, inferred if possible. This concept of tasks that build on each other from basic to advanced was also used by Clarke (2007) to define three map literacy skill levels for the evaluation of functional map literacy: read and understand a single symbol, do simple estimations (entry level); recognise symbol groups, analyse spatial patterns, more complex estimations (level 1); and understanding meaning and inferential reasoning of map phenomena (level 2). Clarke defined 18 map-use tasks and determined the map literacy level required for each task. Based on experimental results, Clarke argued that a person is 'functionally map literate' if the individual is proficient up to level 1. However, professionals working in the development planning environment should preferably be competent up to level 2 (Clarke, 2007; Rautenbach *et al.*, 2014).

Developing an instrument to evaluate map literacy is not a new concept (Hakan and Demir, 2014). However, to our knowledge, there is currently no instrument specifically designed for planning professionals. To develop our map reading task taxonomy for planners, we considered expert knowledge, peer-reviewed publications, and a number of additional resources, such as national

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reports and policy documents, and synthesised them (i.e. Board, 1981; Board, 1978; Morrison, 1978; Saku, 1990; Ordnance Survey, 1992; Keates, 1996; Rayner, 1996; United States of America Department of the Army, 2001; Clarke, 2003; Innes, 2003; Engel, 2004; Australian Government, 2005; Innes, 2005; Wiegand, 2006; Bayram, 2007; South African Department of Education, 2008; Land Information New Zealand, 2009; South African Department of Basic Education, 2011; South African Department of Basic Education, 2012; Bolstad, 2012; Ordnance Survey, 2014). In the proposed taxonomy, we considered tasks for topographic maps, aerial photography and 2D maps (i.e., standard cartographic maps or thematic maps) as alternatives. However, in this study, we report results from an experiment that featured only a single topographic map, as the main idea was to test the taxonomy itself, and not make a map-type comparison.

The proposed taxonomy defines six levels of map reading tasks with increasing difficulty and complexity, ranging from recognising symbols to extracting knowledge (see Table 11). Level 1 to Level 4 (recognise symbology, orientate, locate, and measure or estimate) is considered to be the minimum for functional map literacy. These tasks (Level 1 to Level 4) form the basic building blocks for more advanced tasks. For example, during the first phases of planning (understanding the current environment), a planner/designer needs to extract knowledge from maps (e.g., spatial patterns or relationships between phenomena). For this, planners need to perform basic map reading tasks: recognise symbology on maps, orientate themselves on the map, locate features and estimate distances, etc. on the map.

Table 11. Taxonomy designed specifically for spatial planning related map reading tasks (items we used in our user experiment are highlighted in grey)

Description	Map task
Level 1*: Recognise symbology	1.1. Name the phenomenon represented by the symbol
	1.2. Describe the difference in characteristics of phenomenon based on the symbols or patterns
	1.3. Recognise various topographic features in the area based on symbology or patterns
	1.4. Locate features in different perspectives
Level 2*: Orientate	2.1. Determine direction or bearing
	2.2. Recognise different perspectives
Level 3*: Locate	3.1. Locate a feature
	3.2. Determine the position at a specific point
	3.3. Locate features that exhibit a specific relationship to another feature
Level 4*: Measure or estimate	4.1. Estimate certain topographic elements, for example line-of-sight
	4.2. Determine the distance between two points or length of a linear feature
	4.3. Determine the area or extent of a region
	4.4. Estimate altitude/height/volume of a specific feature
Level 5: Calculate or explain	5.1. Calculate certain topographic elements
	5.2. Produce and reproduce features
	5.3. Explain patterns of occurrence or features
Level 6: Extract Knowledge	6.1. Perform a spatial analysis
	6.2. Infer knowledge of interrelationship of features or patterns

*Functional map literacy (Level 1 to Level 4)

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The proposed taxonomy attempts to update previous map reading tasks that focused on mainly paper maps. For example, Morrison (1978) listed unfolding as a map reading task. The map reading tasks identified by Board (1978) and Morrison (1978) were mainly a list of actions with little explanation that are applicable to various fields and applications. Innes (2003) developed a system for school learners based on the South African Department of Education's (2011) geography syllabus. This system is based on the concept of a hierarchy of tasks that would ultimately contribute to a desired outcome. Innes' (2003; 2005) was basic as it is aimed at high school learners and very broad. The abovementioned literature formed the starting point of the taxonomy that was developed by combining various resources to condense the information and verify that all possible tasks are included. Most taxonomies or map reading tasks list only focus on functional map literacy, the proposed taxonomy includes complex tasks, specifically aimed towards spatial planning.

A map reading task taxonomy, specifically relevant for the spatial planning domain, is not only useful for testing individuals' map literacy, but could also assist in guiding the development of a curriculum or a course for planning students at university level. The taxonomy could be used as a reference to ensure that students are taught the necessary map reading skills.

6.4. Study design

6.4.1. Overview

To investigate whether the proposed map reading task taxonomy can be used to evaluate functional map literacy, we designed a user experiment with topographic maps, using a subset of the proposed map reading task taxonomy from Level 1 to Level 4 (refer to Table 11). For this study, we recruited participants that we expected to be functionally map literate, and should perform well when asked to complete various tasks from the proposed taxonomy, especially with the topographic map. A subset of the taxonomy was used (the subset is indicated in grey in Table 11). We designed a within-subject experiment; meaning that all participants solved all tasks. We presented 22 questions in a randomised order to minimise and distribute the learning effect (Table 12). Table 12 lists the questions presented to the participants and shows how the questions relate to the tasks specified in our proposed task taxonomy. Most tasks from Level 1 to Level 4 were included in the experiment. As indicated in Table 11, tasks 1.4, 2.2 and 4.4 were excluded: Tasks 1.4 and 2.2 deal with perspective, which is not applicable to topographic maps as they are typically produced from a single perspective. Task 4.4 was excluded, because it would require altitude or height estimations that would not be sensible on a topographic map with contours that already provide altitude information, and similarly, object heights or volumes would be difficult to estimate given the scale and level of abstraction of a topographic map. The format of the survey further limited the tasks that could be included. This specifically related to the type of task, for example, participants did not have access to any resources or tools (e.g., a calculator or the Internet), therefore the questions that would require advanced arithmetic (tasks relating to Level 5, Table 11), and tasks involving inference (refer to Level 6, Table 11) were not

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included. Tasks from Level 5 and Level 6 are better suited for an interview or peer-analytical setting to gather additional information beyond the extent of a survey.

Table 12. Relationship between the experimental questions and the task taxonomy

Qn	Experiment question text	Task (refer to Table 11)	Level
1	Name the feature represented inside the red circle (area feature)	1.1. Name the phenomenon represented by the symbol	Level 1: Recognise symbology
2			
3	Name the features represented by A and B	1.2. Describe the difference in characteristics of phenomenon based on the symbols or patterns	
4			
5	Indicate the highest point shown in the map below (click on the map)	1.3. Recognise various topographic features in the area based on symbology or patterns	
6	Indicate the lowest point shown in the map below (click on the map)		
7	What is the relative direction from point A to point B?	2.1. Determine direction or bearing	Level 2: Orientate
8			
9	Locate a sewage works (perennial water) – click in the vicinity of the feature	3.1. Locate a feature 3.2. Determine the position at a specific point	Level 3: Locate
10	Provide the alphanumeric grid position for Blockhouse (monument)		
11	Provide the coordinate position for the top left corner of the Barberton Nature reserve		
12	Locate a school – click in the vicinity of the school		
13	What is the alphanumeric grid position for Abbott's Hill?		
14	Provide the coordinate position for the Garden of Remembrance (monument)		
15	Locate the power line that crosses through the Barberton Nature reserve (click on the symbol)	3.3. Locate features that exhibit a specific relationship to another feature	
16	Locate a recreation ground that is located along the railway line (click on the symbol)		
17	Is point A visible from point B (assuming no buildings are in the way)?	4.1. Estimate certain topographic elements	Level 4: Measure or estimate
18	In which area, A or B is the slope the steepest?		
19	Estimate the straight line distance between the features indicated (in metres)	4.2. Determine the distance between two points or length of a linear feature	
20			
21	Estimate the area of the golf course indicated in the red block below (in square metres)	4.3. Determine the area or extent of a region	
22	Estimate the area of the Barberton Nature reserve (in square metres)		

Therefore, our independent variables were the 10 tasks as shown in Table 12, which increase in complexity from one level to the next. Participants solved the questions using a single topographic map (see Section 6.4.2). We measured the following dependent variables in the experiment: accuracy (also known as effectiveness; *was the answer correct?*), completion time (also known as efficiency;

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time taken to complete the question, or response time), and the participants' confidence in their accuracy *(does the participant think the answer is correct?)*. In the taxonomy, task complexity increases from Level 1 to Level 4, and tasks in each level depend on the skills required for tasks in the previous level. Thus, we can expect the participants' accuracy in solving the tasks, their completion time (*time taken to complete the question*), and confidence *(does the participant think the answer is correct?)* will decrease from Level 1 to Level 4.

6.4.2. Materials

A South African topographic map (Figure 29) from the standard South African 1:50 000 raster map series produced by the *Chief Directorate: National Geo-spatial Information* (CD:NGI) was used in the experiment. CD:NGI is mandated to collect the data and publish the 1:50 000 topographical map series (1 913 sheets) covering the entire South Africa (National Geo-Spatial Information, 2013). Using various symbols and colours, the 1:50 000 topographic map series depict the location of natural and human-made (constructed) features, as well as elevation in 20 m intervals (Innes, 1998; National Geo-Spatial Information, 2013). Specifically, we selected the topographic map of Barberton, a small town in the Mpumalanga province, South Africa, as it shows a combination of urban and natural environments, and thus enables us to test the tasks included in the experiment.

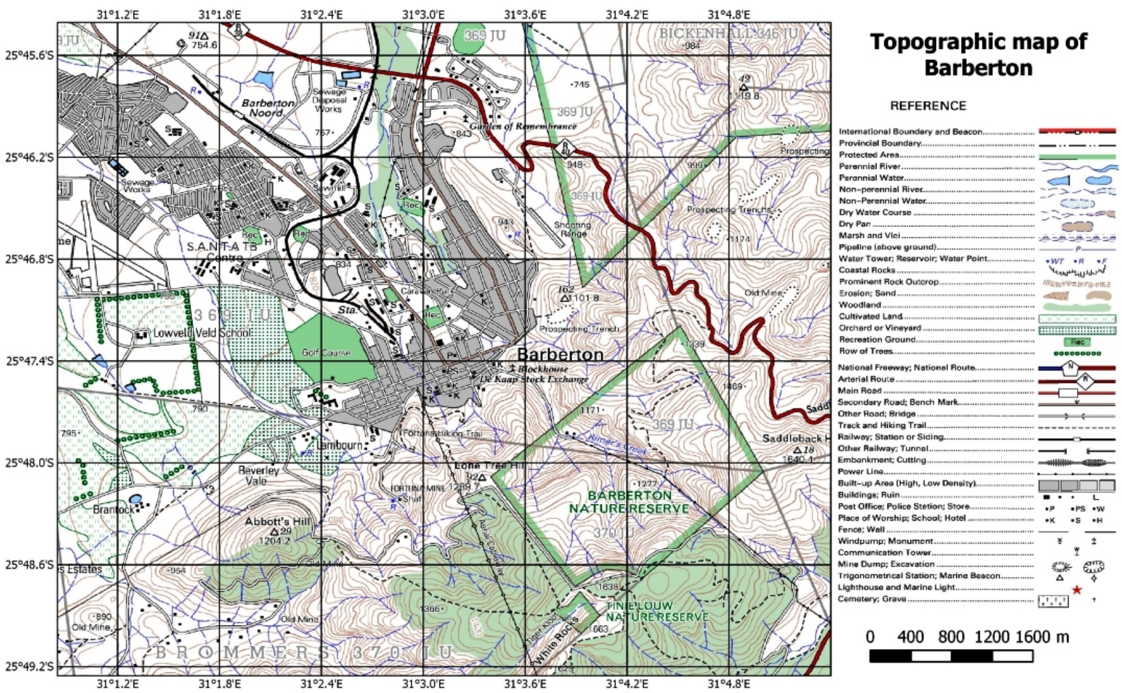

Figure 29. Topographic map of Barberton. Source CD:NGI 2009

The visualisation (i.e. the map) was constant for all participants (no changes in scale or map content or any other detail), as only a single map was used. The 1:50 000 map was altered to a scale of

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1:20 000 to ensure that it was readable on the 19-inch light-emitting diode (LED) computer screen with a resolution of at least 1366x768 which was used in the experiment. The computers used for the experiment were standard issue Windows 7 64-bit lab computers with an i5 3.1 GHz central processing unit (CPU) and 4 gigabytes (GB) of random-access memory (RAM).

6.4.3. Participants

Forty-nine volunteers (24 males and 25 females) ranging from 18 to 42 years old (average age of 23) participated in the experiment. Approximately half of the participants were undergraduate students in geoinformatics (51%) while others were students in related domains (a full breakdown of participants' occupation and degree programs is shown in Figure 30). Forty-five participants (92%) indicated that they took geography at either high school or university level. Thus we assumed that they have a good foundation in map reading, specifically topographic maps, as it is taught already in high school geography in South Africa (South Africa Department of Basic Education, 2011; South Africa Department of Basic Education, 2012). The remaining four participants who indicated that they do not have any formal education in geography were undergraduate students in geoinformatics, who had already completed a number of geography and cartography courses at the university level. We thus deduced that all our participants were functionally map literate.

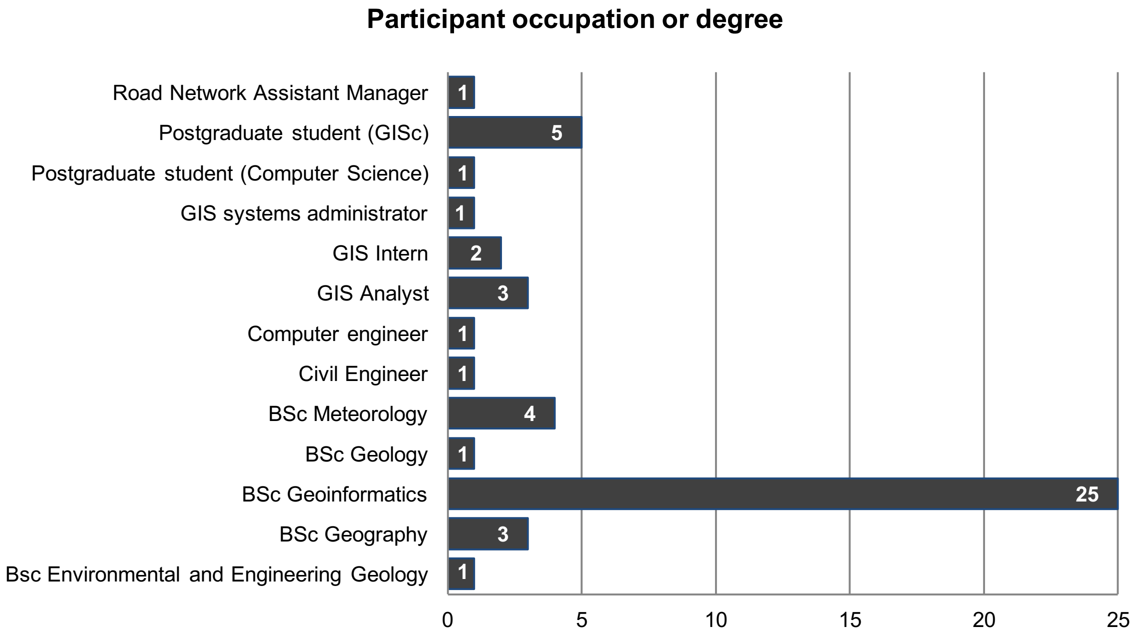

Figure 30. Degree or occupation of participants

Thirty-six participants (73%) were not familiar with Barberton and 13 participants (27%) were familiar with the town (the level of familiarity was not specified; however, familiar and unfamiliar groups were separately analysed). It was important that the participants were not familiar with the Barberton area, as prior knowledge would have affected their overall performance in the experiment.

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To establish the participants' overall experience in map reading and related tasks, they were asked to rate their training and experience on a five-point Likert scale. Their self-reported training and experience levels are shown in Figure 31. In general, all participants rated their experience or training in all aspects as average or above average (3 or higher). The only aspects that were rated lower than the average were *training in cartography, training in computer graphics* and *training in planning*. The lack of training in computer graphics and planning can be attributed to the fact that most participants were geoinformatics students who do not have to complete computer graphics and planning courses.

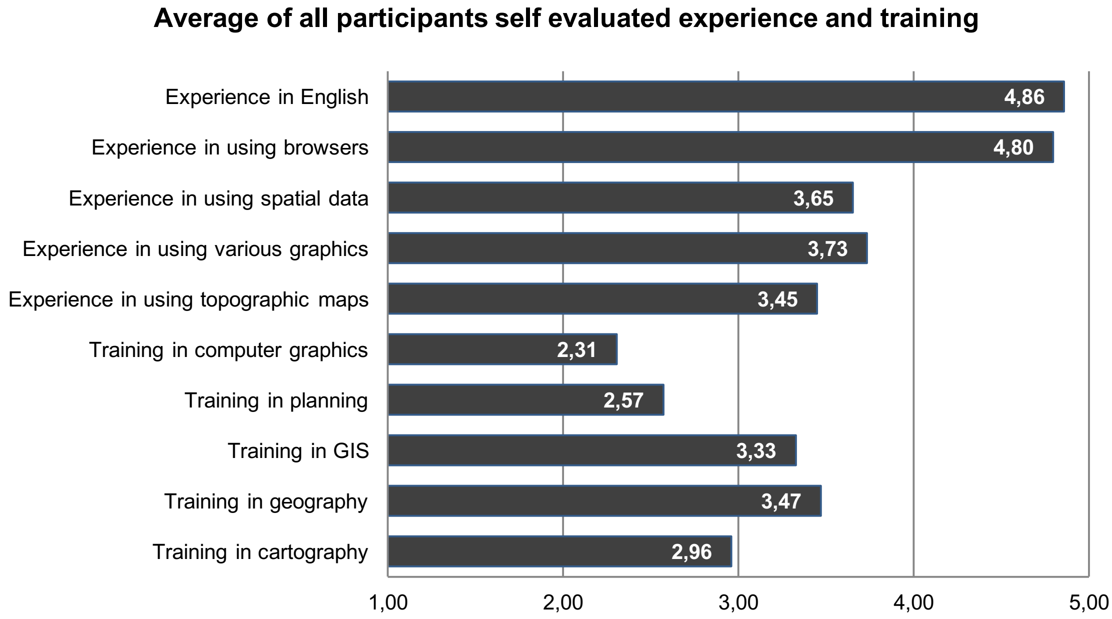

Figure 31. Participants' average self-reported experience and training

6.4.4. Procedure

We conducted the experiment in the form of a questionnaire using an online survey software product, called Qualtrics [6], in a classroom (i.e., in a controlled environment). Groups of participants (approximately 20 participants in a lab with 40 computers) completed the survey using a web browser in a lab on computers connected to the Internet (see Section 6.4.2). Therefore, the processing power of the computers, the display sizes, keyboards as well as the bandwidth, were identical for all participants. Before the survey started, the instructor explained to the participants that they would be asked to complete various map reading tasks, and asked participants not to communicate with each other during the session. They were given no time limits. A technical assistant was available to provide support with any technical issues during the session (fortunately, there were no technical issues during the experiment). After the instructions, the participants responded to the questions, and when they completed the tasks, we thanked them and finished the session. The participation was voluntary, and we offered no compensation to the participants.

[6] http://www.qualtrics.com

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6.5. Results

In this section, we first present the results on whether and how the individual *tasks* (our independent variable) affected the participants' accuracy scores, their completion time and confidence (our three dependent variables). Then we present how *task types* connected to map literacy levels affected performance. The latter is based on our main hypothesis that participants' overall performance (accuracy and completion time) and confidence will vary as the levels are advanced, because all the participants are functionally map literate.

As mentioned earlier, the experiment consisted of 22 questions, and at least two of these questions were linked to a task type (thus associated literacy levels) as indicated in Table 11. A single outlier was removed; the participant only completed two of 22 questions. Based on the participants' accuracy (*was the answer correct?*), an **accuracy score** out of 100 was calculated for each participant. Accuracy scores were normally distributed, i.e., the skewness of the data is -.771 (all skewness values between -1 and 1 are regarded as normal), and the kurtosis is 0.563. The skewness results for the four accuracy scores in relation to the map literacy levels (referring to task taxonomy levels in Table 11) were slightly different: Level 1 (.113), Level 2 (-1.891), Level 3 (-1.195) and Level 4 (-.162). Level 2 and Level 3 indicate a negative skewness, meaning that participants did above average in these two levels.

First, we analysed the effect of familiarity (i.e. prior knowledge) with the area on the map reading tasks. We found that prior knowledge of the area had no effect on the accuracy score [$F(1,46) = .010, p = .922$], confidence [$F(1,46) = .055, p = .816$] and task completion time [$F(1,44) = 3.694, p = .061$]. In other words, the participants who self-reported 'familiar' with the town did not overall perform better, suggesting perhaps the level of familiarity was not very high. Thus we kept their data along with the others in all analyses.

6.5.1. Participant performance and confidence per question (individual tasks)

Figure 32 provides an overview of the relationship between the participants' average accuracy scores (as a percentage), and their average question completion time (in seconds) to complete each individual question. A strong negative correlation (*Pearson correlation = -.732, p = .000 2-sided*) between the average accuracy score and the average question completion time was observed. This shows that the participants made more mistakes with the harder questions *and* they took longer to complete the task – in other words, we did not observe a speed-accuracy trade-off.

Besides the accuracy and question completion time, we analysed how the confidence levels changed over all tasks. As can be seen in Figure 33 participants indicated relatively high levels of confidence for all questions (between 59% and 93%).

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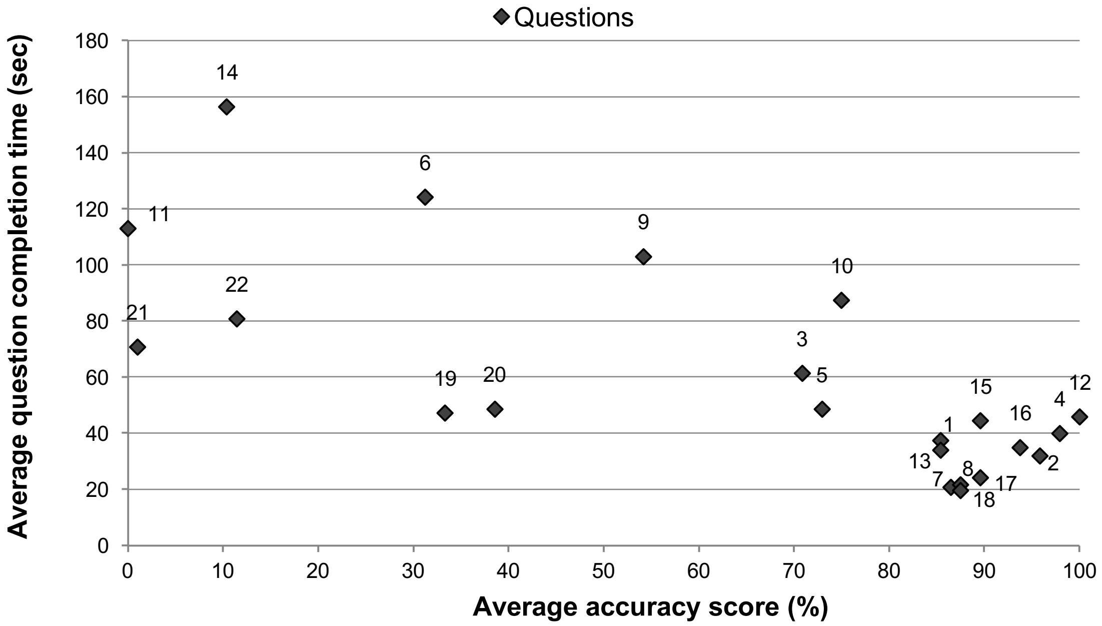

Figure 32. The average accuracy score in percentage compared to the average question completion time

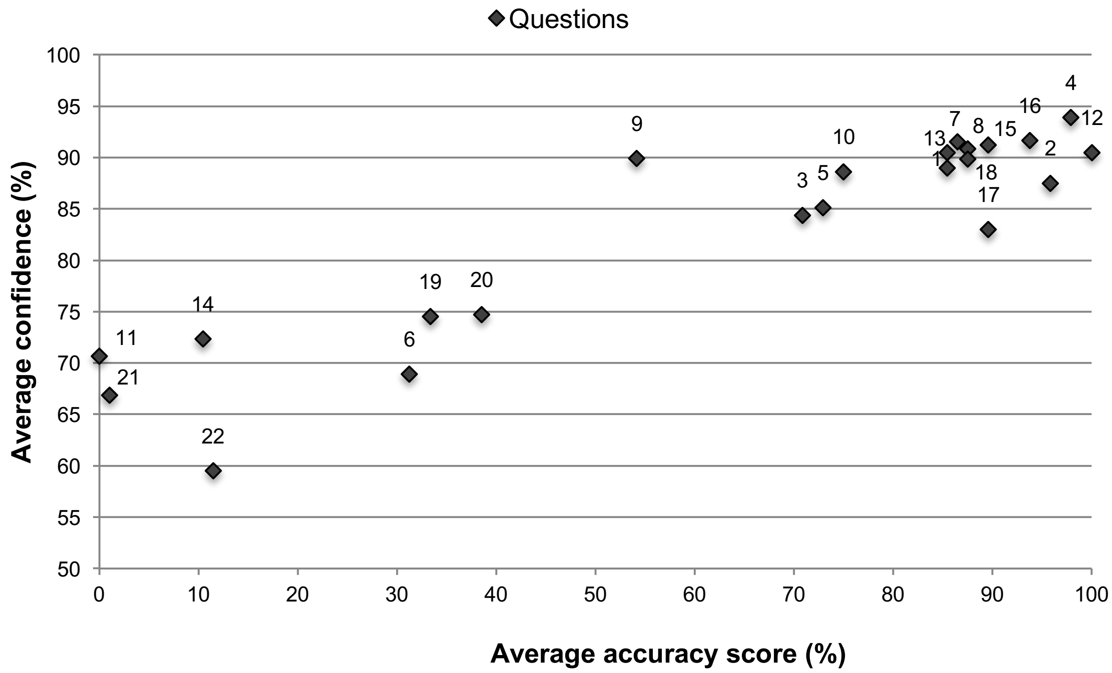

Figure 33. The average accuracy score in percentage compared to the participant's confidence for each question

Considering that the questions were designed to vary from simple to complex as we go from 1 to 22, in Figure 33, we see that on average, the levels of confidence is matching with the levels of difficulty. With questions 21 and 22 (determine the area or extent of a region), participants marked their confidence level the lowest. In these two questions, and question 11 and 14 (specifying a location

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using coordinates), participants' accuracy scores were also the lowest. Despite the matching trend, the average confidence of the participants was skewed negatively (-1.295), supporting the observation that participants were over-confident on average (they overestimated their performance). A two-tailed Spearman's rho test was used to analyse the correlation between the average accuracy score and confidence of participants. We observed a significant correlation between the accuracy score and confidence (*Spearman's rho = .225 p = .028 2-sided*), suggesting that participants were aware of their relative task performance (i.e., they were somewhat able to judge when they did not do too well, despite a general trend of over-confidence).

6.5.2. Participant performance and confidence per task type in relation to map literacy levels

At this point, to verify the patterns at the task level, we aggregated the individual questions into *task types* as presented in Table 12, and studied the relationship between the accuracy scores and task completion time (response time) again, at an aggregate level. Figure 34 shows that a similar pattern (as in Figure 32) emerges as we compare the average accuracy score and task completion times (as specified in Table 12, a task may be represented by two or more questions) and verifies our observations at the question level. Furthermore, we did not observe a statistical correlation between the accuracy scores and task completion time per task type, suggesting that there was no speed-accuracy trade-off at the task type level either.

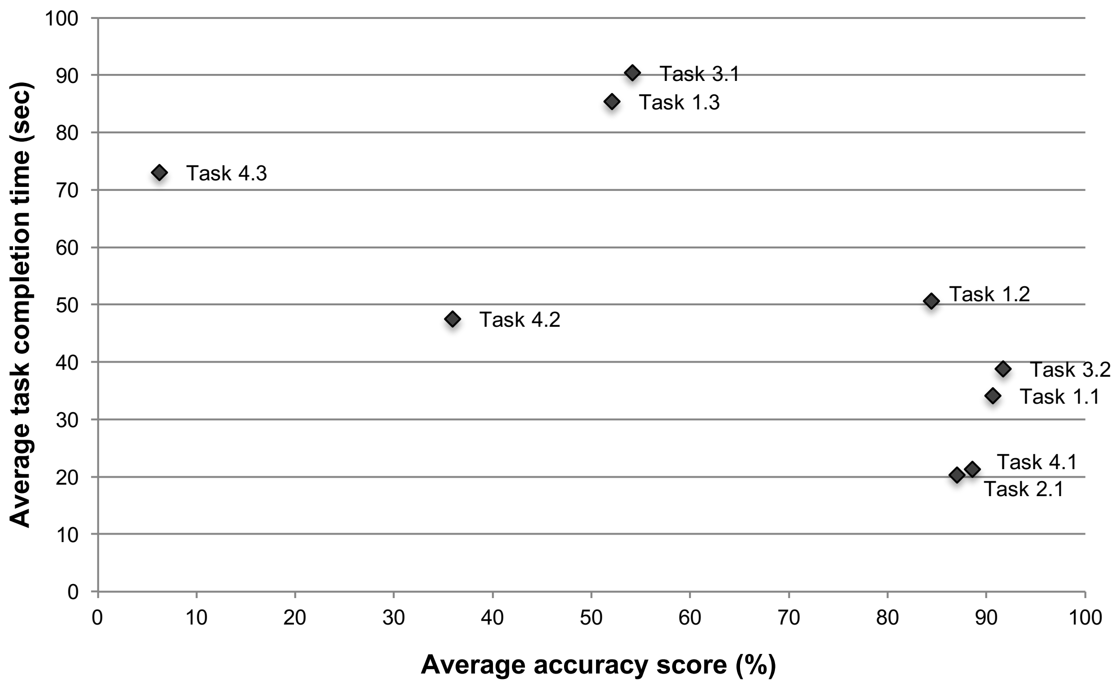

Figure 34. The average accuracy score in percentage compared to the average task completion time for each task (as specified in Table 2)

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6.5.3. Participant performance and confidence per map literacy level

We expected that all participants would attain high accuracy scores, as they are trained in map reading through their educational attainments and self-reported experience levels (see Figure 30 and Figure 31), i.e., our participants are a map-literate sample. However, as mentioned earlier, we also expected the accuracy scores to decrease as the tasks associated with higher levels of literacy were presented, because the higher levels contain presumably harder tasks (as specified in Table 11).

Accuracy scores in relation to the map literacy levels can be seen in Figure 35. The participants achieved a lower accuracy score in Level 1 (75.69%) compared to Level 2 (86.98%), which was an unexpected result. We believe this is mostly explained by the low success rates with Task 1.3, specifically in question 6 (*Indicate the lowest point shown in the map*) where participants performed below expectations (see Figure 35): only 20.4% of the participants were able to find the lowest elevation point on the map. This result can possibly be attributed to the fact that individuals might find it difficult to read and understand contour lines, as suggested by Chang *et al*. (1985).

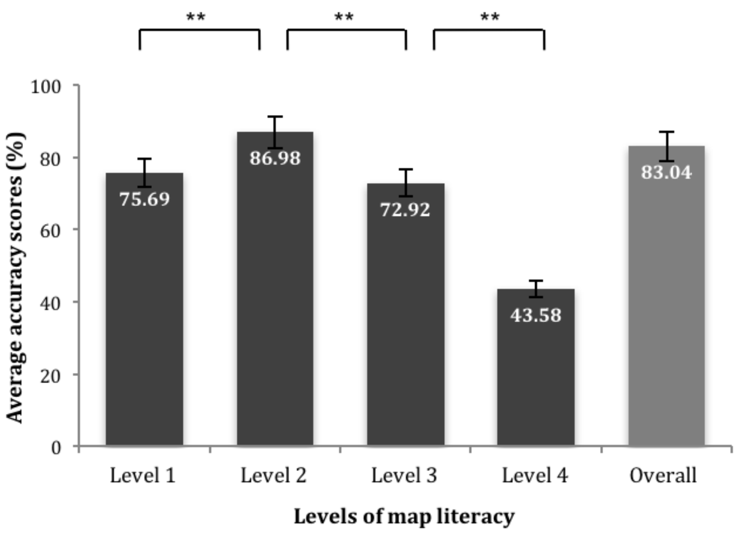

Figure 35. The average accuracy scores for each of the map literacy levels for all participants. Error bars: +-SEM. **p<0.01

A one-way ANOVA revealed that the accuracy score increased between Level 1 and Level 2, $t(47) = -2.9$, $p = .006$ (refer to Figure 35). The accuracy score then decreased from Level 2 to Level 3 as expected, $t(47) = 3.208$, $p = .002$, and also between Level 3 and Level 4, $t(47) = 11.17$, $p = .00$.

To complete the performance analysis, after studying the accuracy (as shown in Figure 35), we analysed the average task completion time per map literacy level, seen in Figure 36.

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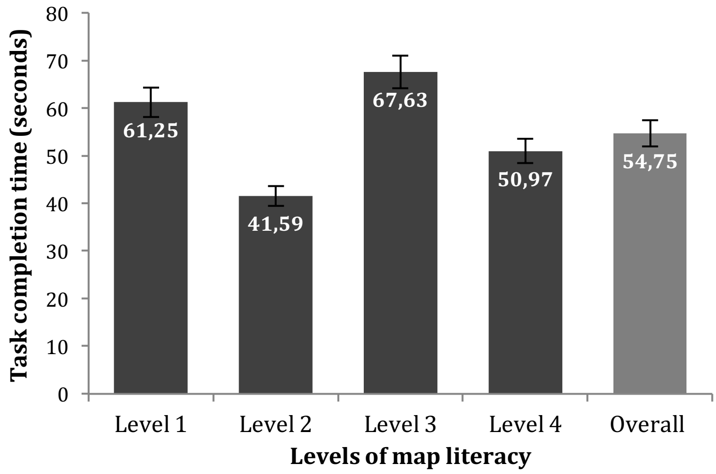

Figure 36. The average completion time for each of the map literacy levels for all participants. Error bars: +-SEM

In Figure 36, we observe that generally participants took a small amount of time (between ~40 seconds and ~70 seconds) to complete the tasks. The correlation between the completion time per level and accuracy scores remains also at this aggregation level, especially when looking at Level 2. A one-way ANOVA was performed to analyse the effect of the different map literacy levels on the average completion time per map literacy level, [Level 1, *F(6,39) = 1.77, p = .129,* Level 2, *F(3,42) = .297, p = .827,* Level 3, *F(8,37) = 1.643, p = .146 and* Level 4, *F(7,38) = 1.194, p = .33*]. The results revealed that the different levels had no statistical effect on the average time taken to complete tasks for each map literacy level.

Furthermore, to understand if the participants' confidence would reflect the task complexity, we analysed the confidence levels in relation to tasks per map literacy level (Figure 37).

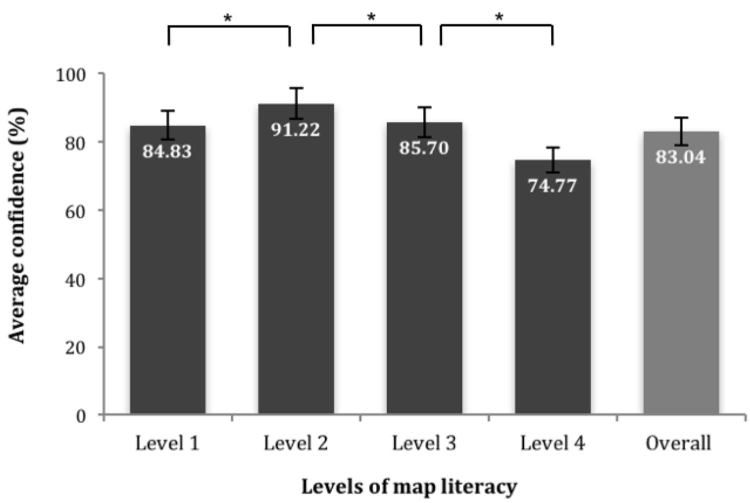

Figure 37. The average confidence for each of the map literacy levels for all participants. Error bars: +-SEM. *p<0.05

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Figure 37 shows the average confidence of participants for each level. Again we can see that participants were very confident in their answers, with a slight decrease at Level 4, which consisted of the most challenging questions, and the participants possibly detected this. The participants' average confidence increased between Level 1 and Level 2, t(47) = -2.37, p = .022, and then slightly decreased between Level 2 and Level 3, t(47) = 2.21, p = .032 and also decreased to Level 4, t(47) = 2.414, p = .020.

6.5.4. Exploratory group differences in performance and confidence based on experience and gender

To better understand if the results vary based on participant characteristics, we studied the effect of experience and gender. Note that the study was not fully counterbalanced (i.e., we did not control for the number of experts among men or women, etc.). However, we present an exploratory analysis here, as previous literature suggests that performance differences might be related to experience levels, and confidence sometimes depends on gender (Biland and Çöltekin, 2016). Experienced participants were defined as participants who rated themselves as 'excellent' in all categories of the self-reported familiarity and experience questionnaire. This resulted in 16 experienced (eight males and eight females) and 32 inexperienced participants (16 males and 16 females).

There was a slight difference between the experienced and inexperienced participants in terms of accuracy scores for each literacy level (see Figure 38). However, a one-way ANOVA revealed that this difference was not statistically significant, *F(1,46) = .413, p = .524*. Additionally, no statistically significant correlation was found between the participants' experience and their performance for each task.

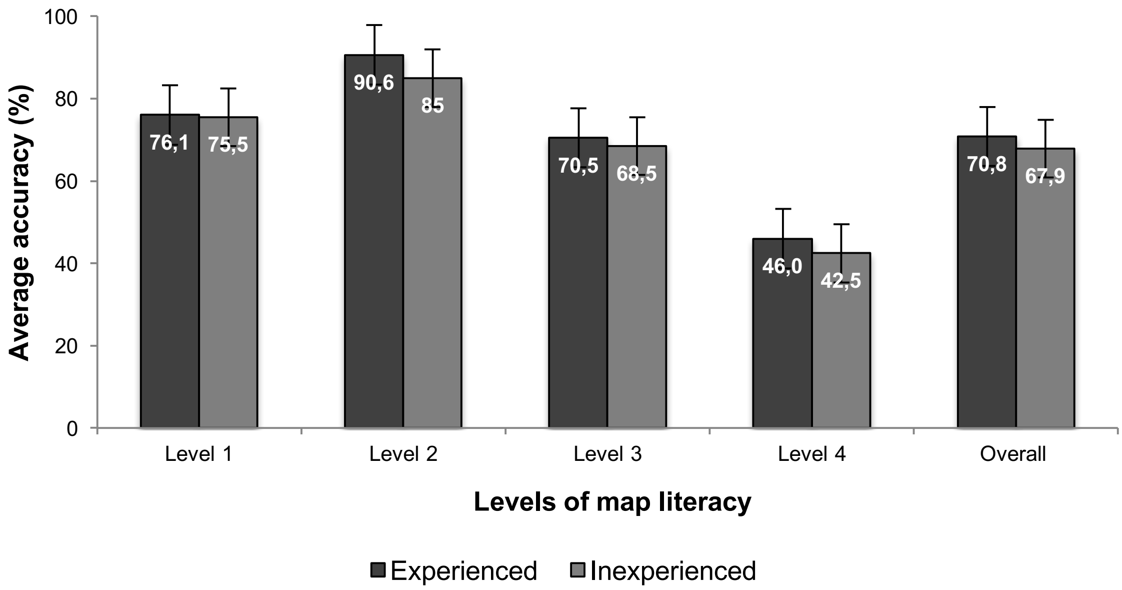

Figure 38. The average accuracy scores in percentage of the experienced and inexperienced participants for each literacy level. Error bars: +-SEM

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Experienced participants took more time to complete the questions in comparison to the inexperienced participants. A one-way ANOVA revealed that this difference was statistically significant, *F(1,44) = 6.540, p = .014*. The experienced participants generally also rated their confidence higher than inexperienced participants, and this difference was found to be statistically significant, *F(1,46) = 6.677, p = .013*.

In terms of gender differences, women achieved a slightly higher accuracy than men (Figure 39); however a one-way ANOVA revealed that this difference was not statistically significant *F(1,46) = 2.424, p = .126*. As with the experts, women also took more time than men to complete the task. However, this was found to not be statistically significant, *F(1,44) = .428, p = .516*. We found that gender had no effect on confidence [*F(1,46) = .091, p = .764*] and task completion time [*F(1,46) = .424, p = .126*].

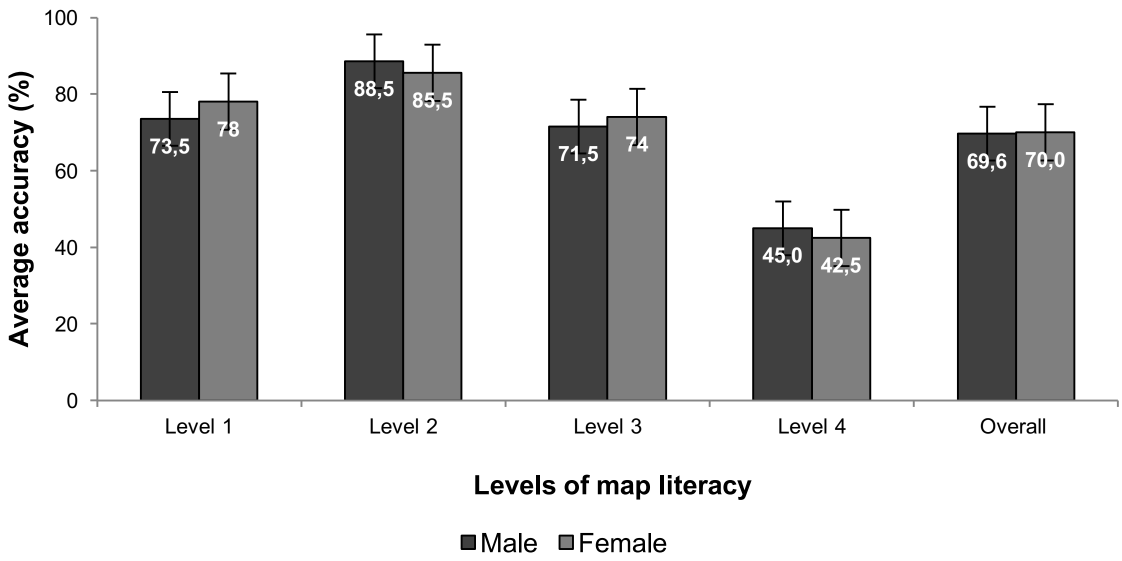

Figure 39. The average accuracy score in percentage of males and females for each task. Error bars: +-SEM

6.6. Discussion and conclusion

In this paper, we first presented a map reading task taxonomy that we specifically designed for spatial planning based on the literature, reports, policies and information we obtained through qualitative consulting with expert spatial planners. Our overarching goal was to identify geographic visualisation (map) types that are helpful and functional for specific spatial planning tasks (or task types) when the levels of map literacy vary, and explain why these visualisations are fit for the given context and the audience. The specific goal of this paper was to investigate whether our proposed taxonomy indeed 'works as expected' in terms of our classification of map literacy levels. To achieve this, we designed a user experiment for a subset of the proposed map reading taxonomy (Levels 1-4), and tested it with a group of 49 functionally map-literate participants using a topographic map. We found that the

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proposed tasks yield results broadly as expected, thus provide a good reference for evaluating topographic map literacy levels.

The results showed that participants' accuracy scores were overall very high in all questions relating to the first two levels (Level 1 and Level 2). It seems that the symbols on a topographic map are generally easy to identify when provided with a comprehensive legend: i.e., the average accuracy on questions 1 to 4 (Level 1) was above 70%. The complexity of tasks in the proposed taxonomy increases from Level 1 to Level 4, and we therefore expected the accuracy scores to decrease from Level 1 to Level 4. This was true for Level 2 to Level 4, but the participants surprisingly performed better in Level 2 compared to Level 1 (discussed below). The average accuracy scores of participants dropped from above 70% to below 50% from Level 3 to Level 4.

Four of the map reading tasks were particularly challenging for our participants: 1) *Recognise various topographic features in the area based on symbology or patterns (Task 1.3)*; 2) *Determine the position at a specific point (Task 3.2);* 3) *Determine the distance between two points or length of a linear feature (4.2);* and 4) *Determine the area or extent of a region (Task 4.3)*. The average confidence of the participants for these tasks was also lower than for the other tasks.

The unexpected increase in the average accuracy score from Level 1 to Level 2 appears to be mainly due to the poor performance in question 6 (Task 1.3). Only 20.4% of participants correctly indicated the lowest point on the topographic map (question 6, Task 1.3). We believe this is explained mainly by the poor interpretation of the contour lines. Chang *et al*. (1985) suggested that the development of a 3D mental image of the terrain from contour lines is challenging for most individuals. The result for Task 1.3 supports this. The evaluation of the responses for the lowest point focused on recognising the correct pattern in the contour lines and a response within an acceptable distance from the lowest point was also considered to be correct. Additionally, spot heights on the map were also printed quite small and the participants might have struggled to read the labels. To overcome this challenge, 3D geovisualisations could be considered as an alternative, shown side-by-side, or to allow interactive change of perspective to oblique or street level viewing where possible. In some environments or terrains, 3D geovisualisations may simplify tasks relating to topography, such as identifying the lowest or highest point (Schobesberger and Patterson, 2008; Popelka and Brychtová, 2013; Rautenbach, Bevis, *et al.*, 2015). The opposite question (question 5, Task 1.3) for indicating the highest point was easier, as there was a distinctive peak with a label on the map and 71.4% of the participants correctly identified "*Saddleback peak*" as the highest point on the map. The remaining 28.6% participants indicated one of the other peaks in the area as the highest (there were six peaks indicated on the entire the map). Note that, for the highest point, only "*Saddleback peak*" was accepted as the correct answer, as the six peaks were displayed with elevation values on the map.

Participants' accuracy with determining the position at a specific point (Task 3.2) was significantly lower in the questions requesting numeric coordinates (question 11 and 14), than in the question requesting an alphanumeric grid reference (question 10). Participants understandably struggled to accurately estimate the decimals for the minute in the coordinates.

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The drastic decline in the average accuracy score from Level 3 to Level 4 can possibly be explained by the lack of tools, such as a calculator, during the experiment. The participants needed to use the scale bar and then calculate distance or area using multiplication. Most of the errors in Level 4 tasks were of an arithmetical nature and related to area calculations. Accuracy in length and distance estimations was higher, most likely because multiplying or dividing by 1,600 for length and distance estimates is simpler than multiplying, for example, 230 with 60, to calculate area. The type of errors observed for Level 4 tasks confirms that participants struggled with complex multiplications but understood the principle of scale, line-of-sight and slope steepness. That is, participants were overall competent on Level 4. Therefore, despite the low average accuracy scores on the four tasks in this level, it can be said that all participants were competent on all four levels, i.e. the participants in our experiment are functionally map literate. We therefore we conclude that the experiment successfully determined the functional map literacy of participants as expected.

We observed a strong negative correlation between the average accuracy scores and task completion time. Furthermore, there is a correlation between performance and confidence: participants achieved higher accuracy scores and took less time to complete the questions with which they reported higher levels of confidence in their performance. We also observed that experienced participants (consisting of 50% females) and females (51% of all participants) tended to take more time than their counterparts did, and slightly outperformed them. The assumption was that all participants were map literate, and confirming this, we found no statistically significant correlation between the self-rated experience of participants and their performance. Even though there was no statistically significance between self-rated experience and performance, it does correlate to other research from Furnham (1999; 2001) and Lloyd and Bunch (2005; 2008). The fact that the overall performance was high was expected, because the experiment included only basic tasks on Level 1 to Level 4, and we recruited map-literate participants who had previous exposure to similar topographic map reading tasks, either at school or at university.

Results of the experiment reported in this paper suggest that our map reading task taxonomy is suitable for evaluating topographic map literacy of a group of map-literate individuals. The proposed map reading task taxonomy was developed based on literature authored by scientists from many different countries. We thus argue that the taxonomy we proposed in this paper could be used as a generalisable reference task taxonomy for evaluating topographic map literacy also in other countries. However, the taxonomy has not yet been tested with participants from other countries using their local topographic maps. In this analysis, a participant with an average accuracy of 70% or above was considered as map literate because with a 70% score most tasks were completed successfully. This being said, map literacy should be considered to be a continuum, rather than discrete or Boolean values. This notion is supported by Lee and Bednarz (2012), who stated that individuals might perform well on certain tasks and fail on others.

We plan to repeat the experiment with participants who have no experience in cartography and geography. If we can demonstrate that the performance by map-illiterate individuals is consistently

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lower than the map-literate ones in this study, we will be able to strengthen the evidence that we created a systematic task taxonomy for evaluating map literacy. Furthermore, because the task taxonomy is customised for spatial planning, we will conduct experiments with spatial planners and support the evaluation process also with interviews where the tasks cannot be tested with close-ended "survey-type" questions. Last but not least, we plan to further refine the map reading task taxonomy and also consider additional spatial visualisations, such as 3D models.

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Chapter 7. Evaluating the usefulness of aerial photographs, 2D maps and 3D models for urban design

7.1. Overview

In this chapter, the results from two user studies and four expert interviews are presented. The hypothesis was that 3D models would be useful to perform map reading tasks relating to topography. The original hypothesis and conceptual design for the user study are presented in Section 5.6.

The aim of the evaluation was to investigate the usefulness of 3D models when performing certain urban design tasks using aerial photographs, 2D maps and 3D models. As these media (i.e. aerial photographs, 2D maps and 3D models) are very different, for example in visual complexity and abstraction, more than one approach was required. The experiment consisted of the following parts:

1. Quantitative part
    - Controlled user study
    - Distributed user study
2. Qualitative part
    - Semi-structured expert interviews

Each of the parts mentioned above are presented in detail in the remainder of the chapter, including the study design and results. Lastly, the results from all parts (i.e. user studies and expert interviews) are combined in the discussion and conclusion of this chapter.

7.2. Quantitative user studies

In this section, the study design of both the controlled and distributed user study is presented, followed by the results of the user studies, and lastly a discussion of the results.

7.2.1. Study design

7.2.1.1. Overview

The aim of the quantitative user studies was to evaluate individuals' map reading skills when asked to perform tasks relating to symbol recognition and topography using aerial photographs, 2D maps and 3D models of a typical South African informal settlement. The user study was conducted in two distinct ways: 1) in a controlled environment to minimise confounding variables, such as noise, light or interruptions, and 2) distributed as an online study through various mailing lists to get results from the larger geospatial community in South Africa. Participants in the controlled user study were mainly undergraduate geoinformatics students, and distributed user study participants consisted of individuals of various backgrounds (geoinformatics, town and regional planning and architecture, to name a few).

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Selected tasks relating to symbol recognition and topography from the proposed map reading task taxonomy (introduced in Section 6.3) were used for this user study. During the user study, participants were presented with 24 questions relating to the four tasks in the proposed map reading task taxonomy (refer to Table 13). The complete user study is available in Annex F. All the questions were presented in a randomised order to minimise fatigue and the learning effect. Qualtrics[7] was used to present the questions to the participants, and to capture the responses in both the controlled and distributed study.

The independent variable was the type of geovisualisation (refer to Section 7.2.1.2): aerial photograph, 2D map and 3D model of a typical South African informal settlement. The following dependent variables were measured: accuracy (*was the answer correct?*), completion time (*time taken to complete the question*) and the participant's confidence (*does the participant think the answer is correct?*), which are common measures in similar experimental studies.

Table 13. Overview of the relationship between the questions in the user study and the task taxonomy

Level	Task	Qn	User study question text
Level 1: Recognise symbology	1.1. Name the phenomenon represented by the symbol	1-6	Which of the following best describes the feature inside the red circle?
	1.2. Describe the difference in characteristics of phenomenon based on the symbols or patterns	7-12	Which of the following best describes the feature inside the red circle?
	1.3. Recognise various topographic features in the area based on symbology or patterns	13-15	Indicate the highest point shown in the map below (click on the map)
		16-18	Indicate the lowest point shown in the map below (click on the map)
Level 4: Measure or estimate	4.1. Estimate certain topographic elements	19-24	In which area, A or B is the slope the steepest?

7.2.1.2. Materials

An informal settlement located on the eastern outskirts of Mamelodi in the City of Tshwane (CoT) Metropolitan Municipality, named Alaska, was used (refer to Figure 40). The settlement is situated at the foot of the Magaliesberg. The informal settlement of Alaska was chosen, as data for the settlement was available. Generally, informal settlements are not mapped and thus the availability of data was the main deciding factor. The geovisualisations were created to be clearly visible on a 19-inch light-emitting diode (LED) computer screen with a resolution of at least 1366x768. The following geovisualisations were used:

a) Aerial photograph

The CoT 2012 aerial photographs were used. These images are outdated now but were the most recent photographs available at the time. Refer to Figure 41.

[7] http://www.qualtrics.com

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b) 2D map

The informal settlement of Alaska is currently not mapped by local government nor other web mapping services, such as Google Maps[8] or OpenStreetMap[9]. However, spatial data for the surrounding Reconstruction and Development Programme (RDP) houses (i.e. government-subsidised housing) and road network were obtained from the CoT. Dwelling footprints and footpaths were digitised from CoT aerial photographs and GeoEye imagery. Additionally, the 2015 third-year geoinformatics students captured the points of interest (POIs) in the field with handheld GPSs and the EpiCollect+[10] mobile mapping solution. The CoT data and additional data captured by the students were combined to create the 2D map used in the study. Refer to Figure 42.

c) 3D model

The same data that was used for the 2D map (i.e. CoT data and additional data captured by the geoinformatics students in 2015) were utilised to develop the 3D model of the informal settlement. The 3D model was generated at LoD2 in Quantum GIS (QGIS) using the qgis2threejs plugin[11]. In the 3D model, each dwelling was shaded according to its use; for example red was used for shops and light brown for informal dwellings. For this user study, only a single still image of the 3D model was used from a bird's-eye perspective, as an interactive 3D model would introduce too many variables. Refer to Figure 43.

Aerial photographs generally do not have a legend. The legend was thus not included for all types of geovisualisations to ensure a consistent and comparable experience. Instead, participants were provided with options to choose from. For example, in Figure 42, the participants could choose from the following options for the feature represented within the red circle marked A: formal dwelling, informal dwelling, land parcel, RDP house and tuck shop.

Additionally, the aerial photograph and 2D map are both viewed from above (approximately a 90-degree angle), whereas the 3D model has a slight perspective shift and is viewed from an oblique angle (approximately a 45-degree angle). Consequently, the aerial photograph and 2D map are more directly comparable, in terms of a uniform scale across the geovisualisation. The 3D model will moreover be cognitively processed differently to aerial photographs and 2D maps.

[8] Google Maps pin close to the Alaska informal settlement, https://goo.gl/maps/sMwa7Jz9EF82
[9] OpenStreetMap pin close to the Alaska informal settlement, http://osm.org/go/k2UenWMd--?m
[10] http://plus.epicollect.net
[11] https://plugins.qgis.org/plugins/Qgis2threejs/

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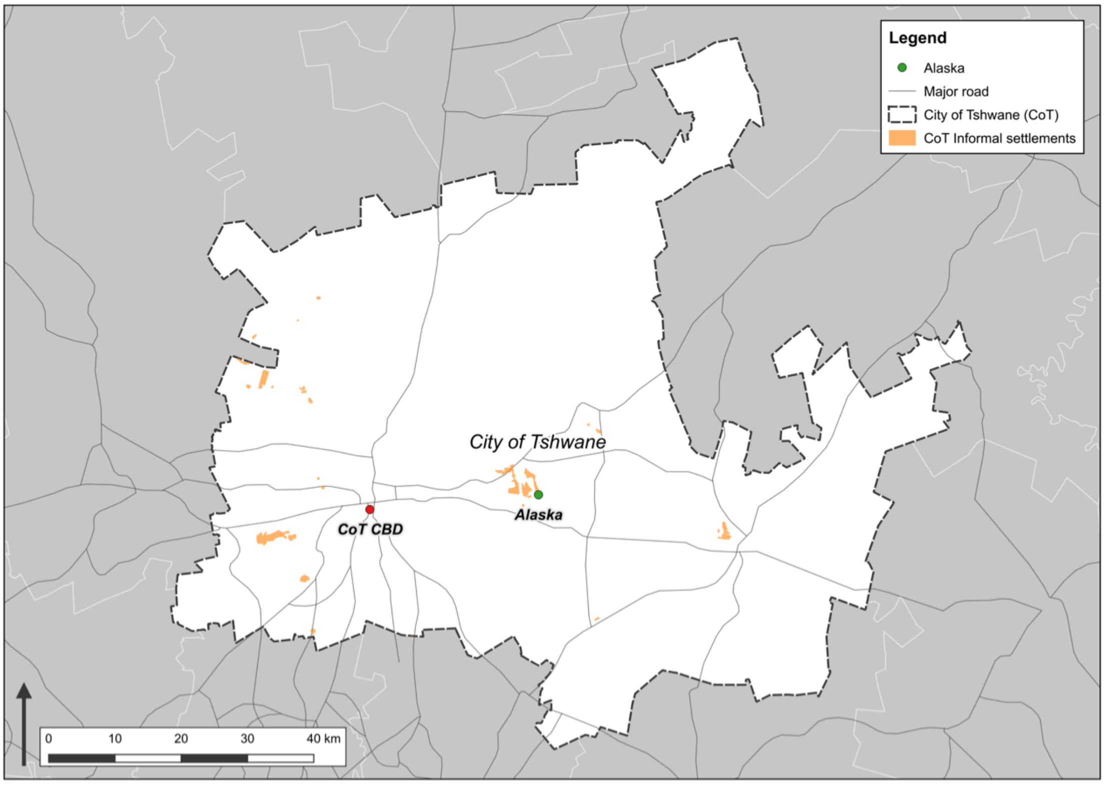

Figure 40. Location of Alaska in relation to the City of Tshwane and the central business district. Source: City of Tshwane and OpenStreetMap

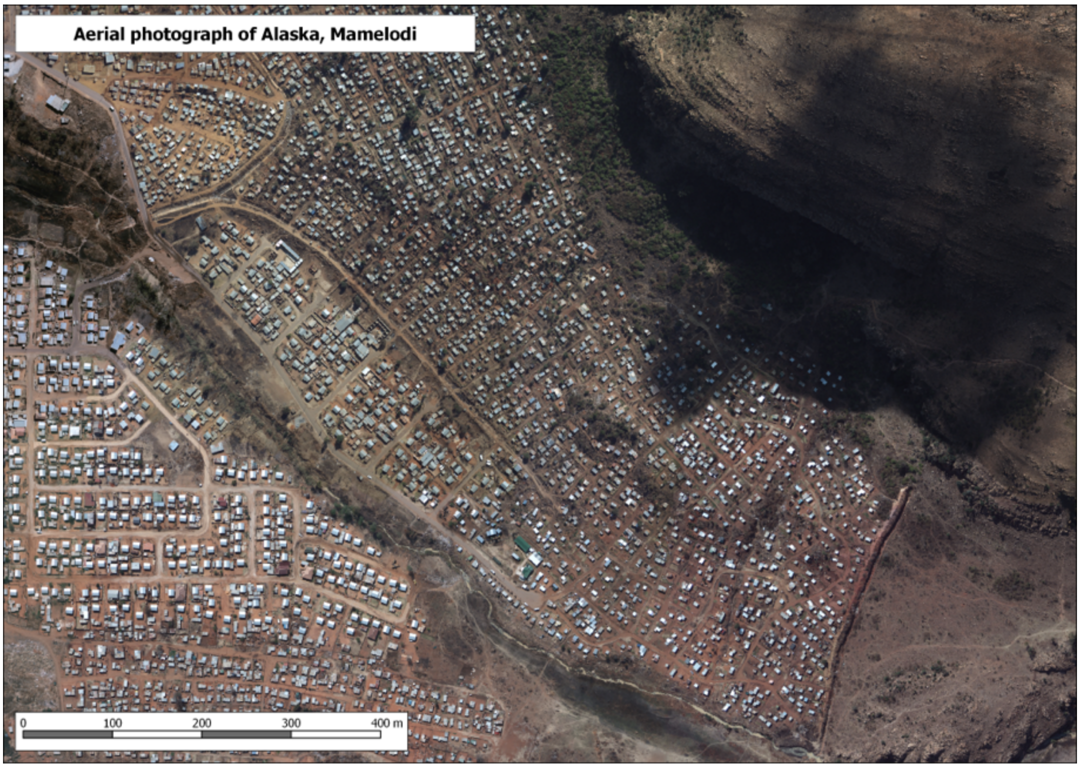

Figure 41. Aerial photograph of the informal settlement of Alaska. Source: City of Tshwane

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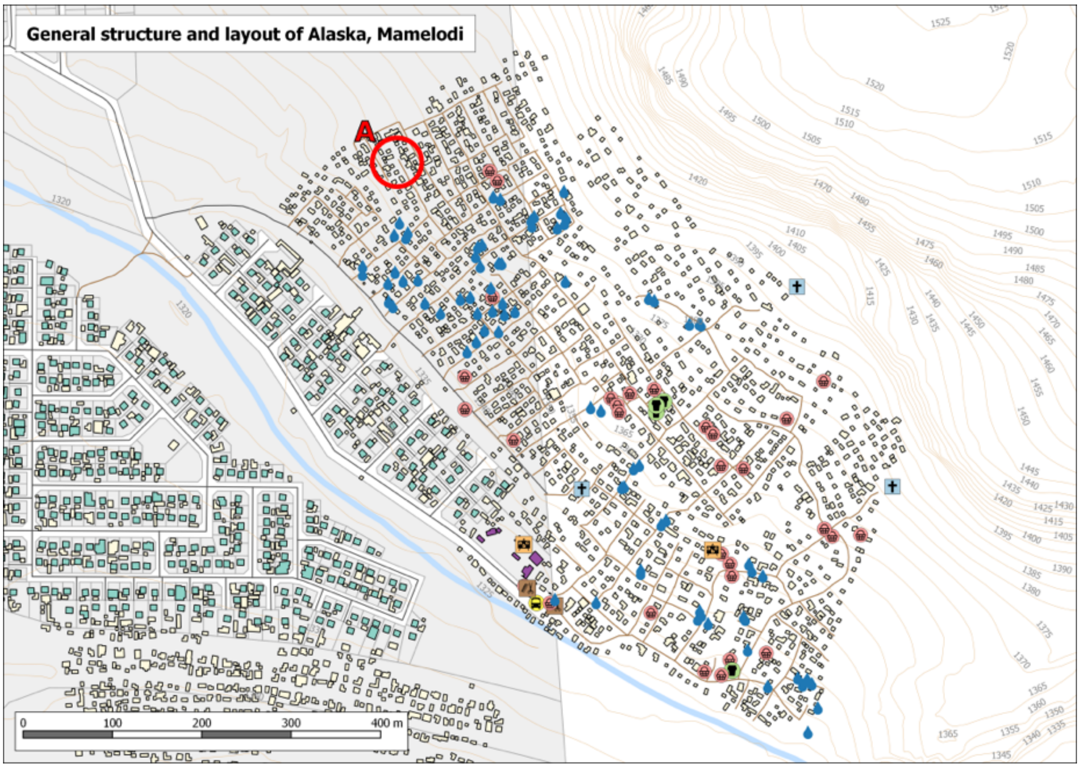

Figure 42. 2D map of the informal settlement of Alaska. Source: City of Tshwane and University of Pretoria

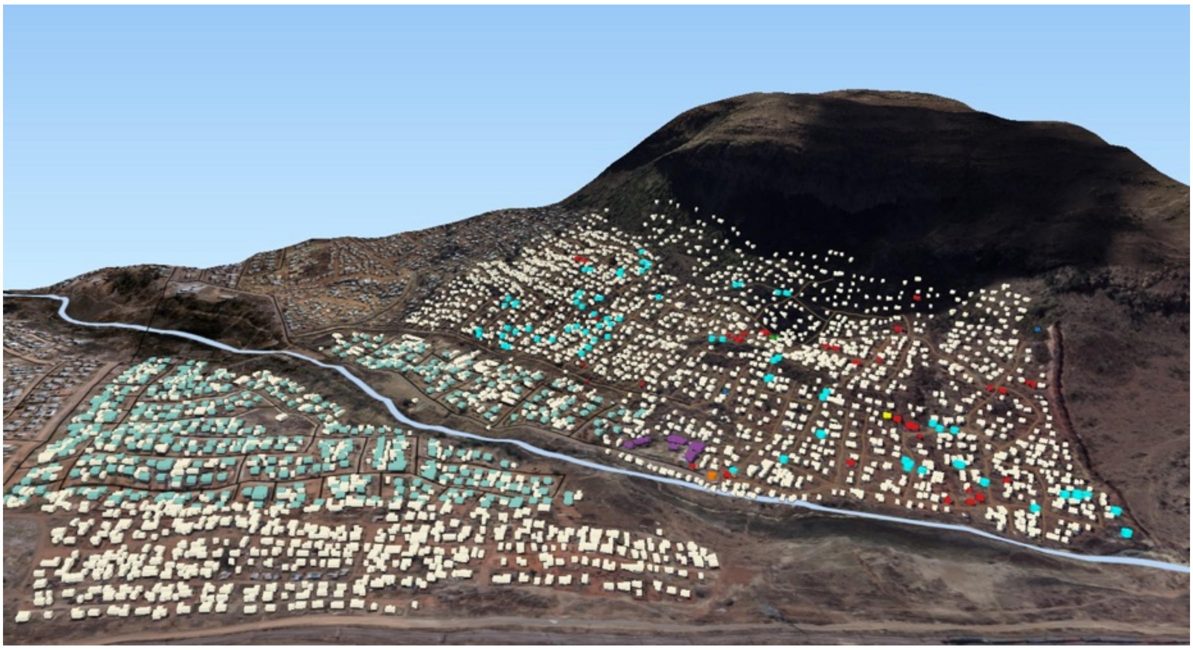

Figure 43. 3D model of the informal settlement of Alaska. Source: City of Tshwane and University of Pretoria

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7.2.1.3. User study structure

The questions in the controlled and distributed user studies were grouped into the following tasks (refer to Figure 44 for an overview):

- **Demography**. In this task, demographic questions, including questions relating to the participant's background and occupation, were asked. Additionally, each participant was asked to rate their training and experience in related fields or topics, such as planning and spatial data.
- **Familiarity with Alaska, Mamelodi**. As the user study was distributed via mailing lists it was not possible to control who completed it. The assumption is that if a participant is very familiar with the area, the participant might be able to complete the questions by relying on their experience and not on the information presented in the various geovisualisations. Thus, it was important to know how familiar the participants were with the informal settlement of Alaska.
- **Mental rotation test**. The mental rotation test is widely accepted as a good indication of an individual's spatial abilities. A mental rotation test based on Vandenberg and Kuse was included to complement the results, and was used to verify results in certain cases. This task consisted of 20 questions. Participants were asked to complete as many as possible within a six-minute period, and were then forced by the system to move on to the next task.
- **Map reading tasks (24 questions)**. In Table 13, an overview of the user study question text and the related tasks from the map reading task taxonomy is provided. Each question, except for the questions about the highest and lowest point, was repeated twice for each of the geovisualisations, and thus there were six questions for every task selected from the taxonomy.

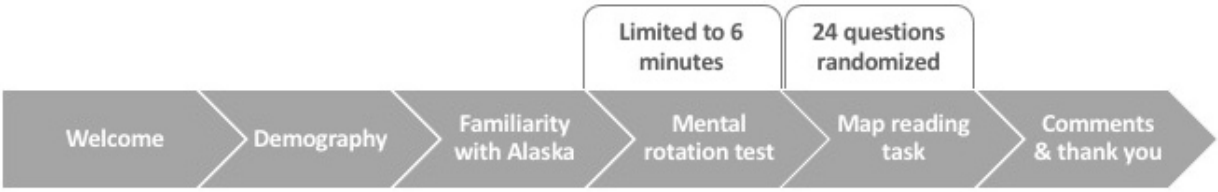

Figure 44. Overview of the sequence of the tasks in the user studies

7.2.1.4. Procedure

The user study was conducted in two distinct methods: controlled and distributed. Both the controlled and distributed user study were presented in the form of a questionnaire using an online survey software product, called Qualtrics. For the **controlled user study** a group of participants (approximately 15 participants in a lab with 40 computers) completed the survey using a web browser on computers connected to the Internet. The external variables, such as the processing power of the computers, display sizes, keyboards and bandwidth, were identical for all participants. No verbal instructions were given to the participants as all instructions were included in the online survey.

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For the **distributed user study**, an invitation to participate in the study was sent to two South African mailing lists (i.e. OSGeo Africa and SDI Africa). A few direct email invitations were sent to members of the geospatial community in South Africa. As the study consisted of various high resolution geovisualisations, and bandwidth capacity of the participants was unknown, response time could not be used as a measure for these participants.

7.2.2. Results – controlled user study

7.2.2.1 Overview of participants

Thirty-six individuals (17 males and 19 females) ranging from 18 to 33 years old participated in the user study. All participants were undergraduate students from the University of Pretoria with the majority of participants being geoinformatics students (81%). Additionally, a number of geography (13%), meteorology (3%) and town and regional planning (3%) students participated in the user study. Thus, the profile and skills of the participants were assumed to be similar; additionally the participants were considered to be future professionals that would be involved in urban design in some respect.

The participants could be further divided into two distinct groups: 1) first-year students (53%) who were unfamiliar with the settlement of Alaska, and 2) third-year geoinformatics students (47%) who had worked in the settlement of Alaska. The third-year geoinformatics students assisted with capturing the dwellings, footpaths and POIs in the settlement as part of their final-year project. These students visited Alaska on three different occasions, and also worked on the data for four months. Thus, they were very familiar with the settlement.

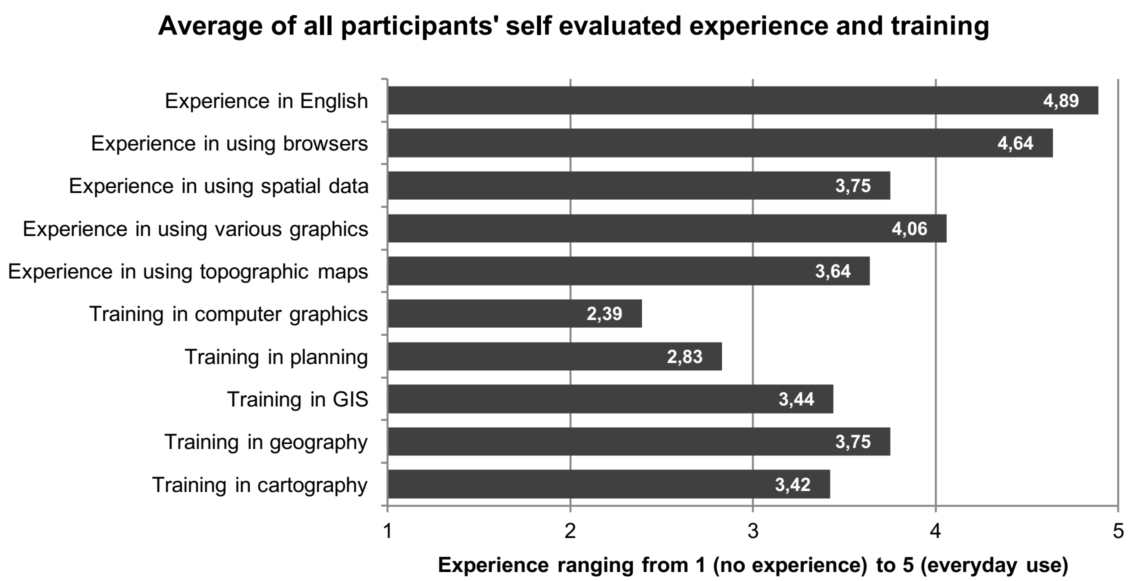

Figure 45. Participants' average self-reported experience and training (controlled user study)

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All the participants were asked to rate their training and experience on a five-point Likert scale (refer to Figure 45). *Training in computer graphics* and *training in planning* were ranked below average, as these aspects are not covered in great detail in the geoinformatics degree.

7.2.2.2 Detailed results of controlled user study

The controlled user study consisted of 24 questions that related to four tasks as specified in the proposed map reading task taxonomy. Table 14 shows performance results for the tasks, broken down according to each geovisualisation (i.e. aerial photograph, 2D map or 3D model). The highest mean confidence is also shown. From the table, it is clear that the participants performed best when using the 2D map. However, for only two tasks the participant's mean confidence was the highest for 2D maps. The table also shows that for two tasks (i.e. *Name a feature* and *Highest point*) the participants were most confident in their answer when using the 3D model. However, participants did not achieve the highest percentage of correct answers for any task when using the 3D model. A detailed reporting of all performance and confidence results is provided in the next sections.

Table 14. Overview of participants' performance per geovisualisations type (controlled user study)

Geovisualisation / *Task*	**Aerial photograph**	**2D map**	**3D model**
Name a feature		✔	★
Difference between features	✔ ★		
Lowest point		✔ ★	
Highest point		★	✔
Steepest slope		✔ ★	

✔ - Highest average percentage of correct answers for the task

★ - Highest mean confidence for the task

Participant performance and confidence per task type

Figure 46 shows accuracy results obtained from the user study. The results show that participants were on average more successful in completing the tasks when using 2D maps, except for the task that involved indicating the *highest point* on the map. For two tasks, *name a feature* and *difference between features*, participants were on average equally successful when using the aerial photograph and 2D map. The participants achieved on average much lower scores when performing tasks using the 3D model of Alaska, except for the task that involved *indicating the highest point*, where the average score was only 2% behind the aerial photograph (94%).

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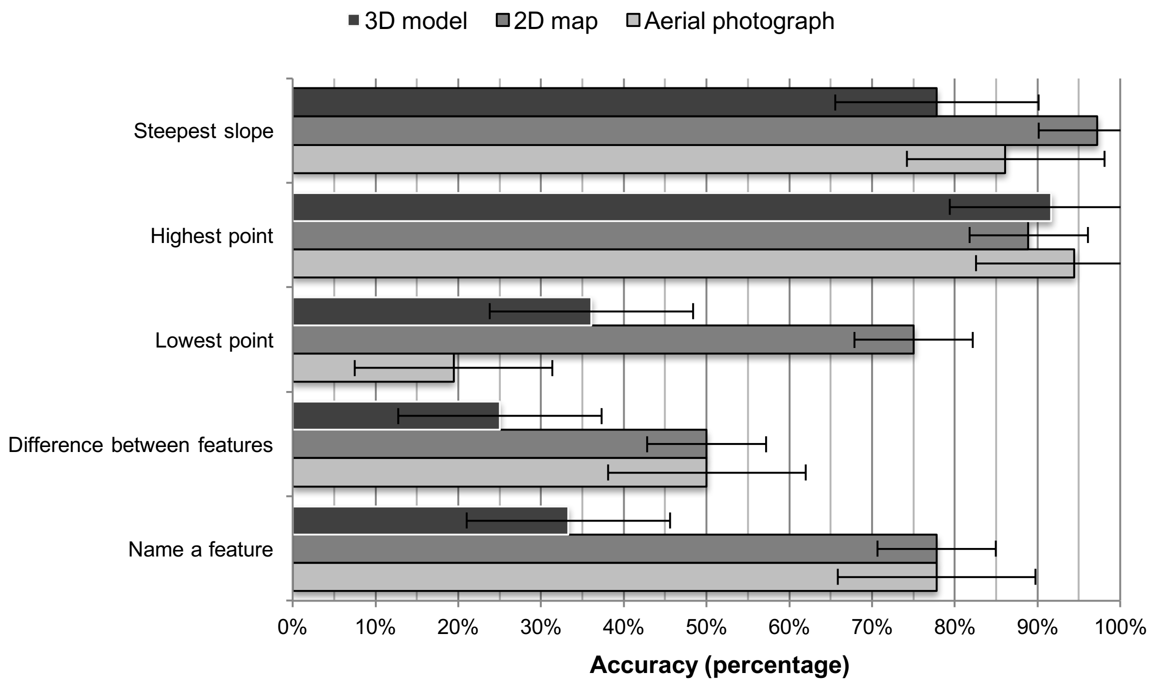

Figure 46. Average percentage of correct answers for each geovisualisation in the controlled user study. Error bars: +- SEM

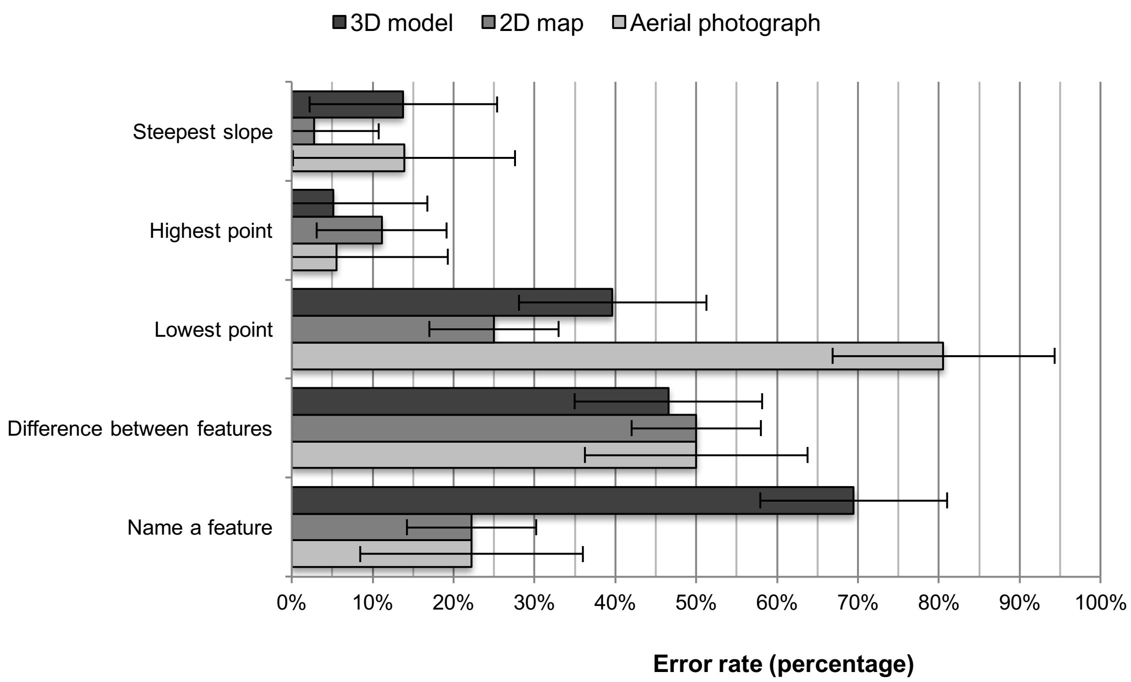

Figure 47. Average percentage of incorrect answers for each geovisualisation in the controlled user study. Error bars: +- SEM

When looking at the incorrect answers in Figure 47 (depicts the inverse or opposite of Figure 46), the task with the highest percentage of incorrect responses (81%) was *indicating the lowest point* in the

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area using an aerial photograph. This was followed by the *name a feature* tasks using the 3D model with 69% incorrect responses. The *differentiating between features* task when no legend is provided also proved to be challenging, as only approximately 50% of participants identified the features correctly in all geovisualisations (aerial photograph, 2D map and 3D model). Overall, the *indicating the lowest point* task was a challenge for participants. This is supported by the mean confidence, as the participants' mean confidence was on average only 59% when using an aerial photograph to *indicate the lowest point* (refer to Figure 48).

A positive correlation *(Pearson correlation = .383, p = .021 2-sided)* between the accuracy and average confidence was observed. Additionally, a negative correlation *(Pearson correlation = -.359, p = .032 2-sided)* was found between the average completion time and average confidence. This shows that the participants took less time to complete a task when they felt confident about their response, and when their confidence was high the participants generally provided the correct response.

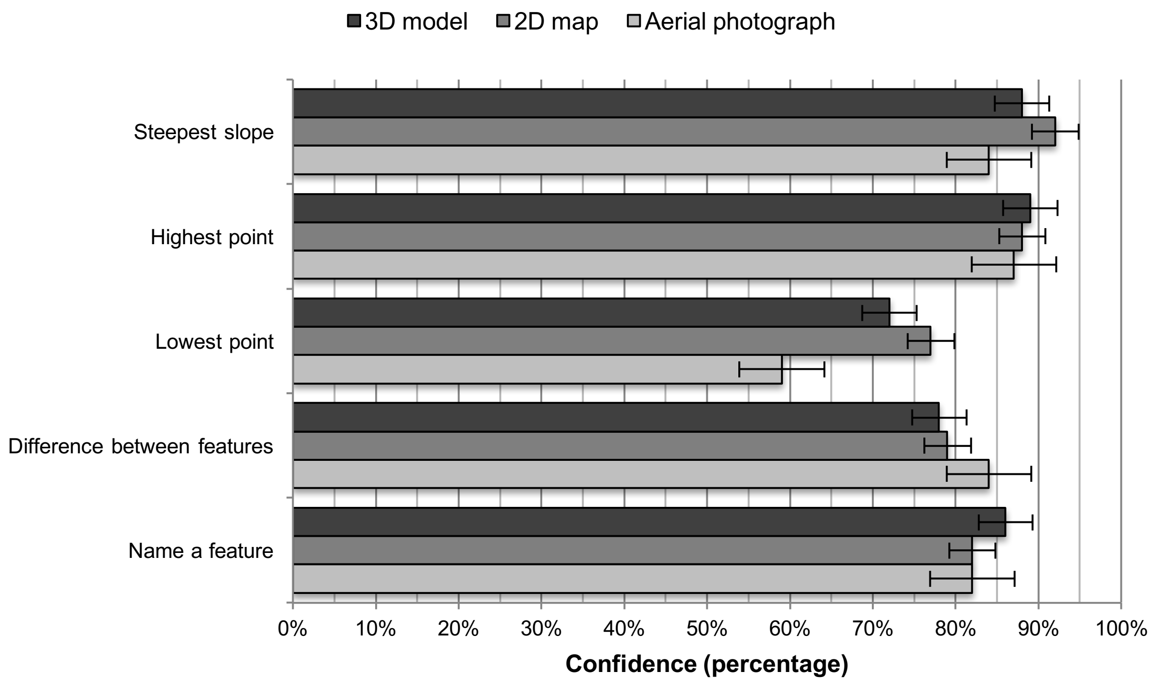

Figure 48. Average confidence of participants for each geovisualisation in the controlled user study. Error bars: +- SEM

Participants' performance and confidence per geovisualisation type

Figure 49 shows the average accuracy (presented as a percentage) in relation to the type of geovisualisation. The participants achieved the highest percentage of correct responses (accuracy) when performing the required tasks using the 2D map (82.98%), compared to the aerial photograph (77.08%) and 3D model (66.67%). The high percentage of correct responses when using a 2D map can be explained: this is the medium most used by geoinformatics students and the symbols used on the map were easy to interpret. Participants on average performed better when using a 2D map

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compared to the aerial photograph [t(35) = -2.221, p = .033] and 3D model [t(35) = 5.720, p = .000] when completing the tasks.

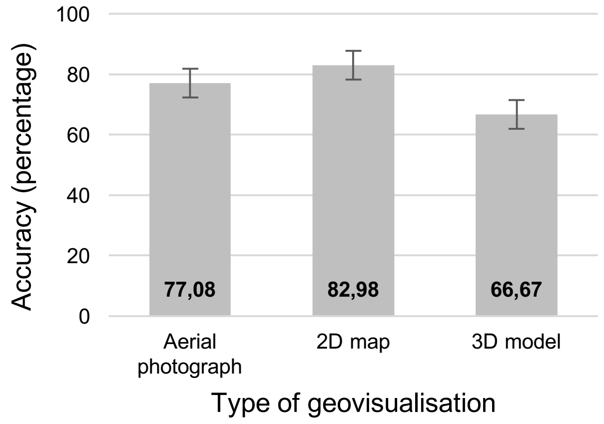

Figure 49. The average accuracy in percentage for each geovisualisation for all participants in the controlled user study. Error bars: +- SEM

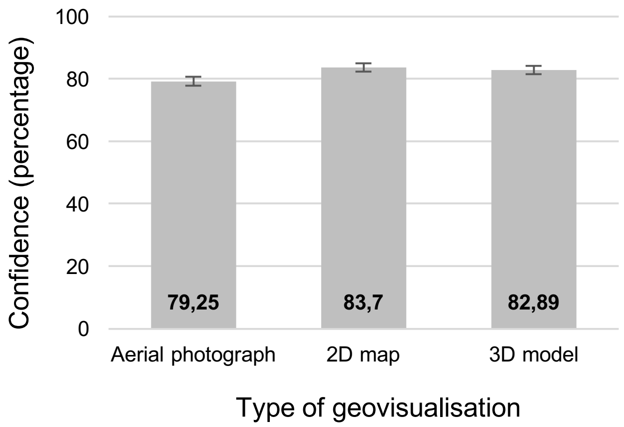

Figure 50. The average confidence in percentage for each geovisualisation for all participants in the controlled user study. Error bars: +- SEM

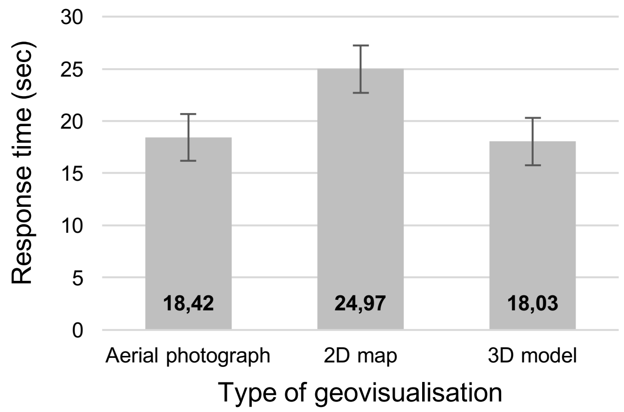

Figure 51. The average completion time for each geovisualisation for all participants in the controlled user study. Error bars: +- SEM

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The participants were generally most confident when completing tasks using the 2D map (refer to Figure 50). When combining this with the previous results, it can be concluded that participants were most successful and confident when performing the tasks using the 2D map. A one-way ANOVA was performed to analyse the effect of the participants average confidence per geovisualisation type on the average accuracy, [aerial photograph: $F(12,23) = 1.322$, $p = .272$, 2D map: $F(12,23) = 1.054$, $p = .438$, and 3D model: $F(12,23) = 1.093$, $p = .410$].

In Figure 51, it can be observed that participants took a small amount of time (around 20 seconds) to complete the tasks. The reason for the small amount of time used to complete the tasks on average can be attributed to the fact that a large portion of participants (47%) are very familiar with the settlement. The negative correlation previously found between the completion time per geovisualisation type and accuracy remains also at this aggregation level. The Kruskal-Wallis test was performed to analyse the effect of the different geovisualisation type on the average completion time [aerial photograph, $\chi^2(12) = 10.339$, $p = .586$, 2D map, $\chi^2(12) = 10.119$, $p = .605$, and 3D model, $\chi^2(12) = 13.382$, $p = .342$].

Exploring group differences in performance and confidence based on familiarity with Alaska

As previously stated, 47% of the participants are familiar with the settlement of Alaska and spent at least three full days in the settlement capturing data and then worked on the data afterwards for four months. This group of participants is thus considered to have intimate knowledge of the area and the structure of the settlement. A strong correlation between the overall accuracy and familiarity with the area (*Pearson correlation = .603, p = .000 2-sided*) supports this statement, meaning that the participants with prior knowledge of the settlement performed better in the experiment than participants with no prior knowledge.

Participants familiar with Alaska generally outperformed the participants that were not familiar with Alaska, except on the following tasks: *indicating the highest point* using the aerial photograph; indicating the *steepest slope* using the 2D map; and *name a feature* using the 3D model (refer to Figure 52, Figure 53 and Figure 54). When using the 3D model (refer to Figure 54), only the *indicate the highest point* task received a high percentage of correct responses. For all other tasks the participants' performance was lower than for other geovisualisations (i.e. aerial photograph and 2D map).

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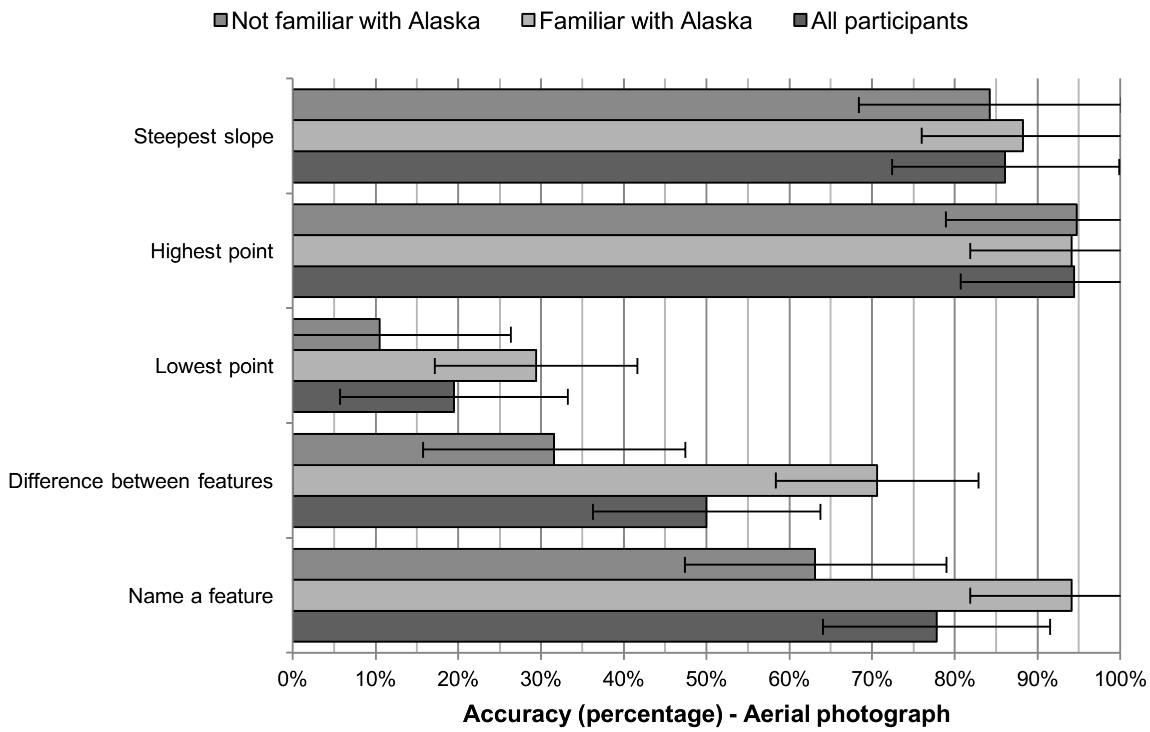

Figure 52. Percentage of correct answers provided according to familiarity with Alaska for the aerial photograph tasks in the controlled user study. Error bars: +- SEM

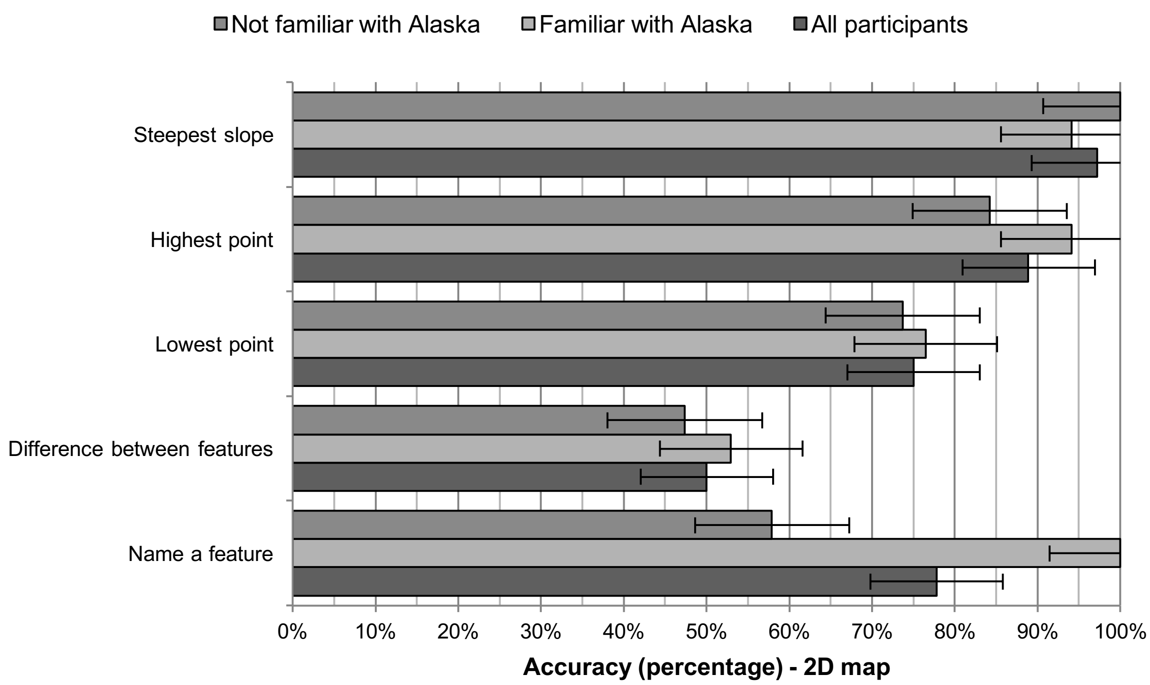

Figure 53. Percentage of correct answers provided according to familiarity with Alaska for the 2D map tasks in the controlled user study. Error bars: +- SEM

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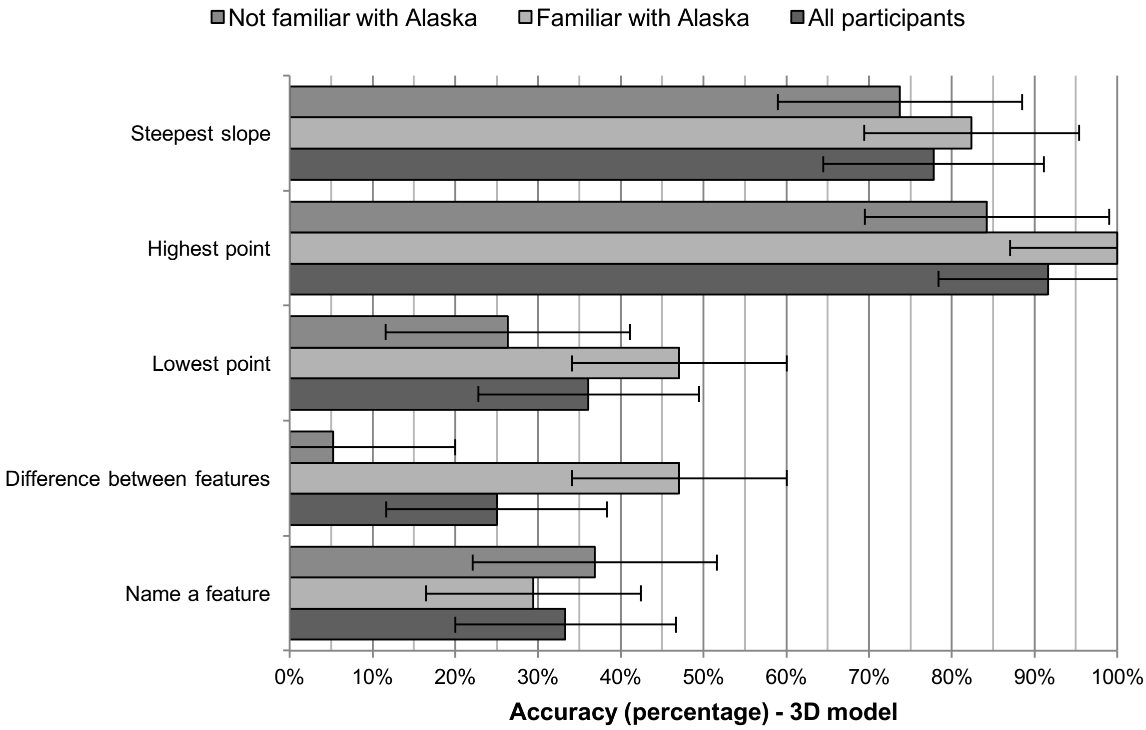

Figure 54. Percentage of correct answers provided according to familiarity with Alaska for the 3D model tasks in the controlled user study. Error bars: +- SEM

Exploring group differences in performance and confidence based on experience and gender

Experienced participants were defined as participants who rated themselves as '*excellent'* in all categories of the self-reported familiarity and experience questionnaire. No participant met this requirement. However, the participants' self-reported experience and training was above average in most cases. No correlation was found between the participants' self-reported familiarity and experience and the average accuracy.

A strong correlation was found between the participants' results for the mental rotation test and average accuracy (*Pearson correlation = .385, p = .020 2-sided*). In terms of gender differences, men on average rated themselves slightly higher than women in the self-reported familiarity and experience questionnaire. Furthermore, men did outperform women in all tasks (Figure 55); however, a one-way ANOVA revealed that this difference was not statistically significant: F(1,34) = 1.708, p = .200.

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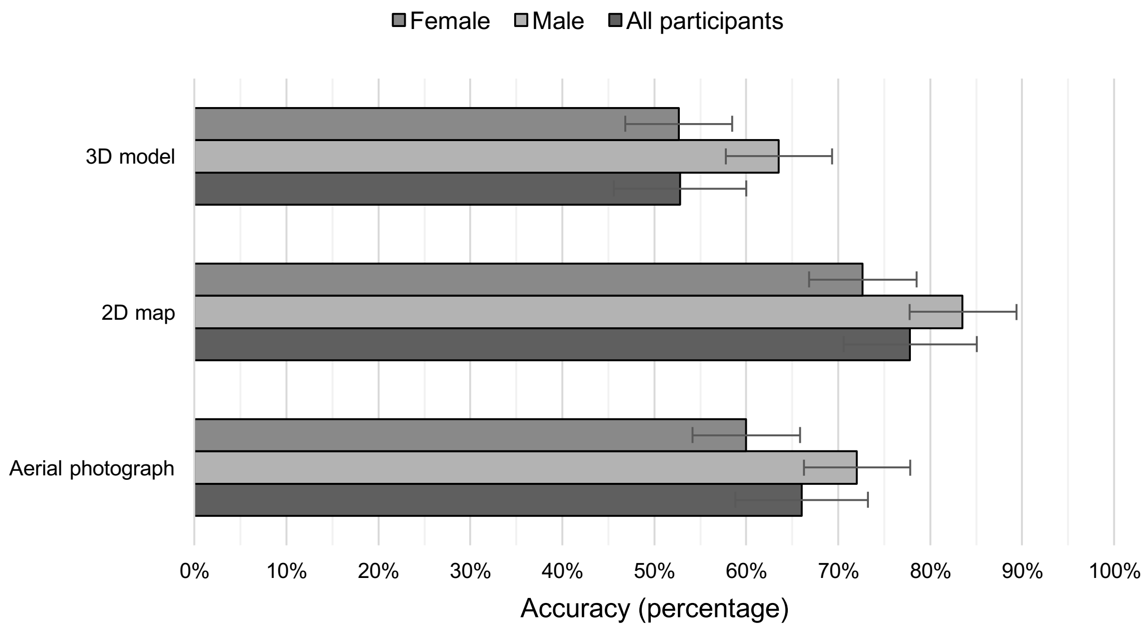

Figure 55. Percentage of correct answers per gender for each geovisualisation type in the controlled user study. Error bars: +- SEM

7.2.3. Results – distributed user study

7.2.3.1 Overview of participants

Fifty-eight individuals (22 males and 36 females) ranging from 19 to 60 years old participated in the user study. An invitation to participate in the distributed user study was sent to two regional mailing lists (OSGeo Africa and SDI Africa), and also to undergraduate and postgraduate students in architecture and town and regional planning at the University of Pretoria. Figure 56 depicts the various occupational fields of the participants. The majority of the participants worked or studied in geoinformatics (45%), followed by town and regional planning (16%) and architecture (12%). Twelve percent of participants were from unrelated fields (classified as other), for example law or psychology. Similar to the controlled user study (refer to Section 7.2.2), a small group of students (15.5%) had previous knowledge of Alaska. These were architecture students who had worked in the settlement as part of their postgraduate studies.

Figure 57 shows the average self-reported training and experience of the participants. An interesting observation is that the participants in the distributed user study on average scored themselves slightly higher in terms of previous training and experience than the participants in the controlled experiment, except for *training in cartography* and *training in geography*. The average self-reported training and experience were equal for both the controlled and distributed user study for *experience using topographic maps* and *training in planning*.

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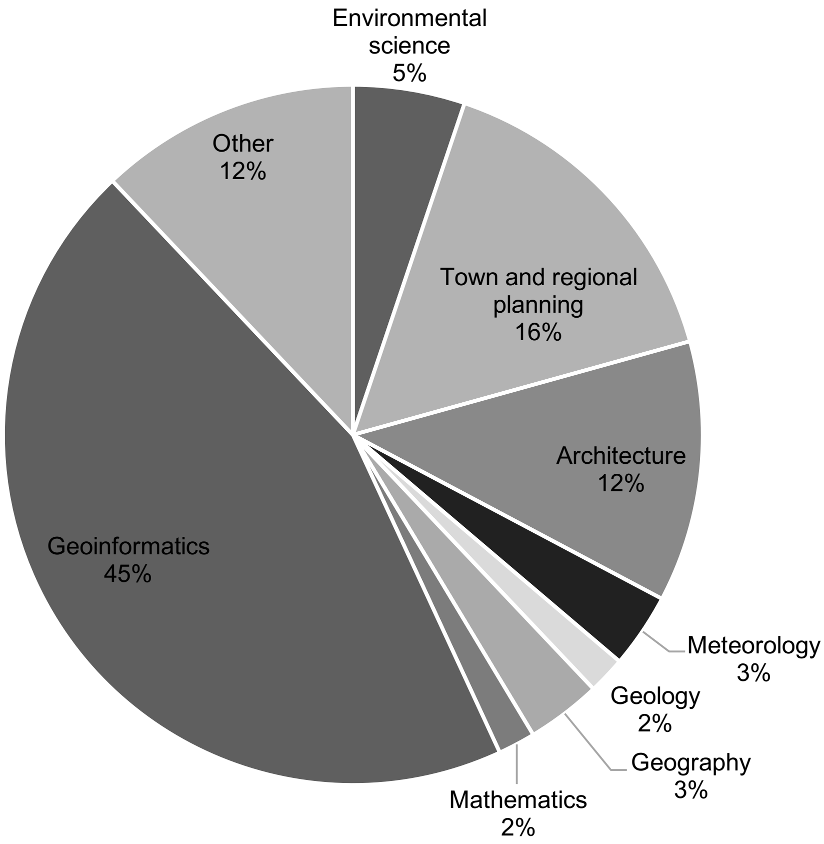

Figure 56. Participants' occupational field

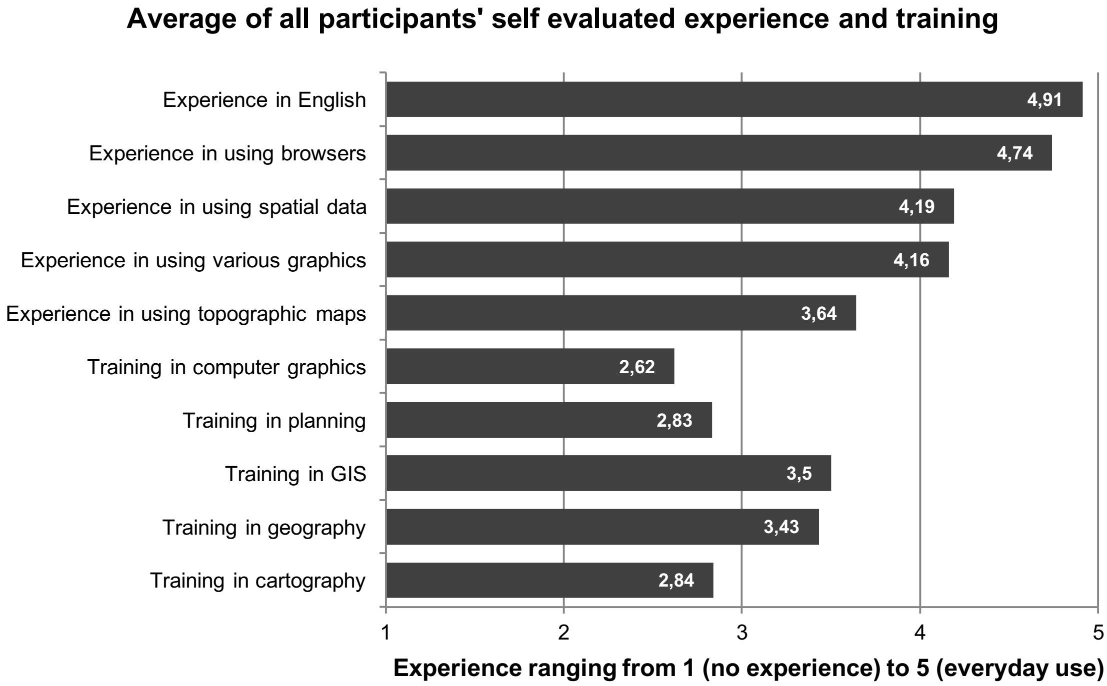

Figure 57. Participants' average self-reported experience and training (distributed user study)

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7.2.3.2 Detailed results of distributed user study

The distributed user study consisted of the same 24 questions (as in the controlled user study) related to four tasks as specified in the proposed task taxonomy. Table 15 provides an overview of the results for all the tasks broken down according to each geovisualisation (aerial photograph, 2D map or 3D model), the highest mean confidence is also shown. From the table, it is clear that the participants performed best when using the aerial photograph and the 2D map. The table also shows that for only one task (i.e. *Highest point*) the participants were most confident with the answer provided when using the 3D model. Additionally, participants also achieved the highest average percentage of correct answers for this specific task (i.e. *Highest point*) when using the 3D model.

Table 15. Overview of participants' performance per geovisualisations type (distributed user study)

Geovisualisation / *Task*	**Aerial photograph**	**2D map**	**3D model**
Name a feature	✔ ★		
Difference between features	✔ ★		
Lowest point		✔★	
Highest point			✔ ★
Steepest slope		✔ ★	

✔ - Highest percentage of correct answers for the task

★ - Highest mean confidence for the task

Participant performance and confidence per task type

Figure 58 shows accuracy results obtained from the distributed user study. The results show that participants were more successful in completing the tasks when using the aerial photograph and 2D map. When *indicate the highest point* participants were on average more successful when completing this task using the 3D model. *Indicating the lowest point* was perceived as the most difficult task (the average mean confidence was the lowest for this task). This was correct, as at most only 60% of participants when using the 2D map were able to correctly indicate the region that was considered the lowest. The tasks relating to recognition of symbols were completed on average more successfully with the aerial photograph and the tasks relating to terrain when using the 2D map. Figure 59 shows that the incorrect answers to the *differentiating between features* task and *indicating the lowest point* task were incorrectly answered by most participants when using the 3D model. The same is also true for aerial photographs when *indicating the lowest point* in the area, with 76% participants answering these questions incorrectly.

Even though the participants' self-reported experience and training was above average in most cases, no correlation was found between the experience and training and the accuracy of the participants (*Pearson correlation = -.055, p = .680 2-sided*). However, a correlation was found between the participants' accuracy and whether they had any exposure or to geography at either school or university level (*Pearson correlation = .283, p = .046 2-sided*). Additionally, no correlation was

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observed between the average completion time and accuracy (*Spearman's rho correlation = .796, p = -.024 2-sided*), nor between the accuracy and average confidence was observed (*Spearman's rho correlation = .105, p = .154 2-sided*).

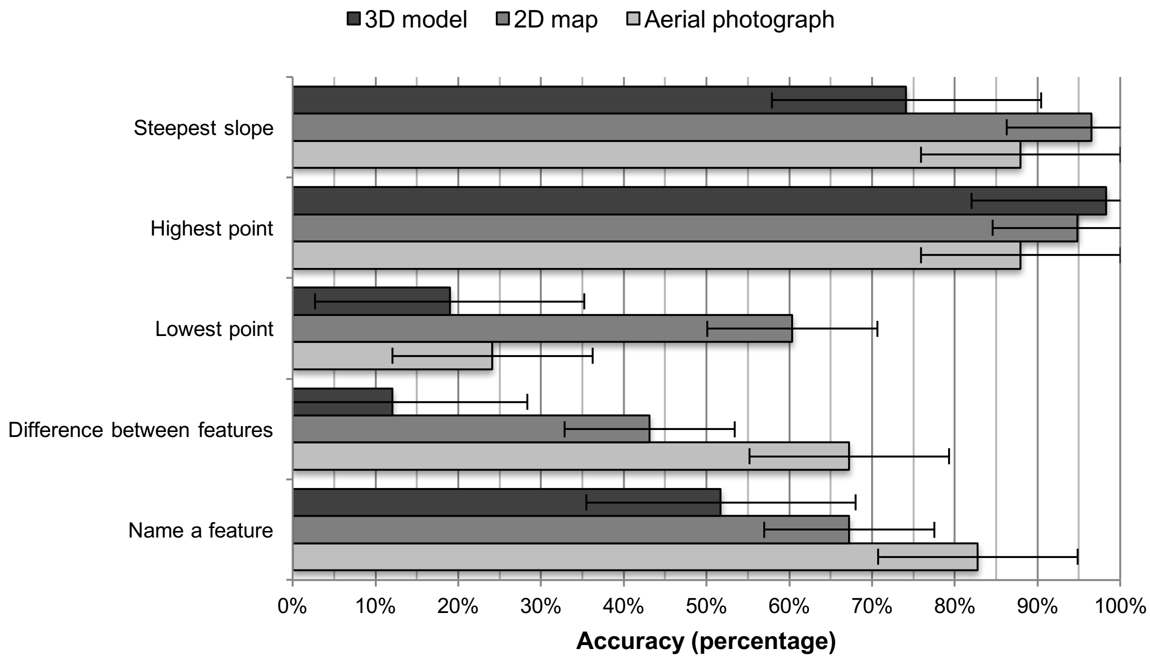

Figure 58. Percentage of correct answers for each geovisualisation in the distributed user study. Error bars: +- SEM

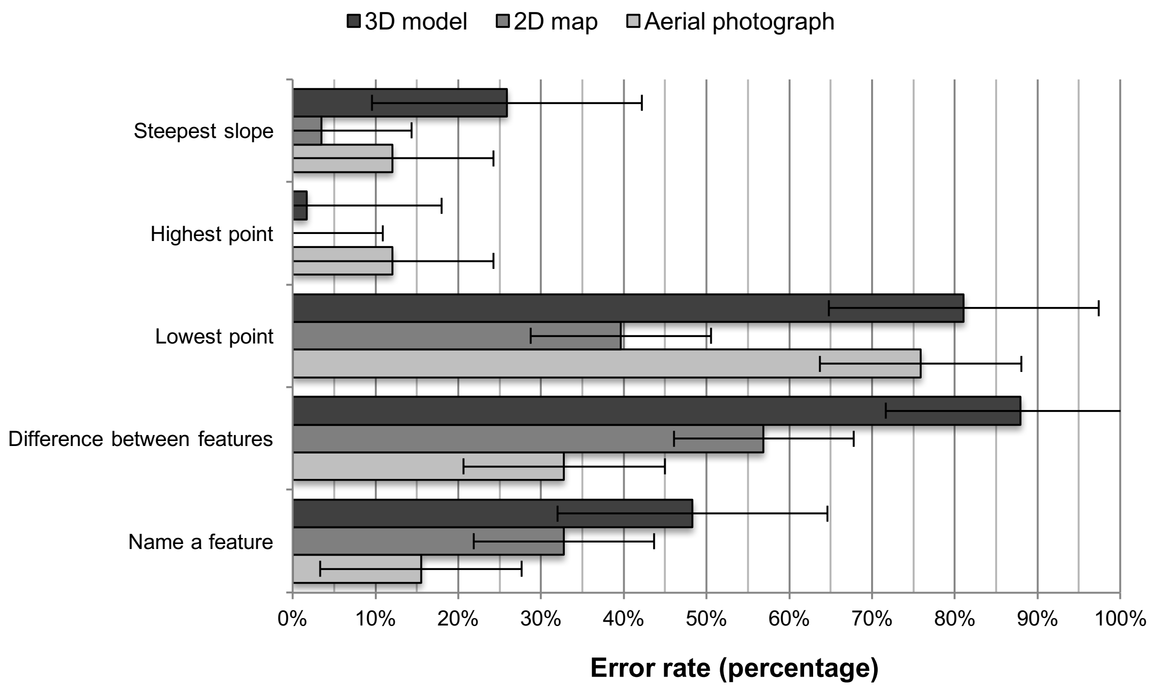

Figure 59. Percentage of incorrect answers for each geovisualisation in the distributed user study. Error bars: +- SEM

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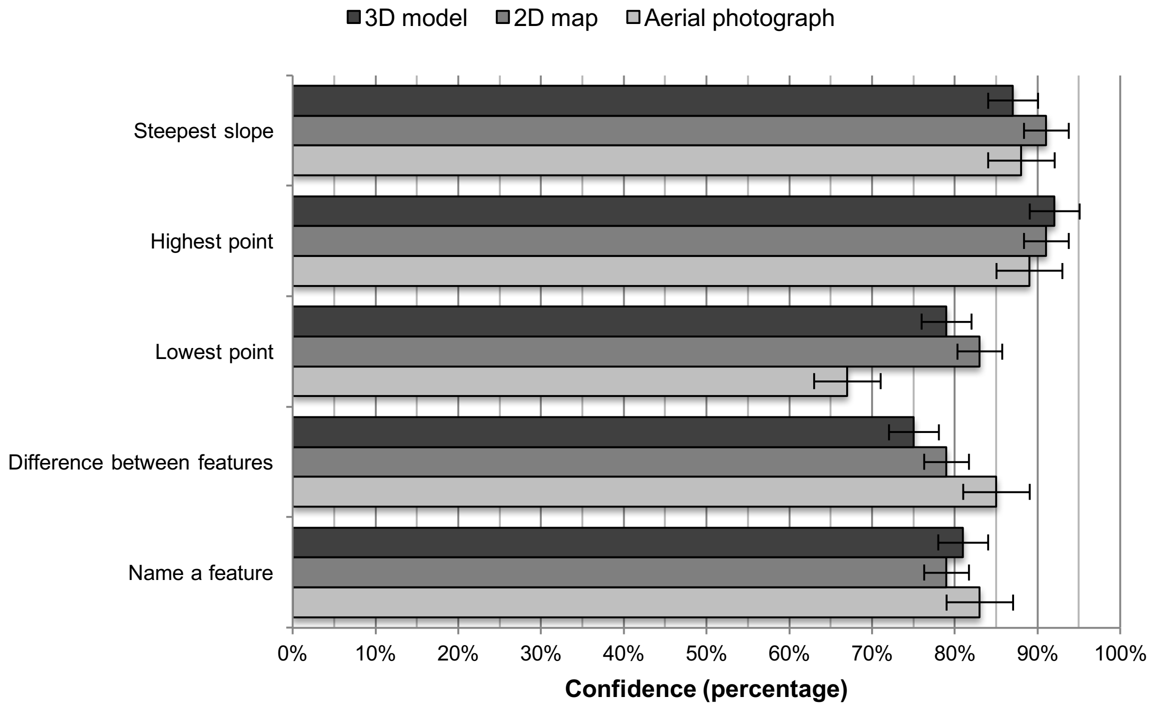

Figure 60. Mean confidence of participants for each geovisualisation in the distributed user study. Error bars: +- SEM

Participant performance and confidence per geovisualisation type

Figure 61 shows the average accuracy (presented as a percentage) in relation to the type of geovisualisation. The participants achieved the highest percentage of correct responses (accuracy) when performing the required tasks using the aerial photograph (81.03%), followed closely behind by the 2D map (80.82%). The high percentage of correct responses when using both the aerial photograph and 2D map was interesting, but understandable as most individuals are exposed to these two mediums using applications such as Google Maps and Google Earth. Participants on average performed better when using both the aerial photograph and 2D map [t(57) = -.110, p = .913] compared to the 3D model [aerial photograph: t(57) = 6.213, p = .000 and 2D map: t(57) = 6.94, p = .000] when completing the specified tasks.

The participants were slightly more confident when completing task using the 2D map (84.5%, refer to Figure 62), followed by the aerial photograph (83.78%) and the 3D model (82.36%). When combining this with the previous results, it can be concluded that participants were most successful and confident when performing the tasks using the aerial photograph and 2D map. The Kruskal-Wallis test was performed to analyse the effect of the participants average confidence per geovisualisation type on the average accuracy, [aerial photograph, $\chi^2(10) = 15.286$, p = .122, 2D map, $\chi^2(10) = 15.211$, p = .125, and 3D model, $\chi^2(10) = 16.386$, p = .089].

In Figure 63, it can be observed that participants took a small amount of time (between 25 and 30 seconds) to complete the tasks using the aerial photograph and 3D map. The Kruskal-Wallis test was

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performed to analyse the effect of the different geovisualisation type on the average completion time [aerial photograph, $\chi^2(10) = 13.259$, $p = .210$, 2D map, $\chi^2(10) = 13.015$, $p = .223$, and 3D model, $\chi^2(10) = 12.147$, $p = .275$].

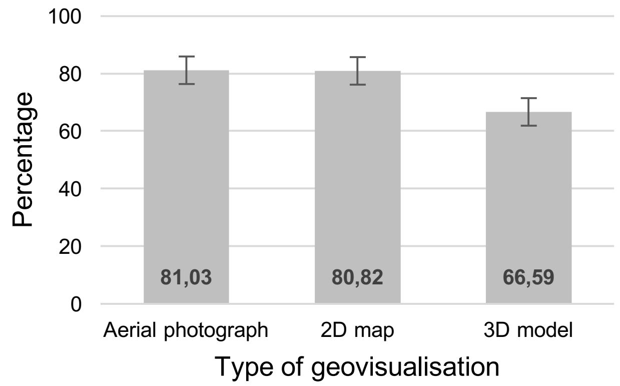

Figure 61. The average accuracy in percentage for each geovisualisation for all participants in the distributed user study. Error bars: +- SEM

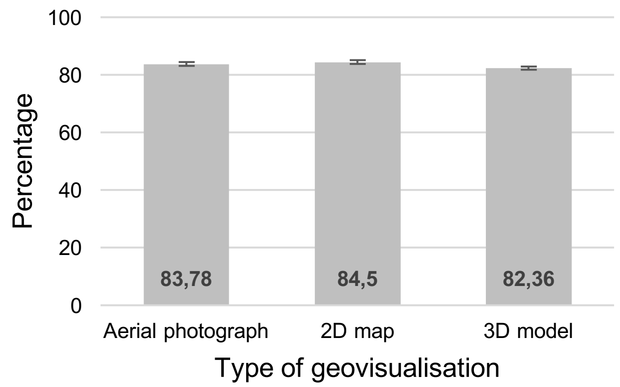

Figure 62. The average confidence in percentage for each geovisualisation for all participants in the distributed user study. Error bars: +- SEM

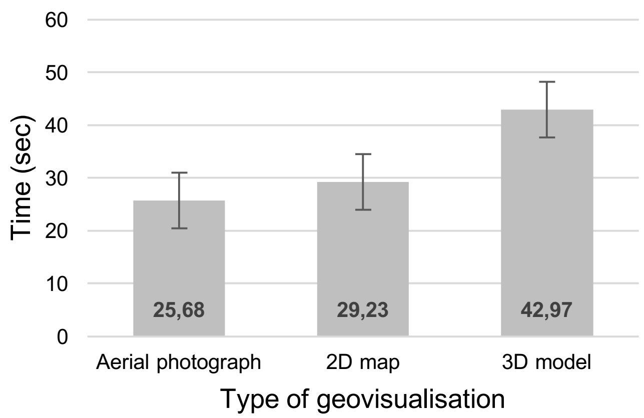

Figure 63. The average completion time for each geovisualisation for all participants in the distributed user study. Error bars: +- SEM

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Exploring group differences in performance and confidence based on familiarity with Alaska

As previously stated, a small percentage of participants (15.5%) had prior knowledge of the Alaska settlement from working on an urban design project in the area. However, unlike the controlled user study no correlation between the overall accuracy and familiarity with the area was found (*Pearson correlation = -.040, p = .764 2-sided*). Thus, in the distributed user study prior knowledge of the settlement did not affect the participants' performance. A possible reason for this might be that the architecture students do not have the appropriate background in cartography and geography.

Participants that were familiar with Alaska on average performed similarly overall compared to the participants not familiar with the area (refer to Figure 64, Figure 65 and Figure 66). However, with the aerial photograph and 2D map the participants with prior knowledge outperformed the other participants with the *name a feature* task. When answering this task, using the 3D model, only 29% of participants familiar with the area were able to correctly identify the feature compared to the 65% of participants without prior knowledge.

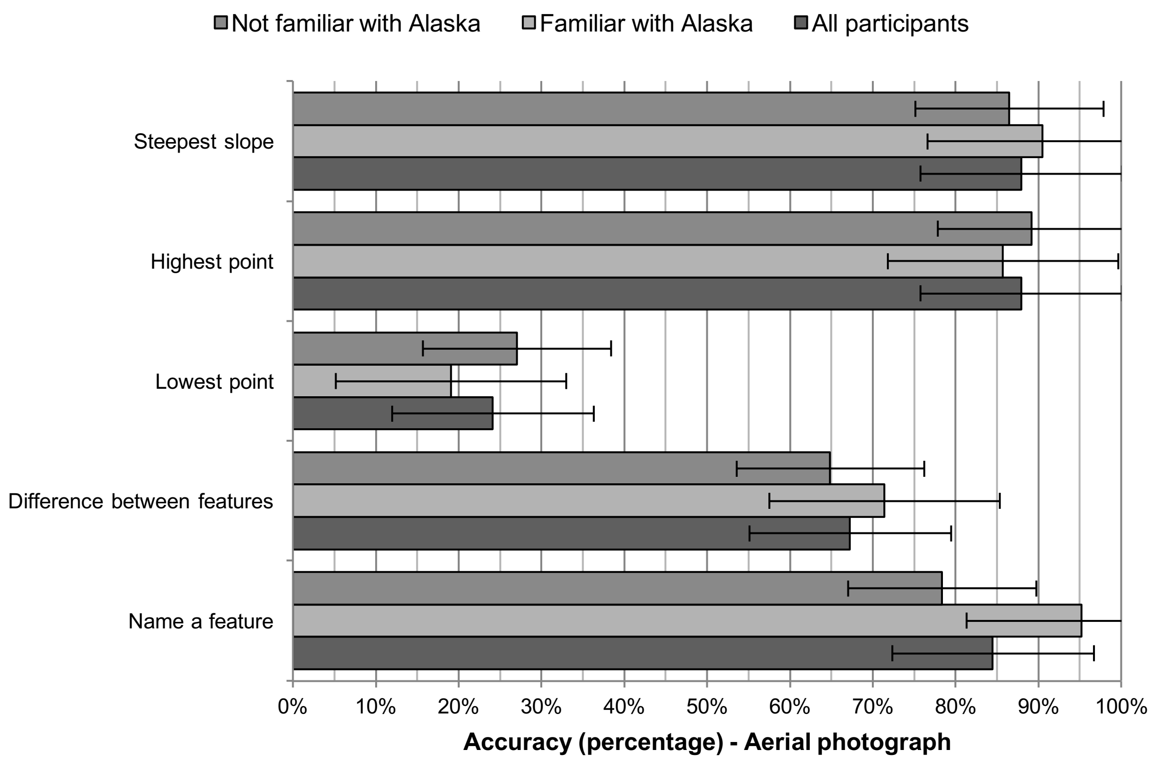

Figure 64. Percentage of correct answers provided according to familiarity with Alaska for the aerial photographs tasks in the distributed user study. Error bars: +- SEM

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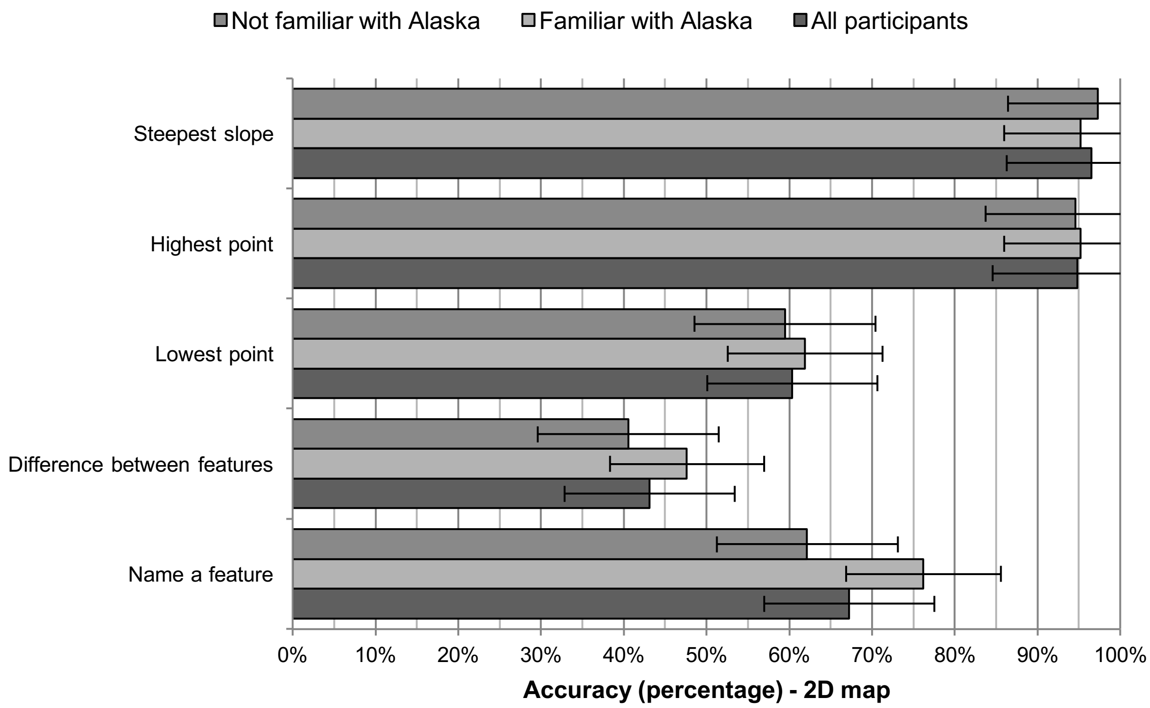

Figure 65. Percentage of correct answers provided according to familiarity with Alaska for the 2D map tasks in the distributed user study. Error bars: +- SEM

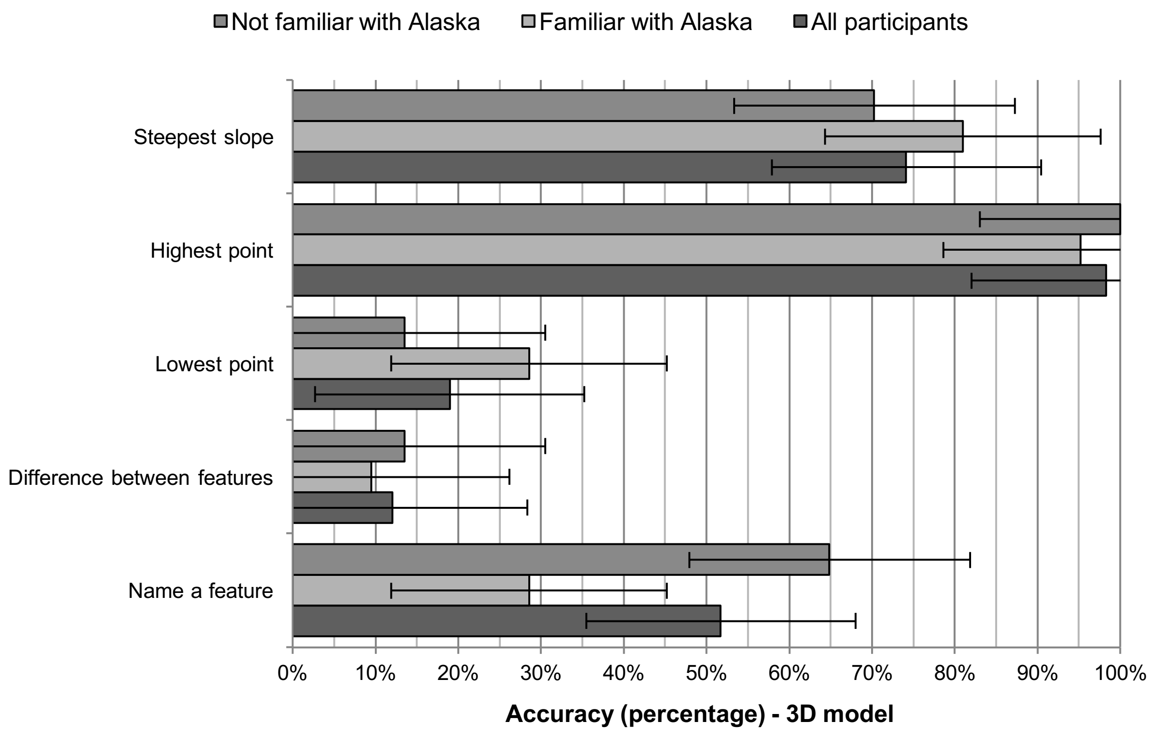

Figure 66. Percentage of correct answers provided according to familiarity with Alaska for the 3D model tasks in the distributed user study. Error bars: +- SEM

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Exploring group differences in performance and confidence based on experience and gender

Experienced participants were defined as participants who rated themselves as '*excellent'* in all categories of the self-reported familiarity and experience questionnaire. However, no participant met this requirement. The participants' self-reported experience and training was above average in most cases; however, no correlation was found between the participants' self-reported familiarity and experience questionnaire and the average accuracy (*Pearson correlation* = *-.055, p* = *.680 2-sided*).

No correlation was found between the participants' results for the mental rotation test and average accuracy (*Pearson correlation* = *.248, p* = *.061 2-sided*). In terms of gender differences, men (n = 22) outperformed women (n = 36) in all tasks (Figure 55) when using the aerial photograph and 2D map. However, their self-reported familiarity and experience only differed very slightly. A one-way ANOVA revealed that this difference was not statistically significant [F(1,56) = 3.492, p = .067].

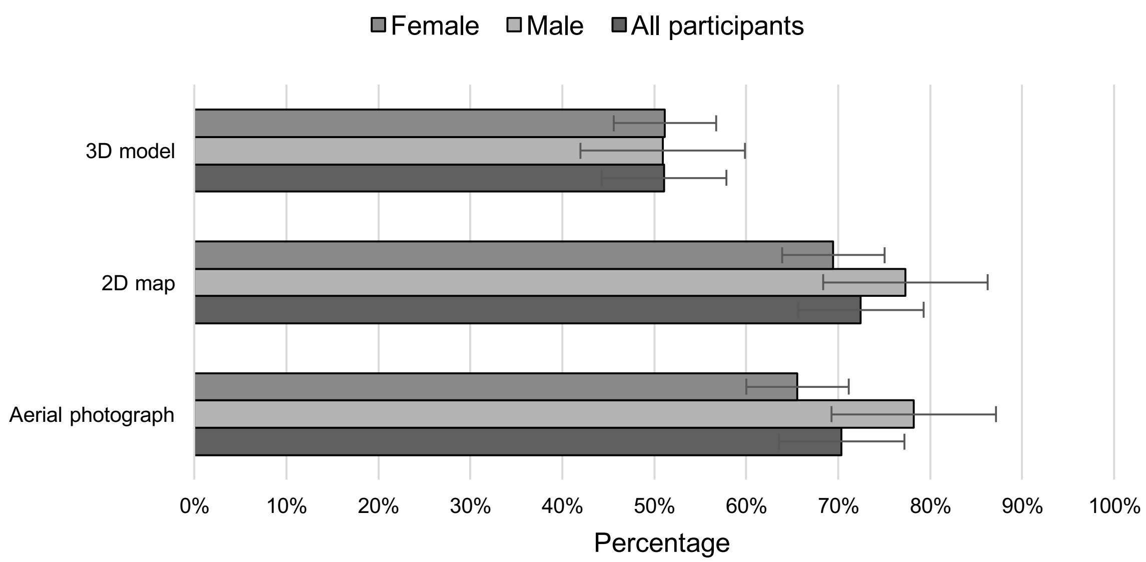

Figure 67. Percentage of correct answers per gender for each geovisualisation type in the distributed user study. Error bars: +- SEM

7.2.4. Discussion

In this section, the results from the controlled and distributed user studies to evaluate individuals' map reading skills are discussed. During the user studies, the participants were asked to perform tasks relating to symbol recognition and topography using an aerial photograph, a 2D map and a 3D model of a typical South African informal settlement. The goal of the user study was to investigate individuals' performance (i.e. accuracy, completion time and confidence) when using three geovisualisation types (i.e. aerial photograph, 2D map and 3D model) in specified tasks. The tasks used in the user study were related to symbol recognition and topography, selected from the proposed map reading taxonomy (introduced in Section 6.3).

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The results from both the controlled and distributed user study showed that participants are on average most successful when completing the specified tasks using the 2D map. However, for the distributed user study the participants were also on average equally successful when using the aerial photograph. This is not surprising as most individuals are generally exposed to aerial photographs and 2D maps when using popular web mapping technology (for example Google Earth and OpenStreetMap), or navigational aids (for example GPSs and hard copy tourist maps). 3D buildings are increasingly used in navigational aids; however, users do not use these to perform any complex map reading tasks and they are merely included to add realism to the maps. Therefore, they will be less familiar with 3D models. Additional barriers with 3D models include the non-uniform scale over the display, occlusion of objects, and the extremely information-rich models.

In the controlled user study, participants that indicated that they are familiar with the area depicted outperformed the other participants when using the 3D model to perform the required map reading tasks. This can be attributed to the fact that they have intimate knowledge of the area and have also worked with the data beforehand, as they also collected the data used for this user study. This knowledge of the area and the data definitely provided these participants with an unfair advantage. Thus it can be concluded that familiarity with the area positively contributes to the individuals' spatial cognition of the 3D model (Cartwright, C Pettit, *et al.*, 2005; Cubukcu, 2011; Herbert and Chen, 2015; Lei *et al.*, 2016). Participants in the distributed user study on average took more time to complete the task using the 3D model. However, their accuracy did not improve when completing the required map reading tasks. This confirms that 3D models are generally more difficult to use as they are cognitively processed differently than aerial photographs and 2D maps (Herbert and Chen, 2015; Lei *et al.*, 2016).

Two tasks were in particular challenging for the participants in both groups: 1) *differentiating between features* and 2) *indicating the lowest point*. The average confidence of participants for these tasks was lower than for the other tasks. This was supported by the participants' accuracy that was generally also low for these two tasks. *Differentiating between features* was challenging as there was no legend available, and participants had to study the geovisualisation and determine the feature from the provided set of answers. The challenge with *locating the lowest point* was that the environment was located at the foot of the mountain, but the lowest point was not very pronounced. Additionally, there was a river in the area, and generally the lowest point would be in the region towards which the river was flowing, but there was a natural depression upstream in the river that was the actual lowest point. The 3D model provided additional challenges, as the model was static and the participants were not able to rotate the model and they could only view the area from the viewpoint provided to them (refer to Figure 43). This viewpoint and tilt created the illusion that the lowest point was located in a different area, thus adding to an already challenging task. Additional user studies are required that incorporate an interactive 3D model to further investigate the usefulness of 3D models and their interpretation.

A speed-accuracy trade-off was observed with participants in the controlled user study when using the 2D map to perform the map reading tasks. 2D maps are information rich (i.e. the 2D map also contained symbols and contour lines), and this information could have been used to solve the required

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map reading tasks. For example, the contour lines provide information about the terrain. This resulted in participants performing on average better when using the 2D map to identify the lowest point irrespective of their familiarity with the area.

A group of participants from both the controlled (47%) and distributed (15.5%) user study had prior knowledge of the Alaska informal settlement, as it formed part of a course they had to complete earlier in 2015. For the controlled user study, a strong correlation was observed between the participants with prior knowledge and their accuracy (i.e. these participants performed better when completing the tasks, including the perceived difficult tasks mentioned). However, there was no correlation between the participants with prior knowledge and their accuracy in the distributed user study. It can thus be inferred that background of the participants (geoinformatics for the participants in the controlled user study) combined with prior knowledge of the area may affect participant's accuracy when completing map reading tasks.

When looking at group differences for both the controlled and distributed user study, no correlation was observed between the self-rated experienced participants and their average accuracy when completing the specified tasks. However, for the controlled user study there was a statistically significant correlation between the participants' mental rotation test and average accuracy. Lastly, men slightly outperformed women in both the controlled and distributed user study; however, in both cases no difference was observed based on gender.

7.3. Qualitative semi-structured expert interviews

In this section, the design of the expert interviews is presented, followed by a discussion of the results obtained from the interviews.

7.3.1. Study design

7.3.1.1 Overview

The aim of the semi-structured expert interviews was to understand how geovisualisations are used in urban design projects, and specifically to understand the usefulness of 3D models when performing tasks associated with informal settlement upgrading. The interview was planned around the Alaska informal settlement in Mamelodi, City of Tshwane, and the requirements for a 3D informal settlement model used in upgrades that was identified in a previous study (refer to Section 3.5).

The interviews were conducted in October 2015. The semi-structured interviews consisted of 14 questions and was about 60 minutes long. The questions were designed to provide insight into the process they followed and geovisualisations they use, and usefulness of 3D geovisualisations for urban design. The interview questions are presented in Table 16. The sessions were voice recorded and the interviewer also took notes during the session.

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Table 16. Interview question

1.	**General urban design process**
1.1.	How do you start with an urban design project? What is the process you follow?
2.	**Representation of the terrain of the stands**
2.1.	Which map or geovisualisation do you normally use when determining the terrain (e.g. is the terrain rocky or does it have a steep slope)?
2.2.	Are you able to estimate or establish the type of terrain with an aerial photograph?
2.3.	Does the DEM in the 3D model contribute to a better understanding of the terrain?
2.4.	Do the contour lines in a 2D map help understanding the terrain?
2.5.	Which of the three (i.e. aerial photograph, 2D map, 3D model) would you prefer, and why?
3.	**Representation of boundaries of the stand**
3.1.	Does any of the visualisations assist with estimating the density of dwellings? Assuming that there are on average one dwelling per stand.
4.	**Representation of spatial patterns among stands**
4.1.	Which map or geovisualisation would you prefer when determining the integration with the adjacent community? And why?
5.	**Representation of spatial relationships between stands and other physical objects**
5.1.	Which map or geovisualisation would you prefer when, for example determining the distributions of taps within the community? And why?
6.	**Representation of the impact of new infrastructure**
6.1.	Which map or geovisualisation would you prefer when, for example determining the visual impact of new infrastructure?
6.2.	Which geovisualisations do you use when communicating with: • peers, and; • local community?
7.	**Concluding questions**
7.1.	Was the 3D geovisualisation advantageous for any of the scenarios?
7.2.	What drawbacks did you experience with the 3D geovisualisation?
7.3.	Would you recommend the use of 3D geovisualisations for urban design projects?

7.3.1.2 Materials

The interviews were planned based on scenario described in Section 3.5, and the experts were asked how they would use the geovisualisations when performing typical urban design tasks. The area of Alaska, in Mamelodi, was used. For the interviews, not only digital, but also printed/hard copy versions of the geovisualisations were provided to the experts. The following geovisualisation was used (the digital versions was created so that it is clear on a 13.3-inch LED display with a resolution of 1280x800):

a) Aerial photograph (hard copy)

The same aerial photograph that were used for the quantitative user studies was used (refer to Section 7.2.1.2 and Figure 41.

b) 2D map (hard copy and digital)

For the hard copy map, the map developed for the quantitative user studies was used (refer to Section 7.2.1.2). The same data was utilised for the development of an interactive web map

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used for the interviews. The web map had limited functionality, but was used to demonstrate the power of interactive dynamic maps. The web map is available at http://3dmodel.geobach.co.za/map2/.

c) 3D model (hard copy and digital)

The process described in Section 7.2.1.2 produced an interactive 3D model. The model is available here: http://3dmodel.geobach.co.za/model8/modelv2b.html. For the hard copy, the image as shown in Figure 43 was used.

7.3.1.3 Participants

Four experts participated in the interview. Table 17 provides a brief overview of the background of the interviewees. Two male and two female experts were interviewed with a combined experience of more than 50 years. Two interviewees had previous experience in informal settlement upgrading and one had previously worked on a project in a rural community.

Table 17. Overview of the background of the interviewees

Interviewee	Interviewee 1	Interviewee 2	Interviewee 3	Interviewee 4
Sector	Academia	Academia Contract work in private sector	City official	Research Contract work in private sector
Background	Architecture	Town and regional planning	Town and regional planning	Geoinformatics and Town and regional planning
Focus area of work	Urban design	Strategic planning	Regional spatial planning	Spatial planning
Work experience	15+ years	5-10 years	15+ years	15+ years
Familiarity with Alaska	Very familiar	Not familiar	Slightly familiar	Not familiar

7.3.2. Results and discussion of interviews

In this section, the results from the expert interviews are presented and discussed under the following topics (adapted and expanded from Section 3.5): the urban design process, understanding the terrain and density of the dwellings, identifying spatial patterns, planning new development, communication planned developments, and the usefulness of 3D models. These topics reflect on the aim of the interviews, namely to understand how geovisualisations are used in urban design projects.

When discussing the **urban design process**, the interviewees all agreed that the urban design process can be broken down in the simplest terms as: understanding the current environment; designing new developments; and communicating the planned developments, with various iterations of the three. However, communication is not only important at the end of the urban design process, but essential throughout the entire process (refer to Figure 68). Interviewee 2 and interviewee 4 highlighted the importance of communication with the stakeholders, especially during the early stages of the process, to ensure buy-in from all stakeholders, and to cultivate a good relationship between

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the project team and stakeholders. It should also be noted that the process will change depending on the size and scale of the project. For example, if the project is stakeholder driven the amount of communication and interaction with the stakeholders will increase.

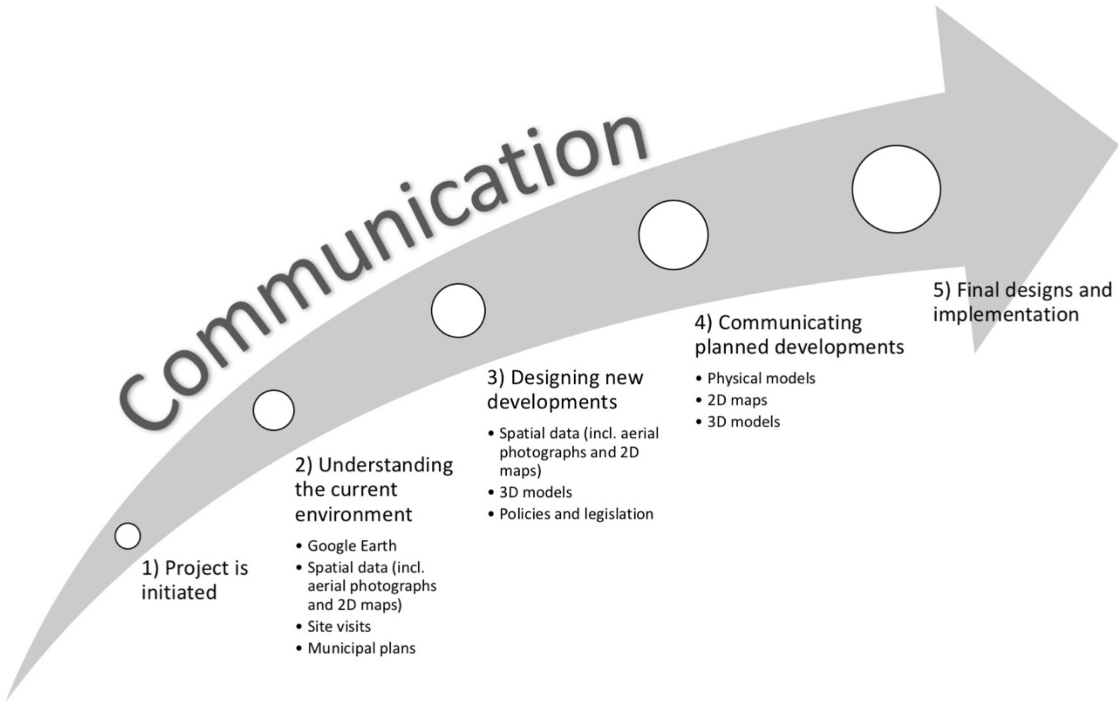

Figure 68. Overview of urban planning process

In Figure 68, some key tools or geovisualisations used during the specific phase of the process are presented. This is not an exhaustive list. Google Earth was mentioned as a useful tool by all interviewees and is generally used as the first port of call. Google Earth allows the user to instantly visit the site to get a sense of the terrain, and view progress or development of the community over time by using the time slider functionality and to viewing historic imagery of the area. The imagery in Google Earth is of good quality and freely available, but when looking at building level (i.e. a single building requiring a high level of detail) it might not be adequate. For informal settlements, interviewee 1 mentioned that the historical imagery is important to understand how the densification of the settlement and surrounding developments took place. This provides clues to whether in-situ upgrading is possible or if the community will need to be relocated.

After this initial view, all spatial data available for the settlement needs to be collected, for example contour lines, digital elevation models (DEMs) and storm water drainage, to name a few. The general perception of the interviewer was that urban designers rely heavily on geoinformatics professionals to collect and process the spatial data to generate a series of maps that would highlight certain aspects, such as slope or density of dwellings in the settlement. An example would be that the interviewees in architecture, and town and regional planning prefer to use maps with contour lines (i.e. 5 metre contours), whereas the geoinformatics professional (interviewee 4) mentioned a preference for using

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a DEM as this provides a visually rich representation and can be used interactively. Some interviewees were not familiar with DEMs, as they do not generally deal with the raw spatial data themselves (mainly using processed data represented on a 2D map).

It can be quite challenging to gather spatial data for informal settlements, as these settlements are rarely mapped or even acknowledged by government. Thus, the data generally needs to be captured in the field or digitised from aerial photographs. Aerial photographs are generally of high quality; however they have to be recent as informal settlements densify and spread very quickly. Information regarding hydrology, such as storm water drainage, is essential when determining if the settlement is located in a suitable area, and when looking at in-situ upgrading possibilities. For example, this data is used to determine if some of the storm water drainage can be retained and used for the upgraded settlement (as no service delivery is available).

Interviewee 1 specified that the next step in the process would be to look into municipal maps, such as water catchment maps, planned developments and current service delivery connections in the area. For example, in the area discussed with the interviewees, the informal settlement of Alaska, there is a RDP development close by and the current illegal electrical connection to the settlement could possibly be formalised.

Next, site visits were mentioned. Site visits can be done at any stage of the process, but earlier is more desirable. During a site visit, one can gain a better understanding of the settlement and the community that resides there. Additionally, one can observe the nearby infrastructure and densification, and opportunities for future densification and economic growth. Regular site visits are advisable, but this is not always possible, especially in remote areas. Light Detection and Ranging (LiDAR) data captured by an unmanned aerial vehicle (UAV) can supplement site visits, as photorealistic 3D models provide a realistic approximation of the settlement, in effect an instant visit.

When discussing the interviewees' preference for geovisualisations for **understanding the terrain**, between the aerial photograph, 2D map and 3D model, the 3D model was most desirable. A 3D model provides the user with a quick glance at the terrain and is easy to understand. Both interviewee 1 and interviewee 4 mentioned that a 3D model provides the viewer with a better understanding of the community. For example, one can see whether they have to cross a river or climb up a steep hill to get to work. Currently, all interviewees use contour line maps or DEMs for understanding the terrain, as 3D modelling software presents various challenges, such as lack of skills or software that is generally not user friendly.

One of the key considerations before in-situ upgrading is **density of the dwellings**. Interviewee 1 explained that examining a map or aerial photograph to determine density is usually not enough. Social surveys are required to determine the number of people in a dwelling. This can then be combined with the planned developments to negotiate with a city council or municipality on how much densification is allowed in the settlement. Social surveys can be combined with interpolation

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techniques to estimate density; this technique is used by all interviewees. Interviewee 2 stated that site visits to confirm this density calculation are required as the reality on the ground can be different.

When examining **spatial patterns** in the settlement, for example the distribution of water taps, the overall preference of all interviewees was to use a 2D map, but interviewee 4 would prefer to work with spatial data (i.e. meaning the raw vector or raster data that can be manipulated in a GIS application). Furthermore, the interviewees also agreed that you would use all the geovisualisations available, as each geovisualisation has its strong and weak points. However, interviewee 1 stated that although 2D maps and information can be very powerful, they can also easily overwhelm the stakeholders and that delayering the information to focus on certain aspects might be useful when communicating with the stakeholders. 3D models might also be useful to illustrate the relationship between the distribution of taps and the slope of the area, as it could be easier to understand compared to a 2D map with contour lines. As discussed in Section 6.2, contour lines can be difficult for some individuals to read and interpret. Interviewee 3 indicated that in 3D symbology might be a barrier to using it as certain objects and colours might overpower the model and distract from the other information.

Traditional 2D maps and spatial data are the preferred medium when **planning new developments** for an informal settlement. This can be attributed to the flexibility when using spatial data in a GIS and the amount of information available on a 2D map. Currently, lack of skills and difficult-to-use software create barriers to the use of 3D models during the planning phase. Most interviewees mentioned that interoperability of data formats, and the variety and individual's preference of software (i.e. various applications exist and interoperability is still a challenge) is a definite obstacle.

Communication is a difficult aspect, as communication is not only with peers, but with a variety of stakeholders with various backgrounds and levels of skills. All interviewees had the same opinion that 2D maps with the focus on principles and highlighting the various issues are most suitable when communicating with peers. However, 3D models can be used successfully when communicating with the local community. Interviewee 2 added that the use of the 3D models depends on the community. They might not be useful for rural communities, but if the community has experience with 3D models from a prior project, they might expect that photorealistic 3D models be used in future projects. Interviewee 4 stated that all geovisualisations (i.e. aerial photograph, 2D map and 3D model) would be preferred when communicating with the community. The various geovisualisations would substantiate to the community that all data and possibilities were considered. The interviewees also stated that decision makers (without technical expertise) like 3D models, as they are interactive and easy to understand generally.

Interviewee 1 has a background in architecture, and thus was asked about the use of physical models for communication. Interviewee 1 stated that it is not essential to use physical models, but it is good to use them in the community as they are tactile and from their experience the community likes to physically interact with the model.

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Lastly, the **usefulness of 3D models** for urban planning was discussed. From interviewee 1's perspective, an advantage of a 3D model is that it can combine aerial photographs and spatial data (i.e. other vector and raster datasets). Interviewee 4 supported this statement, as recent technology allows users to combine various types of spatial data and geovisualisations. Strengths of 3D models mentioned are that they create a sense of realism, provide insight into how the design will look in the environment, and can be very eye-catching. However, there are also disadvantages, such as a 3D model being difficult to operate and requiring specific skills to develop. An interesting point raised by interviewee 3 was that photorealistic 3D models can be distracting and in some cases more abstraction (i.e. lower level of detail) is ideal, specifically for regional projects. Table 18 provides an overview of the preferences expressed by the interviewees.

Table 18. Summary of interviewees preference of geovisualisation for each phase in the process

Phase / ***Interviewee***	**Understanding the current environment**	**Planning new developments**	**Communicating planned developments**
Interviewee 1	Aerial photographs, as these are generally the only information available for the settlements.	2D maps	3D models and specific 2D maps
Interviewee 2	Aerial photographs, spatial data and 2D maps. The geovisualisations used will depend on the accuracy of the data available.	2D maps	3D models and specific 2D maps
Interviewee 3	Aerial photographs, spatial data and 2D maps	2D maps	3D models and specific 2D maps
Interviewee 4	Aerial photographs, spatial data and 2D maps	Spatial data (e.g. shp files and raster images) and 2D maps	Combination of all geovisualisations

Various software options are available to develop 3D models (some options are discussed in Chapter 2). Current challenges or barriers mentioned by the interviewees were: ease of use; lack of skills; limitation of specialised functionality; and that it can be time consuming. All interviewees expressed the need for specialised software that allows the user to develop 3D models with ease from shapefiles, time series animation and the inclusion of 3D objects, for example adding generic objects to software such as Trimble SketchUp or Autodesk Revit that would generally be found in a typical South African informal settlement.

During the interviews, two unexpected topics emerged. Firstly, for town and regional planners, the colours used in the maps and 3D models are very important. They are familiar with certain colours, for example specific zonal colour schemes, and may misinterpret symbols and objects in the geovisualisations as a result. Thus, it is important to note that one should adhere to these colour schemes used by collaborators and stakeholders. Secondly, it is imperative that all stakeholders are in agreement on the meaning of terms used in the project. For example, the definition of a corridor or even an informal settlement should be clarified and used consistently.

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7.4. Conclusion

In this Chapter, the results from two user studies (i.e. controlled and distributed) and semi-structured expert interviews are presented. A mix-method approach was used to evaluate the usefulness of 3D models when performing urban design tasks. In the user studies, participants were asked to perform selected tasks relating to symbol recognition and topography from the task taxonomy presented in Section 6.3. The expert interviews concerned the usefulness of aerial photographs, 2D maps and 3D models when designing upgrades for informal settlements in South Africa. The results of the user studies and expert interviews were discussed in Sections 7.2.4 and 7.3.2 respectively.

The most important finding from the interview is that 2D maps are still the main geovisualisation used and preferred by individuals during the urban design process. This was reflected in the results obtained from the user studies, as the participants performed on average the best when using 2D maps to complete the specified tasks. Although participants' performance when using 3D was less than desirable, the expert interviewees indicated that 3D models are very useful when communicating with the various stakeholders involved in the urban design process. 3D models assist with stakeholder buy-in, and also provide an easy-to-interpret geovisualisation when designed appropriately. This result correlates with research by Herbert and Chen (2015) and Lovett *et al.* (2015) that suggest the 2D maps and 3D models should be used together to complement each other during the urban design process as each have their own strengths (e.g. 3D can be used to increase familiarity with the area or performing volumetric analysis) and weaknesses (e.g. cost of development of 3D models and the increased cognitive load of the user).

This raises the question why individuals struggle to perform map reading tasks on a 3D model. A possible reason for the poor performance is that individuals commonly do not perform map reading tasks on a 3D model, as the software provides tools and functionalities to perform these tasks. For example, a 3D model is commonly in a digital format and needs to be manipulated within a specific application. These applications provide the users functions such as distance measurements and tools for identifying features. Thus, the users do not have to perform these functions themselves.

The results from the user studies presented in this Chapter suggest that 3D models are challenging to use when performing map reading tasks. The user studies were only performed on a small sample. Statistically significant results and a small sample size only provide a limited representation of the results (Ioannidis, 2005; Lambdin, 2012). Conducting a 30- to 60-minute user study on a thousand or more people would be impossible, due to bandwidth limitations and plainly people's lack of interest in completing such a long user study without compensation. Thus, the author found the expert interviews to be of great value in understanding how 3D models are currently being used for urban design, and also what the potential and shortcomings of 3D models are for the urban design of informal settlement upgrading.

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Chapter 8. Discussion of results

This chapter was presented at the XXIII International Society for Photogrammetry and Remote Sensing (ISPRS) congress 12 - 19 July 2016 in Prague, Czech Republic, as a paper by Rautenbach, V., Coetzee, S., and Çöltekin, A. under the title, "Investigating the use of 3D geovisualisations for urban design in informal settlement upgrading in South Africa". This paper was written to provide a summary of all results presented in this thesis.

Contribution: The first draft of the paper was written by V.R., and then all three authors jointly finalised the paper.

8.1 Abstract

Informal settlements are a common occurrence in South Africa, and to improve in-situ circumstances of communities living in informal settlements, upgrades and urban design processes are necessary. Spatial data and maps are essential throughout these processes to understand the current environment, plan new developments and communicate the planned developments. All stakeholders need to understand maps to actively participate in the process. However, previous research demonstrated that map literacy was relatively low for many planning professionals in South Africa, which might hinder effective planning. Because 3D visualisations resemble the real environment more than traditional maps, many researchers posited that they would be easier to interpret. Thus, our goal is to investigate the effectiveness of 3D geovisualisations for urban design in informal settlement upgrading in South Africa. We consider all involved processes: 3D modelling, visualisation design and cognitive processes during map reading. We found that procedural modelling is a feasible alternative to time-consuming manual modelling, and can produce high-quality models. When investigating the visualisation design, the visual characteristics of 3D models and relevance of a subset of visual variables for urban design activities of informal settlement upgrades were qualitatively assessed. The results of three qualitative user experiments contributed to understanding the impact of various levels of complexity in 3D city models and map literacy of future geoinformatics and planning professionals when using 2D maps and 3D models. The research results can assist planners in designing suitable 3D models that can be used throughout all phases of the process.

8.2 Introduction

Informal settlements have been described as a living organism, indivisible and always changing (Kostof, 1993). They are characterised by rapid and unstructured expansion, poorly constructed buildings, and in some cases they are on disputed land (Huchzermeyer and Karam, 2006; Manson *et*

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al., 2012). Informal settlements commonly originate on unoccupied land along the urban edge or land that might be difficult to develop, such as on steep slopes or areas prone to flooding. Kostof (1993) stated that the informal settlement upgrading process immediately starts and never truly ends. A strong sense of community can be observed in these settlements, and the inhabitants often collectively approach upgrading projects, such as constructing communal water taps. Non-profit organisations (NGOs) are also actively involved in community participation initiatives for informal settlement upgrading, through which the inhabitants are empowered and can play an active role in the development process. Another major stakeholder in the informal settlement upgrading process is the government. The two main strategies that can be followed are in-situ upgrading or relocation of the settlement.

Informal settlements are a common occurrence in the South African landscape. In response, the South African government has produced various strategies on informal settlement upgrading, such as the South African Housing Programme (South Africa Department of Human Settlements, 2009) and the National Development Plan (South Africa National Planning Commission, 2012). Informal settlement upgrading by definition requires a strong emphasis and focus on the community. The upgrading process should therefore be flexible so that it can be adjusted to the dynamics of the existing community and potential impact of the various development options. When considering this, the Housing Development Agency (HDA) suggests that an urban design process be implemented (South Africa Housing Development Agency, 2011). As soon as the urban design project is initiated, there are several considerations: how much time is there for the project?; is there sufficient information available?; and is the required human capacity available (including skills)? (Jha *et al.*, 2010).

Pervious research documented that planning professionals in South Africa have a low level of map literacy which can hinder effective planning (Engel, 2004; Clarke, 2007; Marais, 2007). This, worryingly, means that the principal party responsible for planning might not have the adequate skills and abilities to perform the urban design tasks associated with informal settlement upgrading. On the other hand, progress in mapping technology allows the user to display information on digital platforms, such as web maps or virtual globes – these can either eliminate some map reading limitations or introduce new challenges due to computer illiteracy. Geographical visualisation (geovisualisation) provides alternative methods of exploring both the information display and the data behind the information (Cartwright, Pettit, *et al.*, 2005), and the impact of these new alternatives on map literacy needs to be investigated.

The goal of this project is to investigate the use of alternative 3D geovisualisations for urban design of informal settlement upgrading in South Africa. In this paper, the results and observations from various experiments and studies are combined to address this goal. The paper is organised based on three stages in the visualisation process: the 3D modelling, visualisation design, and the user's cognitive processes related to spatial tasks on 3D geovisualisations and comparable alternatives (i.e. topographic maps, aerial photographs, 2D maps) when performing basic map reading tasks for informal settlement upgrading. The remainder of the paper is structured as follows: Section 8.3

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presents procedural modelling as an alternative to manual modelling; in Section 8.4 visualisation design is discussed based on visual characteristics, visual complexity and visual variables; in Section 8.5, results from empirical user studies on the usefulness of 3D models are presented; and in Section 8.6, the overall results and observations are discussed and conclusions are provided.

8.3 Development of 3D models *(Chapter 2)*

Spatial data are generated daily in unprecedented amounts and these new rich and 'big' data need to be visualised, analysed, and managed (Li *et al.*, 2016). Visual representations of spatial data proved valuable to facilitate thinking, understanding, and knowledge construction about humans and their physical environment (Hildebrandt and Döllner, 2010). One such visualisation type is a 3D city model, i.e. a digital representation of spatial objects, structures and phenomena in urban areas. 3D city models have been of interest in domains related to geography for a long time, and are increasingly built and leveraged in various applications, such as urban planning and environmental management (Çöltekin and Haggren, 2000; Ross, 2010; Chen *et al.*, 2011; Krüger and Kolbe, 2012; Biljecki *et al.*, 2015).

3D models allow users to develop and design 3D representations with various datasets, perform analysis, such as line-of-sight (visibility), and to create simulations (Cartwright, Pettit, *et al.*, 2005; Hildebrandt and Döllner, 2009). 3D models can present information that cannot be visualised in 2D maps and designs (Li *et al.*, 2010). However, the development of high-quality realistic 3D urban models is still challenging and requires skilled individuals (Rautenbach, Bevis, *et al.*, 2015). Additionally, manual modelling can be time consuming, and involves a great deal of labour and time (Müller *et al.*, 2006; Rautenbach, Bevis, *et al.*, 2015). Employing only manual modelling when developing 3D models for an informal settlement is not a feasible solution due to the constant changing nature of informal settlements.

Rautenbach, Bevis *et al.* (2015) investigated the use of procedural modelling for generating a 3D model of an informal settlement in South Africa. Procedural modelling employs algorithms to automatically generate 3D objects and construct 3D models (Müller *et al.*, 2006; Ilčík *et al.*, 2010). This is a suitable alternative for modelling South African informal settlements, as the majority of the settlements are composed of numerous structures of more or less the same shape and size (i.e. the dwellings in the settlement). Planners and geoinformatics professionals can utilise procedural modelling to produce high-quality level of detail (LoD), specifically LoD2 3D models that can be used throughout the informal settlement upgrading process (Rautenbach, Bevis, *et al.*, 2015). Refer to Figure 69 for an example of the model that was developed. The generated model is an abstract representation of the settlement and it would be quite difficult to generate a photorealistic representation. It should be noted that procedural modelling does not overcome all the limitations of manual modelling. For example, procedural modelling still requires skilled individuals, but the skill set is different (requires scripting). A great deal of initial planning and preparation is still required to generate models in near real-time.

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Figure 69. A section of the Slovo Park informal settlement modelled at LoD3. Source: Rautenbach et al. (2015)

8.4 Visualisation design and 3D models *(Chapter 2 and Chapter 3)*

Meng (2002) argues that a photorealistic 3D model is not always the most ideal for spatial perception, analysis, understanding and knowledge discovery. For some applications non-photorealistic 3D models can prove to be more effective and efficient. They are also produced at a lower cost. However, there are no guidelines about which method is more optimal for planning. Anecdotal evidence has suggested that non-photorealistic models would be useful when capturing community knowledge, as the local community do not require much detail to recognise the environment and different objects (Rautenbach, Bevis, *et al.*, 2015). In this section, we address some of these issues by discussing the visualisation design of 3D informal settlement models. There are numerous aspects to consider when discussing visualisation design. In this research we considered visual characteristics, visual variables and visual complexity.

Dickmann and Dunker (2014) identified visual characteristics for 3D building models in urban planning. The characteristics were divided into three main aspects: visualisation content, visualisation application environment and functionality, and visualisation performance. Rautenbach, Bevis *et al.* (2015) adapted these characteristics for 3D informal settlement models in urban design activities, and additionally the importance of each characteristic to stakeholders was included. The visualisation characteristics provide guidance to users on which features to focus on when developing 3D models of informal settlements. When considering urban design activities in informal settlements, Rautenbach, Bevis *et al.* (2015) identified the LoD, terrain model, topography, man-made structures, and movement network as major contributions for stakeholder understanding of the model. When considering which software to use for presenting the model, the ability to easily navigate and view the 3D model from various perspectives is very important to consider. Lastly, when developing any 3D model the 'cost-benefit' ratio is an important consideration, as 3D modelling can be very effort and time intensive.

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Visual variables are a well-known concept defined by Bertin (1983) and originally proposed for black and white hard copy maps. Various researchers recommended extensions for interactive displays and animations (DiBiase *et al.*, 1992; MacEachren, 1995; Köbben and Yaman, 1996). The relevance of a subset of the visual variables were evaluated specifically for geovisualisation requirements of upgrades in informal settlements (Rautenbach, Coetzee, *et al.*, 2015). To increase the selectiveness of 3D objects[12], Rautenbach *et al.* (2015) proposed the following visual variables as relevant: position and motion of the camera, and colour and texture, suggesting shape to be replaced with LoD as this is used generally in computer graphics to enhance or reduce the detail of an object. LoD was identified as a characteristic of a 3D informal settlement (Rautenbach, Bevis, *et al.*, 2015), and suggested as a highly relevant visual variable (Rautenbach, Coetzee, *et al.*, 2015). Manipulating the LoD of an object can contribute to the saliency of the object, as a detailed 3D object (higher LoD) will be more pronounced in an environment with few detailed objects. Additionally, the deliberately designed level of detail might contribute to the stakeholders' understanding of the environment and the proposed upgrades in the informal settlement.

8.5 Cognition and 3D models *(Chapter 4 – 7)*

Researchers have been debating the usefulness and effectiveness of 3D representation for various application fields, including domains related to geography (Hegarty *et al.*, 2009; Çöltekin, Lokka, *et al.*, 2015; Çöltekin, Pettit, *et al.*, 2015). One school of thought is that 3D models can assist users to orientate themselves in a familiar environment and can make understanding landforms easier than with traditional 2D representations (Wood *et al.*, 2005; Smallman *et al.*, 2007; van Lammeren *et al.*, 2010; Chen *et al.*, 2011). Another school of thought posits that 3D representations will lead to cognitive overload, and that this might outweigh the benefits (Bleisch and Nebiker, 2008; Métral *et al.*, 2012; Richards and Taylor, 2015).

There have been various studies exploring the feasibility of developing 3D models from existing tools (i.e. various desktop and web technologies) for urban planning (Chen *et al.*, 2011; Chen, 2011; Fisher-Gewirtzman, 2012; Dambruch and Krämer, 2014; Ahmed and Sekar, 2015). These studies found that 3D models with a low LoD can be developed easily and 3D volumetric analyses would be useful in planning activities. Sharing of information and proposed future developments encouraging public participation in urban planning are also highlighted in these studies.

Virtual globes are easily accessible, and allow users to effectively create 3D visualisations of various types of spatial data (Bleisch and Nebiker, 2008; Schroth *et al.*, 2011). However, not all these visualisations are successful which can be attributed to the lack of guidelines for creating effective representation. Schroth *et al.*, (2011) investigated the usefulness of virtual globes as an interactive community engagement tool for landscape planning, specifically focused on 3D modelling of climate

[12] A visual variable is selective if a mark can be changed in only this variable and easily differentiated afterwards (Bertin, 1983; Carpendale, 2003; Halik, 2012; Wang *et al.*, 2012).

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change vulnerability. After stakeholder interviews and questionnaires, Schroth *et al.* found that 3D models portrayed in a virtual globe were a great tool to provide access to spatial data and to raise awareness for the specific project. However, the risk of misinterpretation of the models was a barrier for use.

Herbert and Chen (2015) used a survey and interviews to examine the perceived impact of 3D models on the impact on constructing mental images, shadow preferences and understanding which planning task would be useful for urban planning. Participants indicated that viewing the proposed developments in a 3D environment allowed them to construct and improve their familiarity faster than with traditional 2D maps. However, the participants also indicated that prior knowledge of the site is essential. Herbert and Chen (2015) found that the 3D models were useful for complex planning tasks, such as showdown impact), but not so effective for simple tasks, such as measurements. This was based on asking participants to rate their perceived usefulness of 3D for the specific task using a Likert scale.

Rautenbach *et al.* (2014; 2016) approached this question of the usefulness of 3D models for planning tasks more directly by developing a series of user experiments to assess individuals' map literacy when performing basic map reading tasks with aerial photographs, 2D maps and 3D models. In the first iteration, the preliminary results suggested that basic map reading tasks (i.e. indicating cardinal directions, relative directions, and estimation of distance) could be successfully performed on 3D non-realistic landscapes and 3D models (2014). However, confirming the comparative success of these observations to their alternatives requires further (controlled) experiments.

Thus, following the initial observational study, the authors developed a map reading task taxonomy for planning (Rautenbach *et al.*, 2016). The taxonomy consisted of six levels of map reading tasks, ranging from recognising symbols to extracting knowledge. The first four levels (recognise symbology, orientate, locate, and measure or estimate) were considered the minimum for functional map literacy and thus formed the elementary units for more advanced tasks. A subset of the taxonomy was tested using a 1:50 000 topographic map of the Barberton area in South Africa with map-literate individuals as a validation mechanism (Rautenbach *et al.*, 2016). The results suggest that the taxonomy can provide a proper reference for evaluating topographic map literacy levels.

In the final iteration, a mixed-methods experiment was designed to evaluate the usefulness of 3D models when performing certain map reading tasks (a subset of the map reading task taxonomy for planning) in aerial photographs, 2D maps and 3D models. The experiment consisted of a controlled and distributed online survey, and four in-depth expert interviews. The survey focused on tasks relating to identifying features and interpreting the terrain. For the controlled survey, 36 undergraduate students (17 males and 19 females) ranging from 18 to 33 years old participated in the experiment. The majority of participants were Geoinformatics students (81%), with a couple of Geography (13%), Meteorology (3%) and Town and Regional planning (3%) students also participating in the experiment. The demography for the distributed experiment was very different, as 58 individuals (t22 males and

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36 females) ranging from 19 to 60 years old participated in the experiment. See Figure 70 for an overview of the participant's field of occupations.

The results from both the controlled and distributed survey suggest that map reading tasks involving identification of, or differentiating between features, are challenging to perform in 3D models (refer to Figure 71 and Figure 72). Identifying or differentiating between features was challenging, as no legend was available. Additionally, both the 2D map and 3D model have a great deal of abstraction and it is thus difficult to differentiate between objects. As suspected, participants were more successful in performing tasks relating to interpreting the terrain because the 3D model was static and the terrain was tilted slightly. Due to the tilt, when asked to indicate the lowest point (i.e. lowest elevation) in the environment the participants were not very successful as the lowest point appeared to be in a different location. Thus, camera position and perspective of 3D models appear to be important considerations.

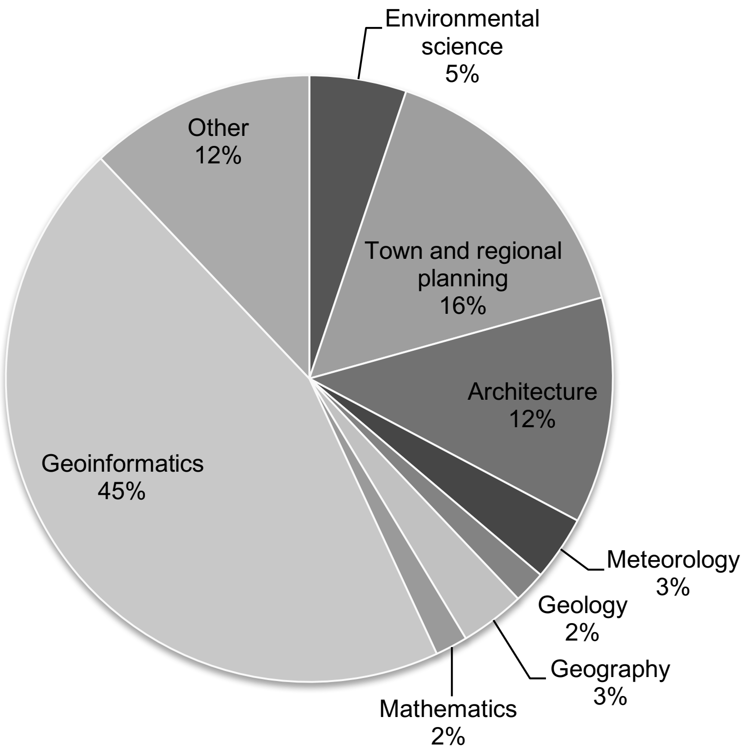

Figure 70. Overview of the participants in the distributed studies occupation

In-depth interviews were conducted with four experts in planning and urban design. The main points that were raised by the interviewees were that there is definitely a place for 3D models in the planning process. The skills required to design and develop the 3D models are still lacking in South Africa, but recent advances in technology might overcome this. Two interviewees supported the use of 3D models for urban planning, specifically for basic analyses and supplementing site visits for locations that are remote and difficult to visit. One interviewee specified that a lower LoD is preferred as too much detail especially for a larger scale project would be costly to produce and would be overwhelming. The general consensus among the interviewees was that a 3D model is a useful tool to use when consulting stakeholders to gain support and to assist with their understanding of environment.

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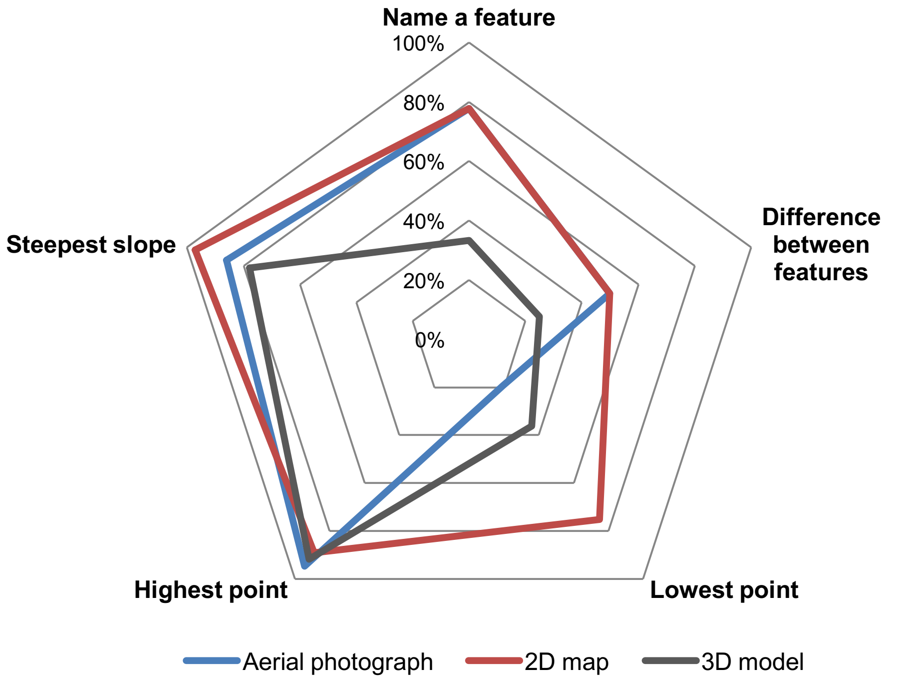

Figure 71. Radar diagram showing the percentage of correct answers for each geovisualisation in the controlled experiment

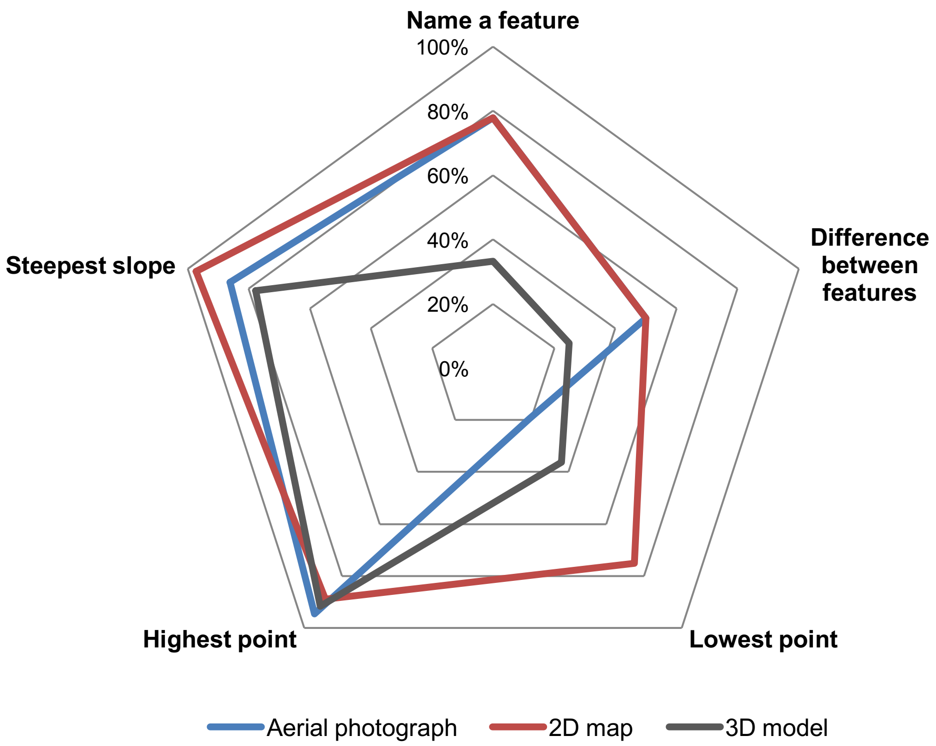

Figure 72. Radar diagram showing the percentage of correct answers for each geovisualisation in the distributed experiment

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8.6 Discussion and conclusion

In this paper, observations and results from various studies on the use of 3D geovisualisations for urban design in informal settlement upgrading in South Africa were presented. The focus of the studies was on the development and visual design of 3D models, and cognition related to spatial tasks on 3D geovisualisations when performing basic map reading tasks. To combine the results presented and draw some final conclusion on the usefulness of 3D geovisualisation for the urban design of informal settlement upgrades, we will use the urban design processes and guide the discussion around these processes.

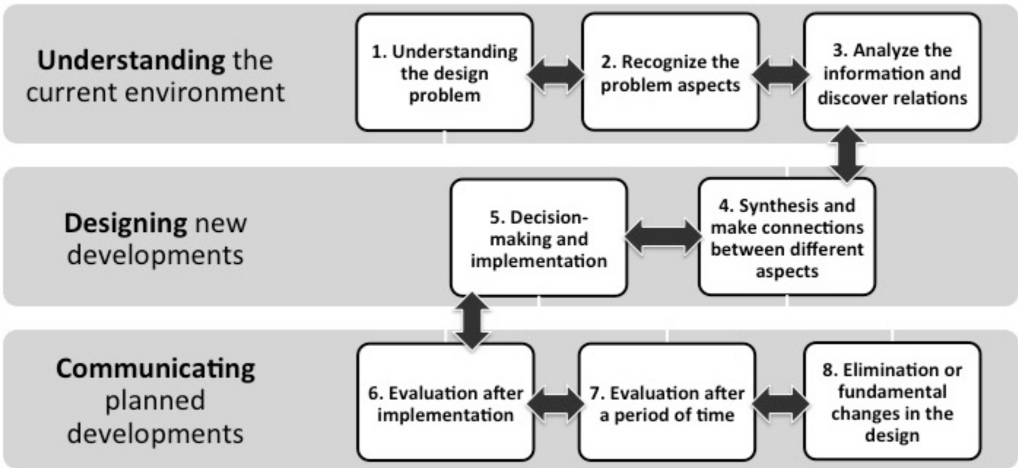

Figure 73. Conceptual design process from Parsaee et al. (2015) adapted by Rautenbach et al. (2016)

Simply stated, design is the process of creating various solutions before implementation. It has also been defined as 'a complex process of gathering and combining diverse data and information into a coherent solution' (Parsaee *et al.*, 2015). This process was then simplified by the authors further to see urban design as an iterative process that involves understanding the current environment, designing new developments, and communicating the planning. Figure 73 presents an adaption of the conceptual model of the design process as defined by Parsaee *et al*. (2015).

Before the 3D model can be used in the urban design process, it first needs to be developed. A 3D model of an informal settlement can be developed using modelling software, LiDAR or photogrammetry. LiDAR and photogrammetric tools are expensive technology, and while they may be available for urban centres, they are rarely available for informal settlements. Thus, 3D models are often created using manual modelling software, such as Trimble's SketchUp or Autodesk's Revit. We found procedural modelling (e.g. Esri CityEngine) a feasible alternative to time-consuming manual modelling. To evaluate the usefulness of procedural modelling, a 3D model was generated. All the visual characteristics of an informal settlement could be generated using procedural modelling; however, the learning curve with it might be steeper compared to manual modelling.

Whether in 2D or 3D, whether as graphic design or cartography, a successful visualisation design can contribute to the understanding of the represented phenomena, and can ensure that the intended

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message is conveyed. Visual variables provide fundamental elements to use for improving the selectiveness of objects in the model. For example, the position of the camera is important, as it can be set to focus on the planned development in a settlement. Similarly, an object with a higher LoD is a good candidate for guiding attention as it might stand out from other objects. Thus, even though visual variables were originally proposed for black and white paper maps, with some alterations they can be useful to improve selectiveness in 3D colour geovisualisations. Another design aspect that should be considered is visual complexity. Complex visualisation environments can lead to cognitive overload for the users, and would render a model inadequate.

Most urban design projects start with a visit to the site, to become familiar with the environment and gain insight into the community's needs. However, site visits are often not possible due to a site being located remotely or being difficult to reach. A well-designed 3D model can supplement site visits by allowing planners to view the environment from their offices at any time. Expert interviews confirmed that 3D models can be very useful to complement site visits, but they cannot replace them.

When using 3D models to plan a new development in an informal settlement, user experiments and expert interviews suggested that currently they are most relevant to understanding and interpreting the terrain. Three user experiments were designed and implemented to assess individuals' map literacy when performing basic map reading tasks with aerial photographs, 2D maps and 3D models. The results suggested that the participants struggle to perform tasks such as identifying or differentiating between features in the LoD2 model. However, the participants were more successful when performing the tasks relating to terrain interpretation. It should, however, be noted that it is difficult to compare 2D to 3D, as the level of abstraction the dimensions are different. It has been said that comparing 2D to 3D is like comparing apple to pears. Nevertheless, the results from the experiments provided an indication to what can be expected when using 3D models for urban planning map reading tasks.

During the interviews, the experts mentioned that more advanced analyses capabilities would be useful, however, the software is not easy to use. Additionally, modifying the 3D model to include new objects or to remove objects in real-time is not a simple task in most software applications. Currently, the development of 3D models is outsourced in most cases.

The communication phase of the urban design process is where the strength of 3D models lies. During the expert interviews, all interviewees stated that currently 3D models would be used to communicate the planned developments to the various stakeholders, from the community to government officials. Portraying the planned development as a 3D model enables the stakeholders to get a clearer picture of how the planned developments would affect themselves and the environment, thus increasing stakeholder buy-in for planned developments.

To conclude, 3D models can definitely be used in the urban design process of informal settlement upgrading. It should be noted that innovations for 3D modelling and viewing software are still necessary to improve the usefulness of 3D models for urban design. In future work, the requirements

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for 3D software will be specified. These requirements should take into consideration the technical expertise of the intended users, and the analyses and viewing capabilities that might be required during the urban design process.

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Chapter 9. Conclusion

9.1. Introduction

The work in this thesis investigated how 3D geovisualisation can be used successfully during the urban design process of in-situ informal settlement upgrading in South Africa. This final chapter provides both an overview of the main results, and recommendations on aspects that still need to be addressed in further research.

9.2. Main results from this thesis

The goal of the research is to investigate the use of 3D geovisualisation as a new visual representation for urban design of informal settlement upgrading in South Africa. Throughout this thesis, various results are presented and some conclusions are drawn based on these results in Chapter 8. In the remainder of this section, the objectives of the research and the related results are reviewed and discussed.

Objective 1: Understand informal settlement upgrading, urban design or planning process, map reading and map literacy, visual variables, geovisualisation, and other related work based on a literature review of existing theory and related work.

The various topics are presented and discussed throughout this thesis, and a good understanding of these topics and related work was essential for designing the various experiments. Objective 1 indirectly contributed to the author's understanding of experimental design, as this was a new field of which the author had no prior knowledge. The improvement in experimental design is visible between Chapter 5 and Chapter 7.

Additionally, objective 1 contributed to all the subsequent objectives. For example, this objective assisted with identifying design aspects (i.e. visual characteristics and visual variables) that should be considered when developing 3D models for informal settlements.

Objective 2: Define the map reading tasks and associated maps required as input for planning informal settlement upgrading during the urban design process.

In Section 6.3, a map reading task taxonomy is presented. The taxonomy was developed by reviewing and comparing various peer-reviewed publications, and other resources (e.g. national reports and policy documents). This was synthesised into a proposed task taxonomy specifically designed for spatial planning. The taxonomy consists of 18 realistic map reading tasks spread over six levels increasing in difficulty. The following levels were proposed: level1: recognise symbology; level2: orientate; level3: locate; level4: measure or estimate; level5: calculate or explain; and level6: extract

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knowledge. The hypothesis is that an individual who is competent in the first four levels (i.e. level1 to level4), is functionally map literate. The results from an empirical experiment confirm the hypothesis that the taxonomy can be used to evaluate functional map literacy of individuals with a topographic map.

The various raw vector and raster datasets (including aerial photographs), maps, and 3D models used during the urban design or urban planning process were determined through literature review and the expert interviews (discussed in Section 7.3). Figure 68 presents an overview of the urban design process and the various types of input generally used during each of the phases. Currently, 3D models are not used in the early stages of the process as the spatial data is generally not available for informal settlements. Planning professionals and geoinformatics specialists still rely heavily on aerial photographs and 2D maps (including spatial data) during the *understanding the current environment* and *designing new developments* phase of the process. 3D models and tools are still not used as widely in South Africa, due to various challenges and barriers, such as lack of skills, the time it takes to generate them compared to 2D maps, and the need for specialised tools for urban design, to name a few.

Objective 3: Evaluate the relevance of a subset of visual variables for 3D geovisualisations of South African informal settlements for urban design.

In Chapter 4, the relevance of a subset of Bertin's (1983) visual variables for planning in-situ upgrades of informal settlement using 3D models was investigated. The impact on selectiveness was specifically investigated. The subset of variables was evaluated against specific requirements for planning in-situ upgrades for an informal settlement; for example, the terrain should be considered. The results of the evaluation showed that although visual variables can contribute to the selectiveness of objects in 3D model, only colour and texture were directly transferrable. Other variables, such as position, orientation and motion, should not only relate to the objects in a 3D environment, but also to the camera or viewing perspective. Additionally, shape should be reconsidered rather than focusing on the LoD of an object, as changing the shape of 3D object is not suitable.

Objective 4: Assess the usefulness of various map designs (ranging from 2D and 3D geovisualisations) for urban designers, planning professionals and geoinformation specialists aimed at planning informal settlement upgrades in South Africa.

To achieve this objective, a series of user experiments (three iterations) were designed and implemented, and also expert interviews were conducted. Three iterations of the user experiments (presented in Chapters 5–7) were required to assess the usefulness of 3D models for urban design of in-situ upgrading of informal settlements. The reason for this is that it is not an easy task to compare 3D models to other geovisualisations, such as aerial photographs and 2D maps, as the level of

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abstraction is different in each of these and their dimensions, to name a few differences. Thus, there are hardly any criteria for making a valid comparison. Considering this, the results from the third user experiment showed that participants were able to complete the required tasks using a 3D model, but they were not as successful as when using the aerial photographs and 2D map (refer to Section 7.2). Individuals might have difficulties performing map reading tasks using 3D models, as this is generally not an expectation when using 3D models with a specific tool, since the tools provide the functionalities. For example, the user does not need to use map reading skills to identify an object, as the tool provides this functionality (i.e. identify tools in software such as ArcGIS Pro).

The results from the expert interviews suggest that 3D models can be used during all the phases of the urban design process. However, it is not commonly used and provides unnecessary detail. The expert interviewees all agreed that a 3D model of the settlement would be very useful to supplement site visits and to communicate planned developments to the various stakeholders. UAVs, also known as drones, can be used with a LiDAR sensor to capture and generate highly accurate 3D models of an informal settlement. These models can be viewed from the office without visiting the settlement in cases where it is remote or difficult to reach. However, the 3D model should never completely replace a site visit, as being physically in the environment and speaking to the people is important for not only getting stakeholder buy-in but also gaining insight into the community's daily activities and their needs.

This thesis was started with the Chinese proverb, "*A picture is worth ten thousand words*". All expert interviewees agreed that based on their experience at present 3D models' power lies in communication. The agreement is that when communicating with the decision makers and other stakeholders, 3D models are good at gaining their attention and showing them the impact of the planned development or even the issues in the current environment. This is supported by other research, for example Batty (2013) and Philips *et al*. (2015), that states that design is a bottom-up approach and that an immersive 3D environment could increase the stakeholders' motivation to participate.

Objective 5: Based on all findings, draw conclusions for the design and use of 3D geovisualisations for informal settlement upgrading in South Africa.

Conclusions based on the results of this thesis are presented at the end of every chapter (refer to Sections 2.7, 4.6, 3.7, 5.7, 6.6, and 7.4) and also in Chapter 8. Below are the main conclusions from this thesis:

- Aerial photographs, 2D models and additional vector and raster spatial data should be the main focus when planning new developments. However, a well-designed 3D model can enrich the process.
- 3D geovisualisations, specifically 3D models of the informal settlement, are useful for designing in-situ upgrades of informal settlements. 3D models have the potential not only to

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assist with communication, but will in future be used more during the *understanding the current environment* and *designing new developments* phase of the urban design process.

- 3D models are essential when communicating with stakeholders, and to ensure stakeholder buy-in.
- Due to the repetitive nature of an informal settlement (the settlements mainly consist of various dwellings that are very similar in construction and aesthetics), procedural modelling can be used effectively to generate 3D models of a typical South African informal settlement. It may be less time consuming than manual modelling, but there are still some drawbacks, such as the steep learning curve and additional skills required.
- When designing a 3D model of an informal settlement there are some things that the designer should consider (i.e. best practices):
    - In Section 2.5, visual characteristics of an informal settlement are defined and their importance for urban planning discussed. When designing a 3D model, this provides guidance to which features to include to improve the model.
    - Visual complexity can improve or hinder an individual's ability to orientate themselves in the 3D model and the construction of a cognitive map. The following visual complexities should be considered when designing a 3D model: LoD, the extent of the model (scale), scene complexity (number, structure and density of objects), and the camera angle (perspective).
    - Visual variables, specifically colour and texture, can be used to improve the selectiveness of objects in a 3D model.
- A variety of 3D modelling tools are available, but there is a need for easy-to-use specialised tools designed and developed specifically for the requirements of an urban design project.

9.3. Recommendations for further research

The following areas or topics are recommended for future research efforts:

Development of 3D informal settlements models. In this thesis, procedural modelling was only evaluated when generating a 3D model of one specific informal settlement. The process should be verified for other informal settlements, in South Africa and possibly sub-Saharan Africa and internationally. Additionally, the design and development of a 3D object library for procedural modelling of informal settlements should be investigated. Such a library would improve the models developed.

User experience when employing 3D models for urban design. User experience is gaining popularity and should also be considered when investigating the usefulness of 3D models for urban design. Interactive user studies that evaluate the user experience when using a 3D model to solve a specific problem should be designed. For example, colour schemes, placement of light sources and

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also the method of interacting with the model should be considered (e.g. using a game console remote or even virtual reality).

Visual complexity of 3D models. Each of the visual complexity factors (i.e. LoD, the extent of the model, scene complexity, and the camera angle) should be assess individually to better understand the impact of these factors on individuals' orientation and cognition when using 3D models.

Relevance of visual variables. In this thesis only the relevance of selectiveness of a subset of visual variables for 3D models were investigated. The other characteristics, i.e. associative, quantitative and order, should also be investigated. Additionally, empirical user experiments or expert interviews might be required.

Map literacy of individuals when using 3D models. There are various types of 3D models (relating to the different LoDs, for example) can be generated and individuals' map literacy when using these variations should be assessed. Empirical user experiments that assess the map literacy of, for example, 3D non-realistic and 3D realistic models, will contribute to the understanding of how 3D models should be designed and used during the urban design process.

Specialised 3D modelling tools. In this thesis, the need for specialised 3D modelling tools arises. Requirements for such a tools, should be elicited for the potential user community. The requirements should be used to evaluate existing 3D modelling tools, to establish if a suitable tool is available. If no tool is suitable, the development of the tool might be required, and subsequently the new tool's functionalities and usefulness should be evaluated.

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Annex A. Acronyms and abbreviations

Table 19. List of abbreviations used in this thesis

2D	Two-dimensional
3D	Three-dimensional
CD:NGI	Chief Directorate: National Geo-spatial Information
CGA	Computer Generated Architecture
CityGML	City Geography Markup Language
CoJ	City of Johannesburg
CoT	City of Tshwane
Esri	Environmental Systems Research Institute
GIS	Geographic Information System
GISc	Geographic Information Science
GML	Geography Markup Language
GPS	Global Positioning System
HDA	Housing Development Agency
ICA	International Cartographic Association
ICC	International Cartographic Conference
IDP	Integrated Development Planning
ISO	International Organization for Standardization
ISPRS	International Society for Photogrammetry and Remote Sensing
LoD	Level of Detail
MDG	Millennium Development Goals
NASA	National Aeronautics and Space Administration
NDP	National Development Plan
NGO	Non-governmental organisation
NPC	National Planning Commission
OGC	Open Geospatial Consortium
OSM	OpenStreetMap

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PC	Personal Computer
RDP	Reconstruction and Development Programme
SASDI	South African Spatial Data Infrastructure
SDI	Spatial Data Infrastructure
SHP	Shapefile
Stats SA	Statistics South Africa
STEM	Science, Technology, Engineering and Math
UN	United Nations
VC	Visual Complexity
VRML	Virtual Reality Markup Language

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Annex B. Ethical approval

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

ETHICS COMMITTEE
Faculty of Natural and Agricultural Sciences

14 May 2013
Dr S Coetzee
Department of Geography, Geoinformatics and Meteorolgy
University of Pretoria
Pretoria
0002

Dear Dr Coetzee

EC130424-039: Methodology for the design and use of Geovisualization tools in community

This protocol conforms to the requirements of the NAS Ethics Committee.

Kind regards

Prof NH Casey
Chairman: Ethics Committee

Agriculture Building 10-20
University of Pretoria
Private bag X20, Hatfield 0028
Republic of South Africa

Tel: 012 420 4107
Fax: 012 420 3290

ethics.nas@up.ac.za

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UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

ETHICS COMMITTEE
Faculty of Natural and Agricultural Sciences

25 November 2014
Dr S Coetzee
Department of Geography, Geoinformatics and Meteorology
University of Pretoria
Pretoria
0002

Dear Dr Coetzee

EC140506-041 (Amended: EC130424-039): Methodology for the design and use of Geovisualization tools in community

This protocol conforms to the requirements of the NAS Ethics Committee.

Kind regards

Prof NH Casey
Chairman: Ethics Committee

Agriculture Building 10-20
University of Pretoria
Private bag X20, Hatfield 0028
Republic of South Africa

Tel: 012 420 4107
Fax: 012 420 3290

ethics.nas@up.ac.za

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Annex C. Visual complexity user study - Answer sheet

Research project/title: ***Methodology for the design and use of geovisualisation tools in community participation projects***

Researchers: Serena Coetzee (supervisor) and Victoria Rautenbach (PhD student)

University of Pretoria

Part A. Demography

What is your age?

____

What is your gender?

Male ☐ Female ☐

How would you classify your race? ____

What is your home language? ____

For which degree are you enrolled? ____

Academic year (eg. 1^{st}, 3^{rd}, Masters, etc.)? ____________________________________

Which year did you matriculate? ____

Part B. Description of Experience

Answer the following question with a rating between 1 and 5 (*1 being not good/never and 5 excellent/regularly*).

	1	2	3	4	5
1. How would you rate your sense of orientation?					
2. Do you frequently feel disoriented or confused about where you are in a new environment?					
3. Do you play video games?					
4. How often do you interact with computer simulations?					

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Part C. Real world

We will ask you to indicate the direction of buildings on campus from your current location.

	Front	
Left		Right
	Behind	

Use the above method to indicate (use an **X**) the direction.

1)

2)

Part D. Level of Detail 1

After the walk through of the 3D model, please draw a 2D map of the environment walked in demonstration.

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Part E. Level of Detail 2

After the walk through of the 3D model, you will be asked to indicate the direction of a specific building or object.

Use the above method to indicate (use an **X**) the direction.

1)

2)

Part F. Level of Detail 3

Use the same method as in Part D to indicate (use an **X**) the direction.

1)

2)

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Part G. Feedback

During the walk through the model, did you ever feel that you were captivated by the model?

____

Which level of detail model did you prefer?

LoD 1 ☐ LoD 2 ☐ LoD 3 ☐

Thank you for your participation!

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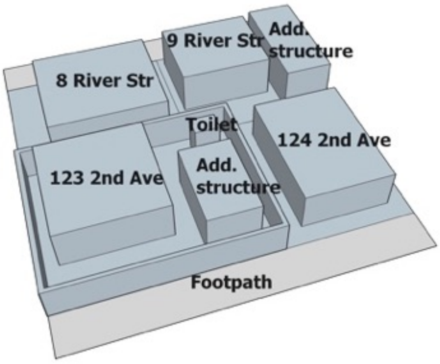
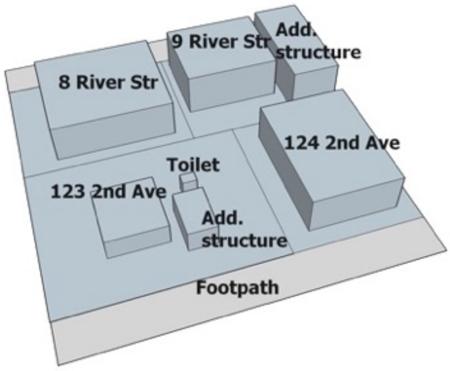
Annex D. Selected examples of visual variables for cartographic design

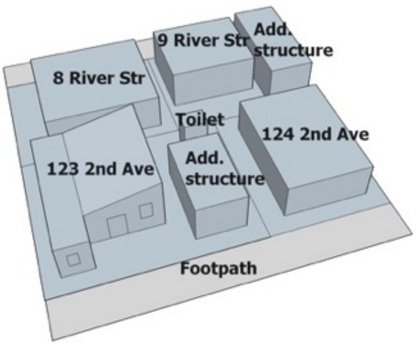
Figure 74. Selected examples from the evaluation discussed. For illustration purposes, the shelters are represented by basic geometry and boundaries as a line on the terrain



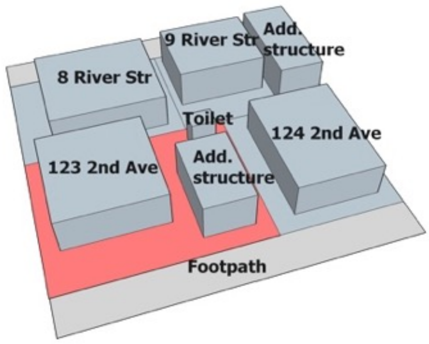
I) Change in the **size** of the boundary



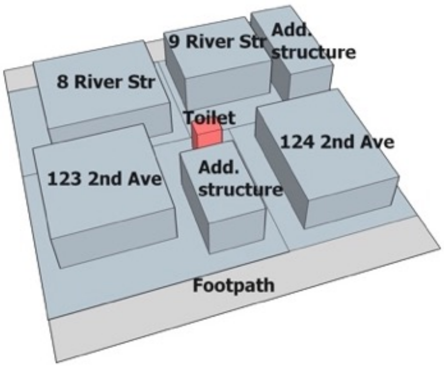
II) Modifying the **size** of shelters



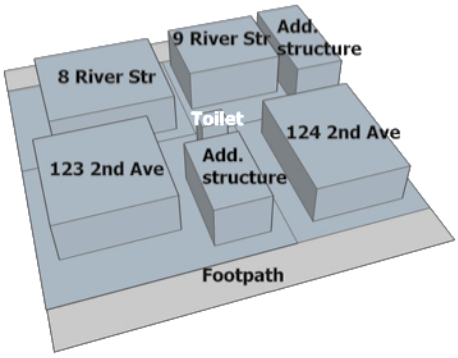
III) Altering the **shape** (higher LoD)



IV) Highlighting through changes in **colour**.



V) Highlighting a structure through a change in **colour**.



VI) Enhancing label's selectiveness with a **colour** changes.

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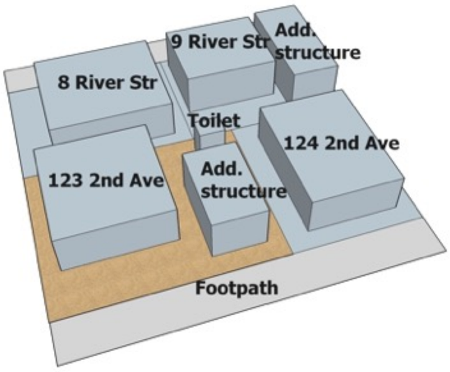
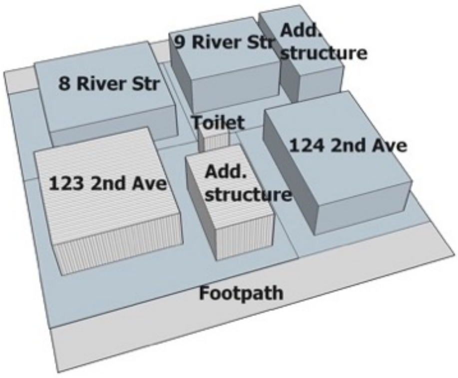


VII) Depicts a change in **texture**



VIII) Depicts a change in **texture**

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Annex E. Topographic map reading user experiment – export of online survey

Welcome

These page timer metrics will not be displayed to the recipient.
First Click: *0 seconds*
Last Click: *0 seconds*
Page Submit: *0 seconds*
Click Count: *0 clicks*

Browser Meta Info

This question will not be displayed to the recipient.
Browser: **Firefox**
Version: **45.0**
Operating System: **Macintosh**
Screen Resolution: **1280x800**
Flash Version: **21.0.0**
Java Support: **1**
User Agent: **Mozilla/5.0 (Macintosh; Intel Mac OS X 10.11; rv:45.0) Gecko/20100101 Firefox/45.0**

Dear participant,

This survey documents map literacy of users when working with topographic maps. The goal of this experiment is to understand and evaluate the relevant aspects of digital map literacy. The results will contribute to the development of guidelines for the use of 2D maps and 3D models for planning of informal settlement upgrading in South Africa.

This study involves an anonymous survey. Your name will not appear on the questionnaire and the answers you give will be treated as strictly confidential. You cannot be identified in person based on the answers you give. (Note that consent cannot be withdrawn once the questionnaire is submitted as there is no way to trace the particular questionnaire that has been filled in).

Your participation in this study is very important to us. You may, however, choose not to participate and you may also stop participating at any time without any negative consequences. Please answer the questions in the questionnaire as completely and honestly as possible. This should not take more than 30 minutes of your time.

The results of the survey may be published in the media and/or an academic journal without identifying any of the participants individually. We will provide you with a summary of our findings on request.

Recommended screen resolution is 1280x720 or higher.

Please click the forward arrow signs at the lower right corner of the screen to continue.

Demography

These page timer metrics will not be displayed to the recipient.
First Click: *0 seconds*
Last Click: *0 seconds*
Page Submit: *0 seconds*
Click Count: *0 clicks*

Age

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Gender

Male
Female

In which country do you reside?

South Africa
Other

Have you ever been told by a professional that you have imperfect color vision?

Yes
No

Please specify your occupation or, if you are a student, your degree program.

Which of the following best describes you:

Spatial Planner (registered)
Spatial Planner
GISc Professional (registered)
GISc Professional
GISc Technologist (registered)
GISc Technologist
GISc Technician (registered)
GISc Technician
Decision maker
Student
Citizen
Other

Did you take geography at high school or university?

Yes
No

Are you familiar with the Barberton area in Mpumalanga?

Yes
No

Please rate your level of training in the following categories:

	0	1	2	3	4
Cartography	○	○	○	○	○
Geography	○	○	○	○	○
GIS	○	○	○	○	○
Planning	○	○	○	○	○
Computer graphics	○	○	○	○	○

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Please rate your level of experience in using:

	0	1	2	3	5
Topographic maps	○	○	○	○	○
Graphics of any kind (maps, charts, etc.)	○	○	○	○	○
Spatial data of any kind (maps, digital elevation models, etc.)	○	○	○	○	○
Internet browsers	○	○	○	○	○
English	○	○	○	○	○

Learn legend

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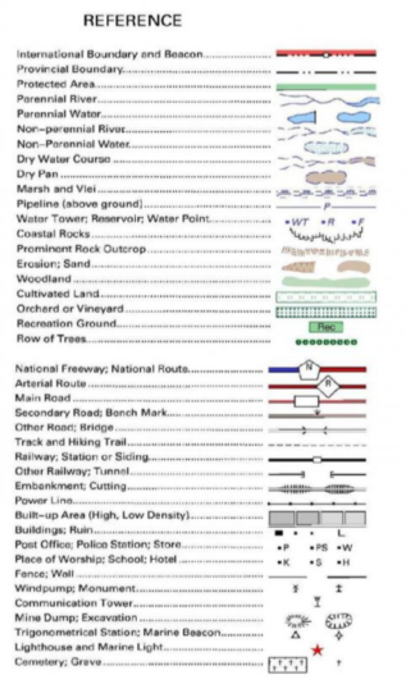
Page Submit: *0 seconds*
Click Count: *0 clicks*

Take some time to review the legend, as it will be used in the maps that follow. Note that the legend will be available in all tasks that follow.



Question 1 - name the feature (1.1)

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These page timer metrics will not be displayed to the recipient.
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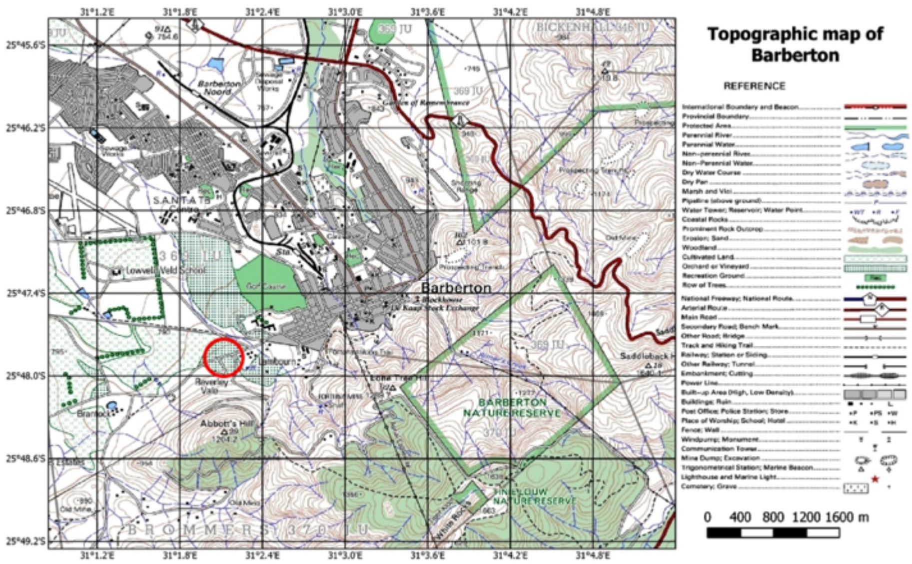
Name the feature represented inside the red circle (area feature).



	0	10	20	30	40	50	60	70	80	90	100
Please indicate your confidence with this answer											

Question 2 - name the feature (1.1)

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Last Click: *0 seconds*
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Click Count: *0 clicks*

Name the feature represented inside the red circle.

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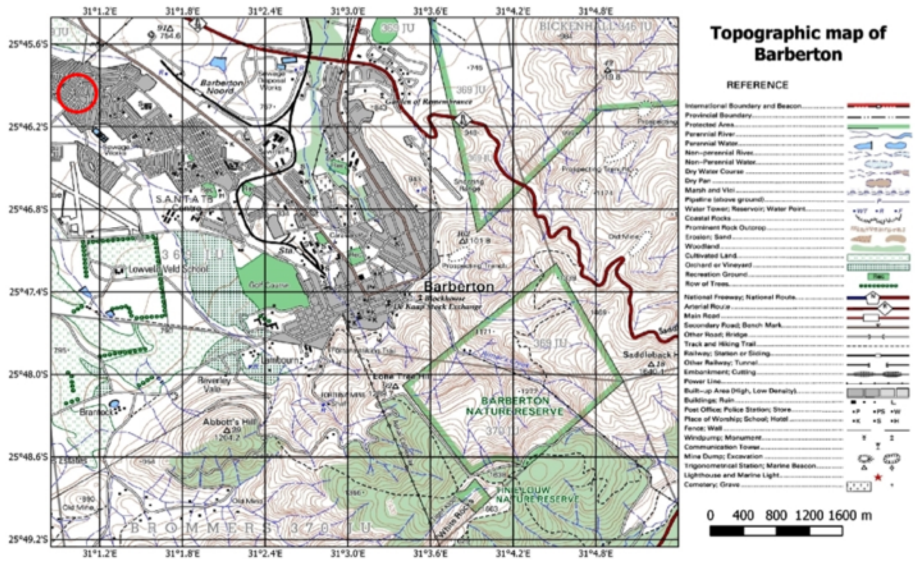

	0	10	20	30	40	50	60	70	80	90	100
Please indicate your confidence with this answer											

Question 3 - difference btw features (1.2)

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Name the features represented by A and B.

A

B

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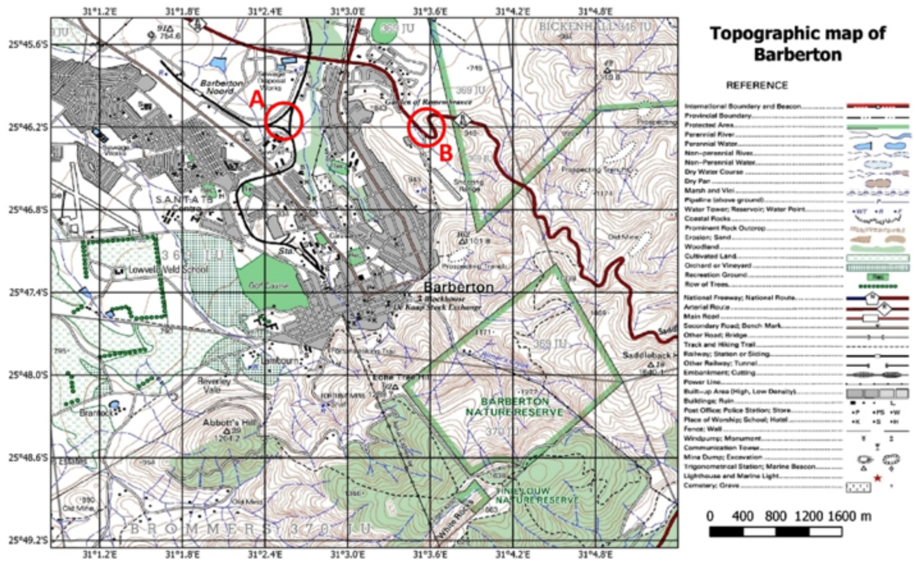

	0	10	20	30	40	50	60	70	80	90	100
Please indicate your confidence with this answer											

Question 4 - difference btw features (1.2)

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Name the features represented by A and B.

A

B

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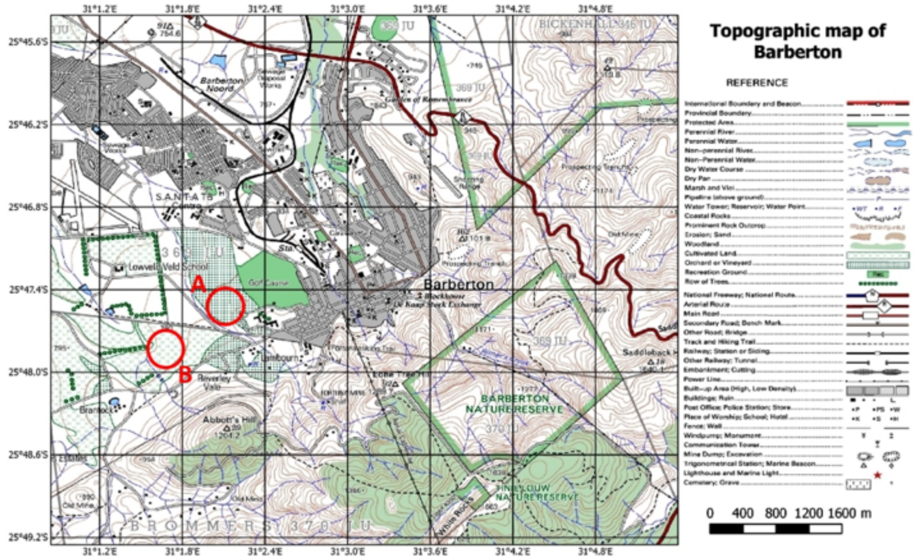

	0	10	20	30	40	50	60	70	80	90	100
Please indicate your confidence with this answer											

Question 5 - highest point (1.3)

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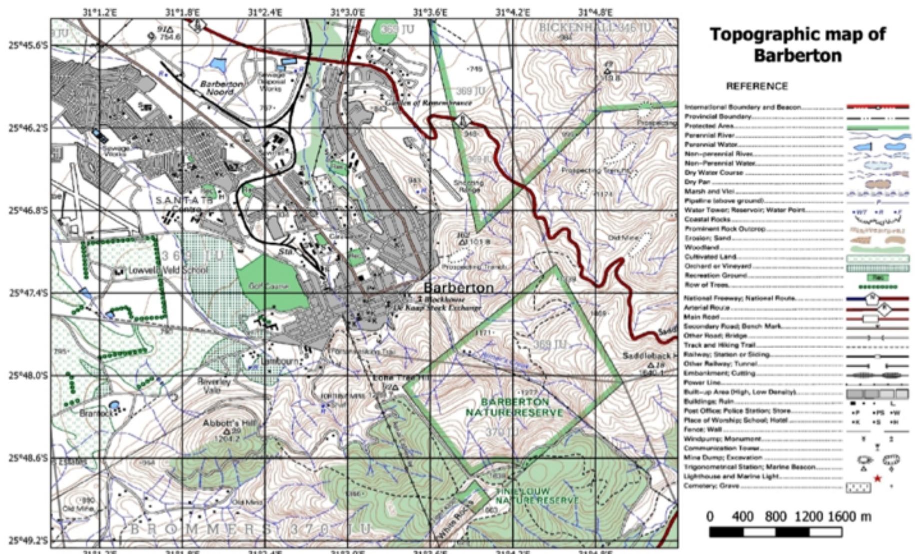
Indicate the highest point shown in the map below (click on the map).



	0	10	20	30	40	50	60	70	80	90	100
Please indicate your confidence with this answer											

Question 6 - lowest point (1.3)

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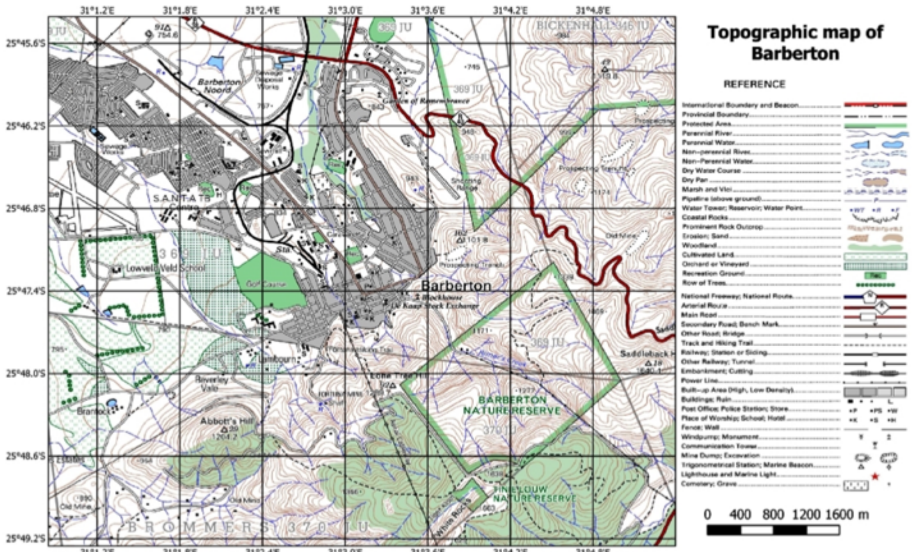
Indicate the lowest point shown in the map below (click on the map).



	0	10	20	30	40	50	60	70	80	90	100
Please indicate your confidence with this answer											

Question 7 - relative direction (2.1)

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Click Count: *0 clicks*

What is the relative direction from point A to point B?

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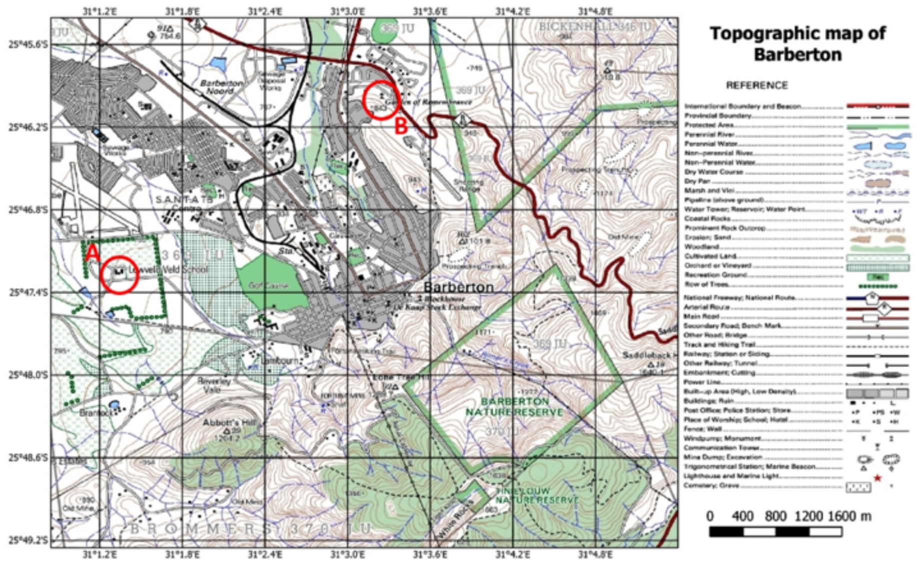

	0	10	20	30	40	50	60	70	80	90	100
Please indicate your confidence with this answer											

Question 8 - relative direction (2.1)

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What is the relative direction from point A to point B?

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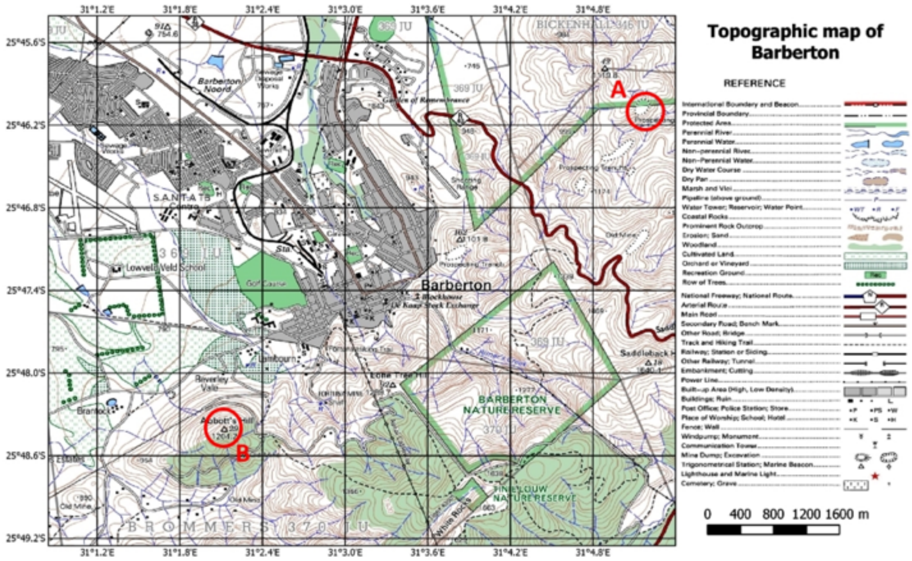

0 10 20 30 40 50 60 70 80 90 100

Please indicate your confidence with this answer

Question 9 - locate a feature (3.1/3.2)

These page timer metrics will not be displayed to the recipient.

First Click: *0 seconds*

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Click Count: *0 clicks*

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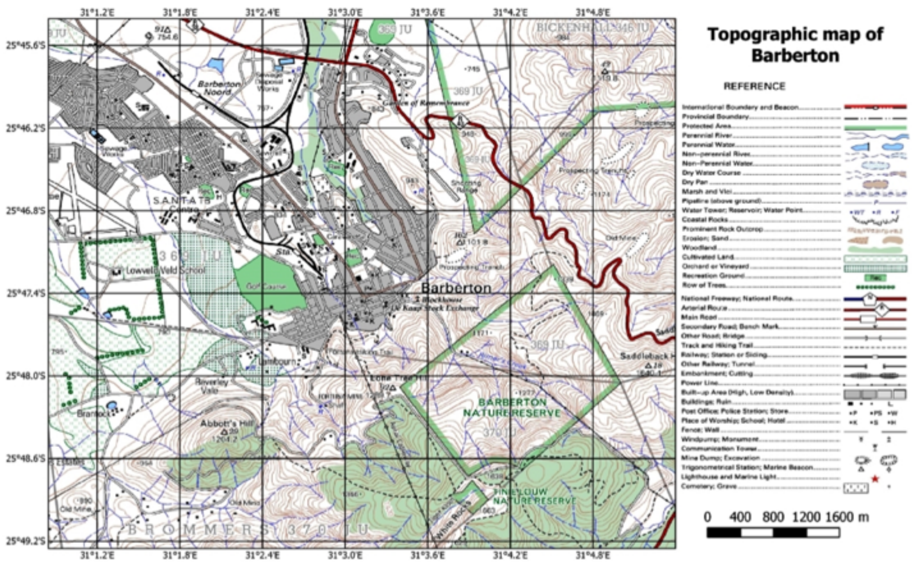
Locate a sewage works (perennial water) - click in the vicinity of the feature.



	0	10	20	30	40	50	60	70	80	90	100
Please indicate your confidence with this answer											

Question 10 - locate a feature (alphanumeric) (3.1/3.2)

These page timer metrics will not be displayed to the recipient.
First Click: *0 seconds*
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Click Count: *0 clicks*

Provide the alphanumeric grid position for Blockhouse (monument).

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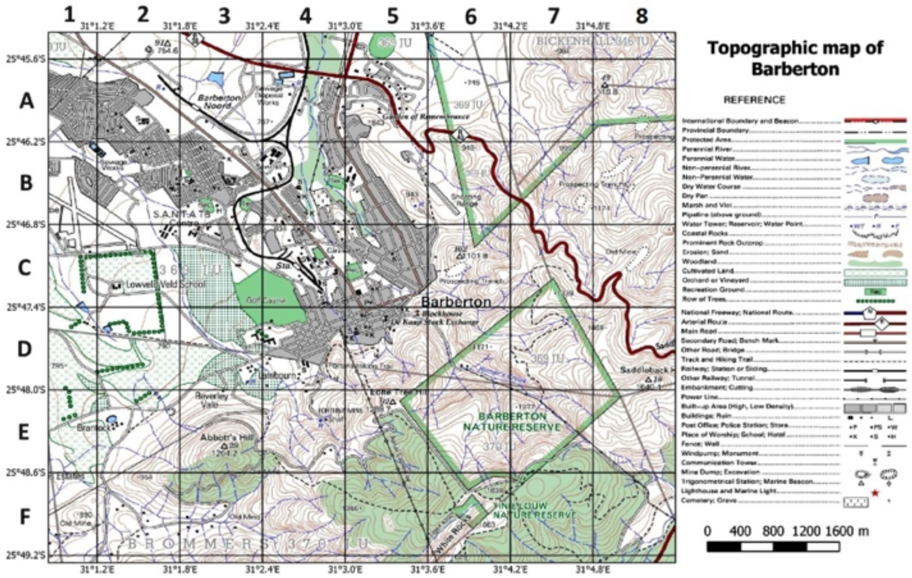

Please indicate the you confidence with the answer

0	10	20	30	40	50	60	70	80	90	100

Question 11 - locate a feature (coordinate) (3.1/3.2)

These page timer metrics will not be displayed to the recipient.

First Click: *0 seconds*

Last Click: *0 seconds*

Page Submit: *0 seconds*

Click Count: *0 clicks*

Provide the coordinate position for the top left corner of the Barberton Nature reserve.

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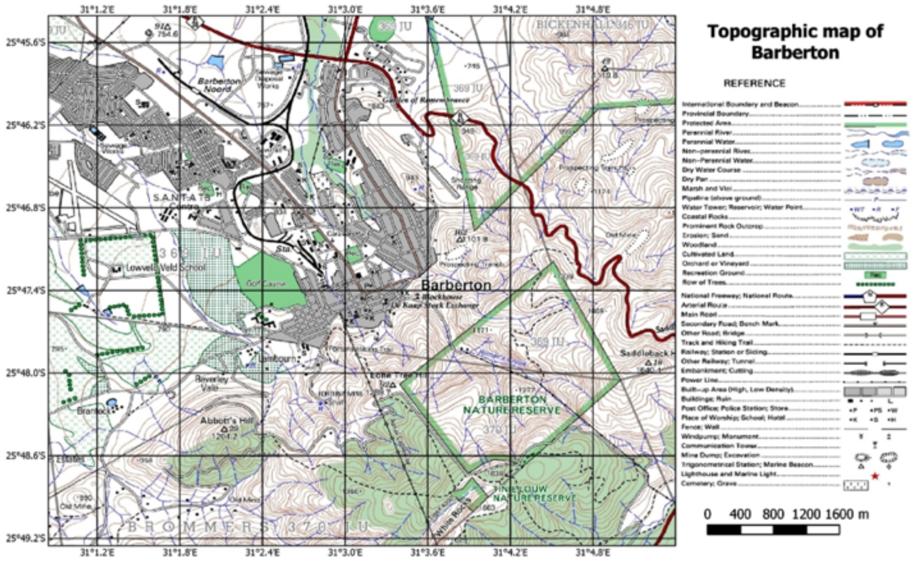

	0	10	20	30	40	50	60	70	80	90	100
Please indicate your confidence with this answer											

Question 12 - locate a feature (3.1/3.2)

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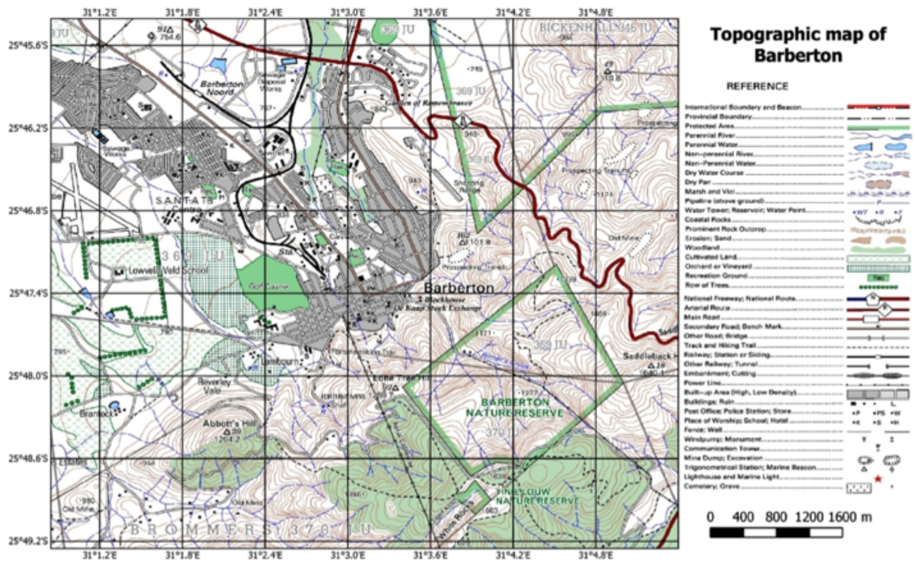
Locate a school - click in the vicinity of the school.



0	10	20	30	40	50	60	70	80	90	100

Please indicate your confidence with this answer

Question 13 - locate a feature (alphanumeric) (3.1/3.2)

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What is the alphanumeric grid position for Abbott's Hill?

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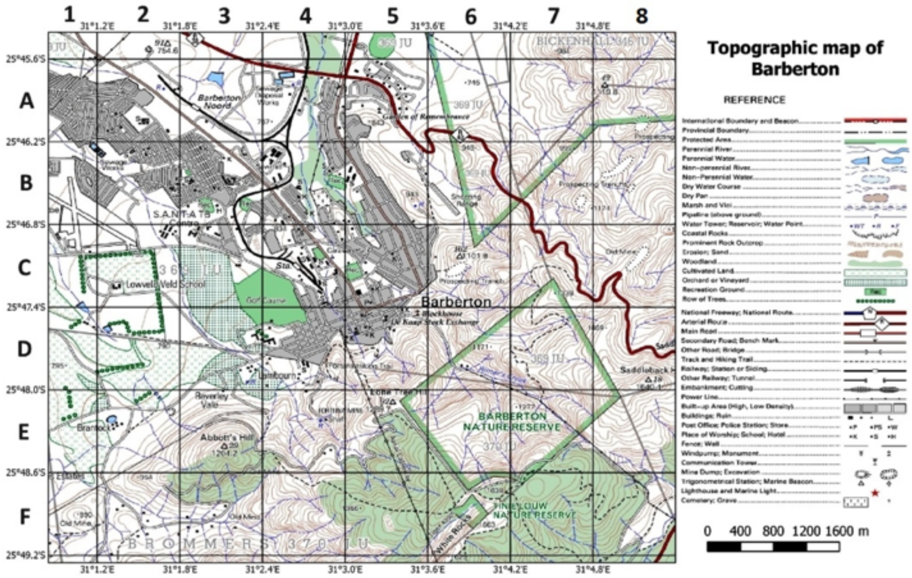

	0	10	20	30	40	50	60	70	80	90	100
Please indicate your confidence with this answer											

Question 14 - locate a feature (coordinate) (3.1/3.2)

These page timer metrics will not be displayed to the recipient.
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Provide the coordinate position for the Garden of Remembrance (monument).

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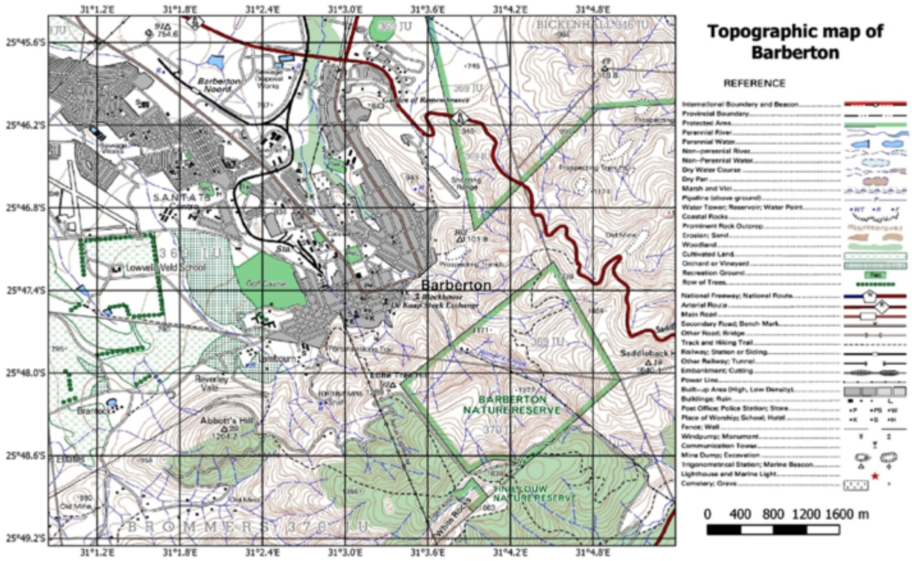

	0	10	20	30	40	50	60	70	80	90	100
Please indicate your confidence with this answer											

Question 15 - spatial relationship (3.3)

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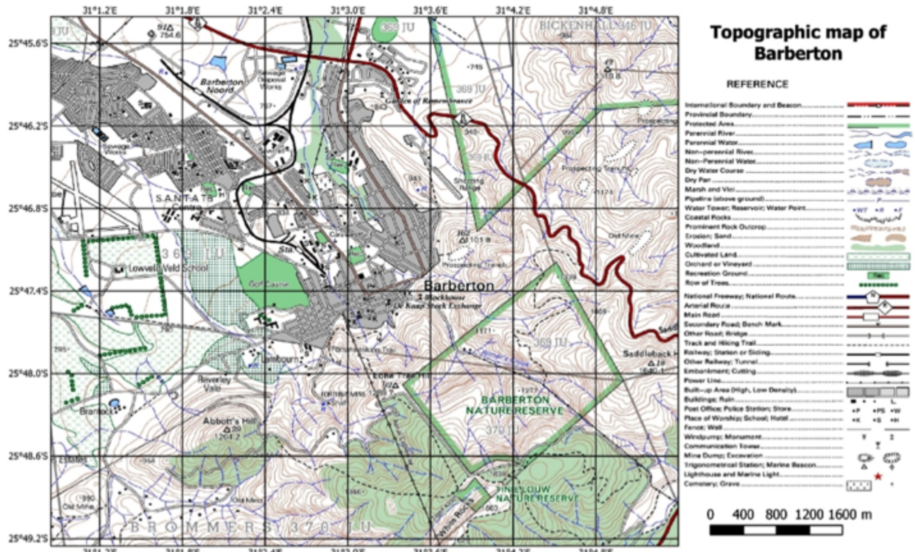
Locate the power line that crosses through the Barberton nature reserve (click on the symbol).



	0	10	20	30	40	50	60	70	80	90	100
Please indicate your confidence with this answer											

Question 16 - spatial relationship (3.3)

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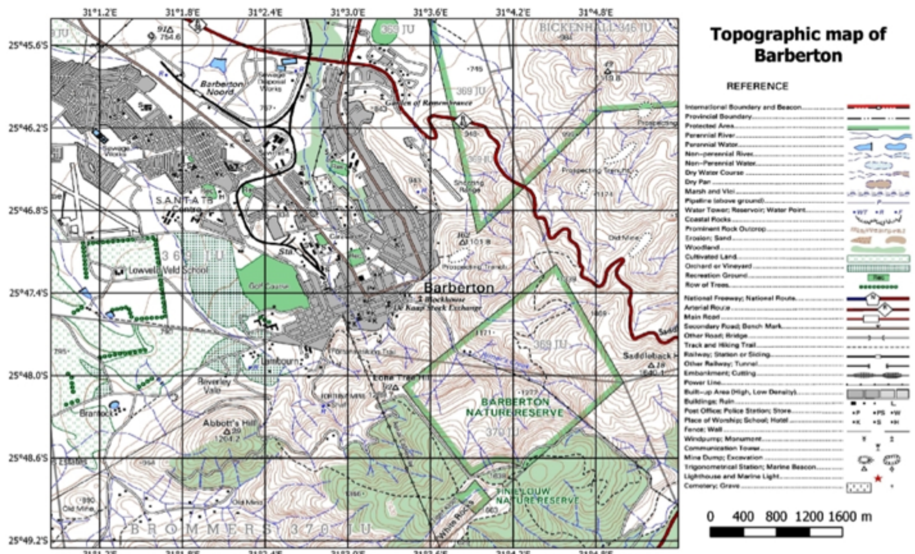
Locate a recreation ground that is located along the railway line (click on the symbol).



	0	10	20	30	40	50	60	70	80	90	100
Please indicate your confidence with this answer											

Question 17 - topography (4.1)

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First Click: *0 seconds*
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Click Count: *0 clicks*

Is point A visible from point B (assuming no buildings are in the way)?

Yes
No

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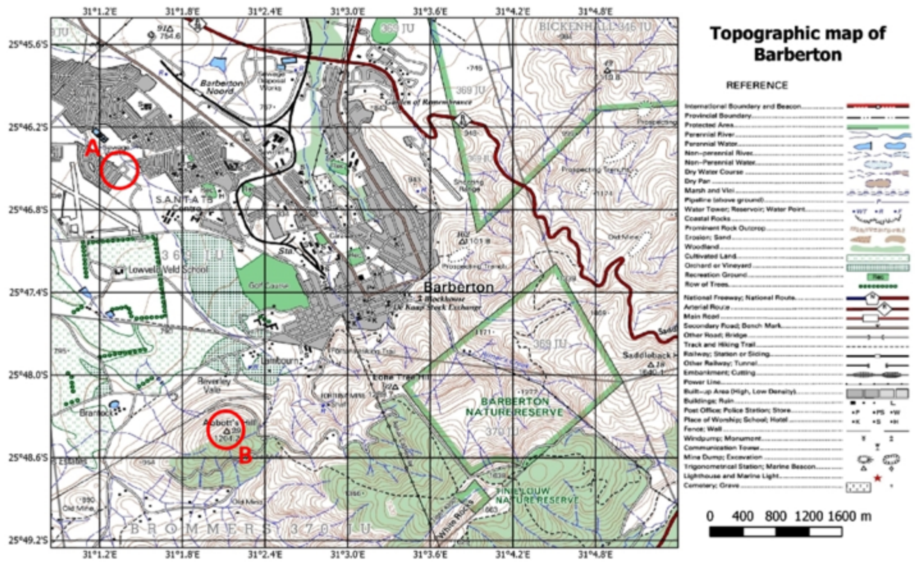

	0	10	20	30	40	50	60	70	80	90	100
Please indicate your confidence with this answer											

Question 18 - topography (4.1)

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First Click: *0 seconds*
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Click Count: *0 clicks*

In which area, A or B, is the slope the steepest?

A

B

Slope is similar

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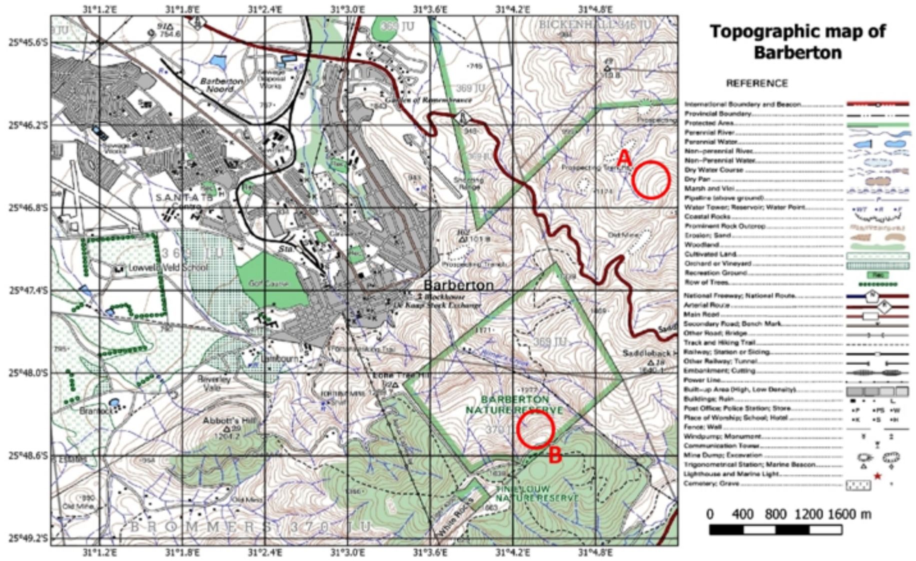

	0	10	20	30	40	50	60	70	80	90	100
Please indicate your confidence with this answer											

Question 19 - distance (4.2)

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Click Count: *0 clicks*

Estimate the straight line distance between the features indicated (**in meters**).

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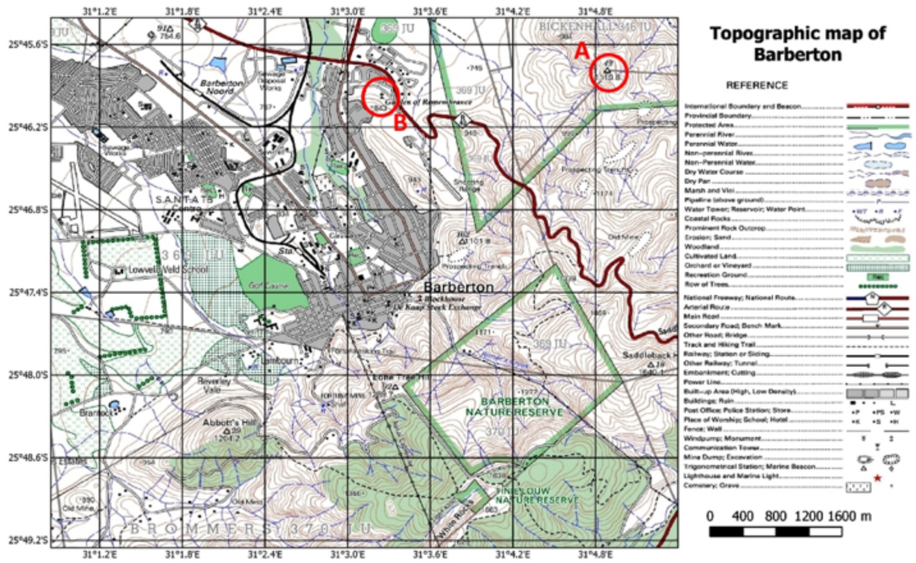

	0	10	20	30	40	50	60	70	80	90	100
Please indicate your confidence with this answer											

Question 20 - distance (4.2)

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Estimate the straight line distance between the features indicated (**in meters**).

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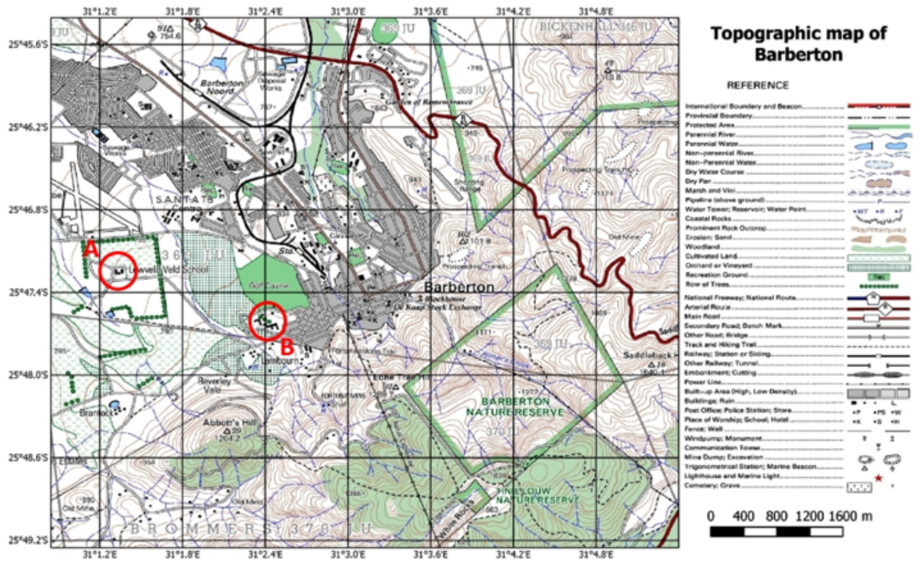

	0	10	20	30	40	50	60	70	80	90	100
Please indicate your confidence with this answer											

Question 21 - area (4.3)

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Estimate the area of the golf course indicated in the red block below (**in square meters**).

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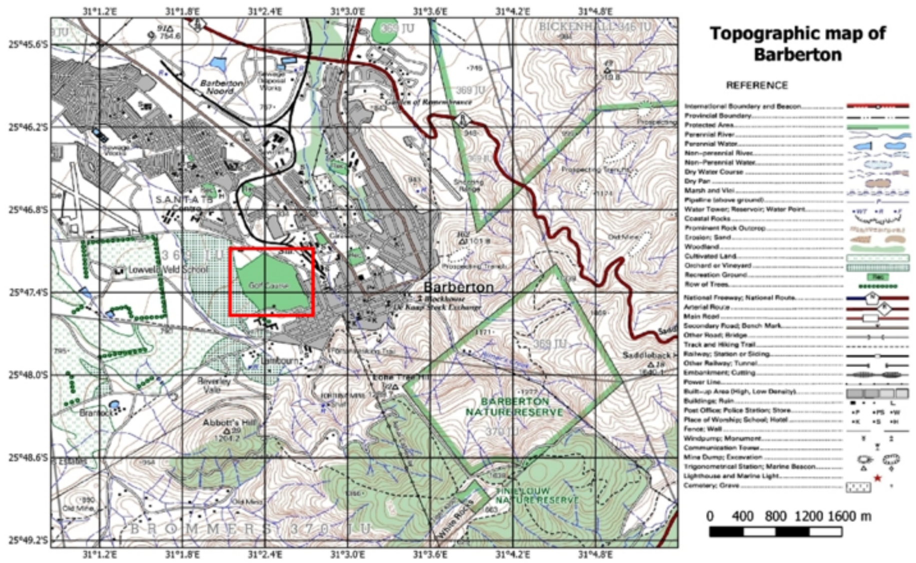

	0	10	20	30	40	50	60	70	80	90	100
Please indicate your confidence with this answer											

Question 22 - area (4.3)

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Estimate the area of the Barberton Nature reserve (**in square meters**).

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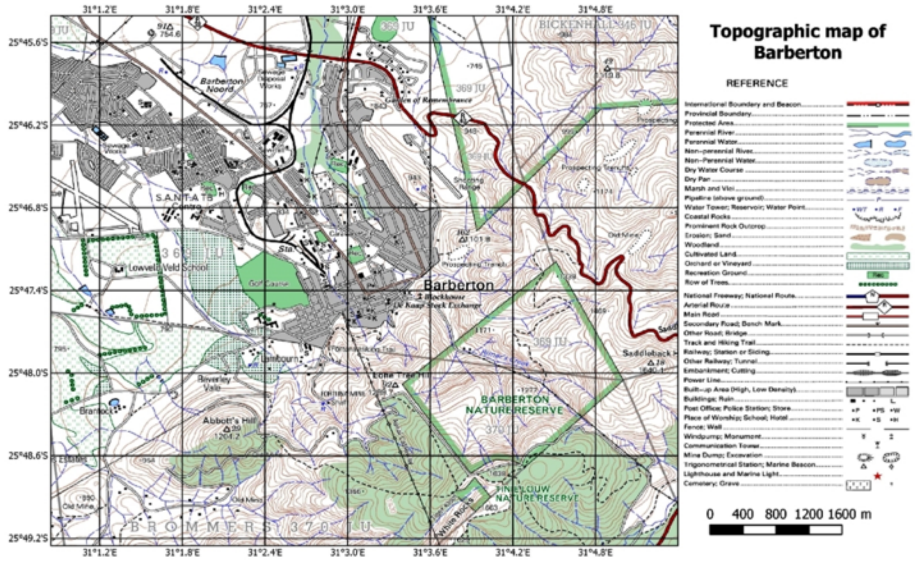

	0	10	20	30	40	50	60	70	80	90	100
Please indicate your confidence with this answer											

Thank you

Thank you for your participation.

Please contact Victoria Rautenbach (victoria.rautenbach@up.ac.za) if you have any questions.

Comments

Please click the forward arrow signs at the lower right corner of the screen to exit.

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Annex F. Evaluating map literacy in aerial photographs, 2D maps and 3D models – export of online survey

Welcome

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#QuestionText, TimingClickCount#: *0 clicks*

Browser Meta Info

This question will not be displayed to the recipient.

Browser: **Safari**

Version: **10.0**

Operating System: **Macintosh**

Screen Resolution: **1920x1080**

Flash Version: **-1**

Java Support: **1**

User Agent: **Mozilla/5.0 (Macintosh; Intel Mac OS X 10_12) AppleWebKit/602.1.50 (KHTML, like Gecko) Version/10.0 Safari/602.1.50**

Dear participant,

This survey documents map literacy of users when working with 2D and 3D geovisualizations. The goal of this experiment is to understand and evaluate the relevant aspects of digital map literacy. The results will contribute to the development of guidelines for the use of 2D maps and 3D models for planning of informal settlement upgrading in South Africa.

This study involves an anonymous survey. Your name will not appear on the questionnaire and the answers you give will be treated as strictly confidential. You

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cannot be identified in person based on the answers you give. (Note that consent cannot be withdrawn once the questionnaire is submitted as there is no way to trace the particular questionnaire that has been filled in).

Your participation in this study is very important to us. You may, however, choose not to participate and you may also stop participating at any time without any negative consequences. Please answer the questions in the questionnaire as completely and honestly as possible. This should not take more than 30 minutes of your time.

The results of the survey may be published in the media and/or an academic journal without identifying any of the participants individually. We will provide you with a summary of our findings on request.

Recommended screen resolution is 1280x720 or higher.

Please click the forward arrow signs at the lower right corner of the screen to continue.

Demography

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Click Count: *0 clicks*

Where did you hear about this survey?

- ○ Class or lecturer
- ○ Personal invitation

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- Mailing list
- Forwarded by a colleague or friend
- Other ______

Age

______

Gender

- Male
- Female

In which country do you reside?

- South Africa
- Other ______

Have you ever been told by a professional that you have imperfect color vision?

- Yes
- No

Please specify your occupation or, if you are a student, your degree program.

______

Which of the following best describes you:

- Architect (registered)
- GISc Technologist

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- Architect
- Spatial Planner (registered)
- Spatial Planner
- GISc Professional (registered)
- GISc Professional
- GISc Technologist (registered)
- GISc Technician (registered)
- GISc Technician
- Decision maker
- Student
- Citizen
- Other

Did you take geography at high school or university?

- Yes
- No

Please rate your level of training in the following categories:

	No training				Qualified
Cartography	○	○	○	○	○
Geography	○	○	○	○	○
GIS	○	○	○	○	○
Planning	○	○	○	○	○
Computer graphics	○	○	○	○	○

Please rate your level of experience in using:

	No experience				Everyday use
Topographic maps	○	○	○	○	○
Graphics of any					

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kind (maps, charts, etc.)	○	○	○	○	○
Spatial data of any kind (maps, digital elevation models, etc.)	○	○	○	○	○
Internet browsers	○	○	○	○	○
English	○	○	○	○	○

Familiarity with Alaska

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Click Count: *0 clicks*

Are you familiar with the informal settlement of Alaska in Mamelodi?

- ○ Yes
- ○ No

How many times have you visited the settlement (Alaska)?

- ○ Once
- ○ Less than five times
- ○ Less than ten but more than five times
- ○ Once a month
- ○ Once a week
- ○ Daily

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Video game experience

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Have you ever played video games?

- ◯ Yes
- ◯ No

Do you currently play video games?

- ◯ Yes
- ◯ No

Why don't you play video games?

- ☐ Cost
- ☐ Not interested
- ☐ Not enough time
- ☐ Lack of skill
- ☐ Not allowed
- ☐ Other ______

How long have you been playing video games?

- ◯ 6 months
- ◯ 1 year
- ◯ 2-5 years
- ◯ 5-10 years

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- 10 or more years

How often (approximately) do you currently play video games?

- daily
- weekly
- once a month
- once in 6 month
- once a year
- less than once a year or never

How good do you feel you are at playing video games?

- very good
- moderately good
- not very skilled
- no skill

What consoles do you own (if any)? Please list all.

If you do not own a console, how do you play?

- other friends that own
- online/internet
- arcade
- on my phone
- handheld

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- ○ other

What are your Top 3 (in order) genres, or video game categories, that you enjoy to play?

- ☐ Action
- ☐ Fighting
- ☐ First-person shooter
- ☐ Role-playing
- ☐ Massively Multiplayer Online Games
- ☐ Simulators
- ☐ Flight
- ☐ Racing
- ☐ Sports
- ☐ Military
- ☐ Space
- ☐ Strategy
- ☐ Strategy wargames
- ☐ Real-time strategy and turn-based strategy games
- ☐ Real-time tactical and turn-based tactical
- ☐ God games
- ☐ Pinball Economic simulation games
- ☐ City-building games
- ☐ Adventure
- ☐ Arcade
- ☐ Educational
- ☐ Maze
- ☐ Music
- ☐ Platform
- ☐ Puzzle
- ☐ Stealth
- ☐ Survival horror
- ☐ Vehicular combat
- ☐ Other

Would you be interested in playing video games in the future?

- ○ Yes
- ○ No

Metal rotation test - intro

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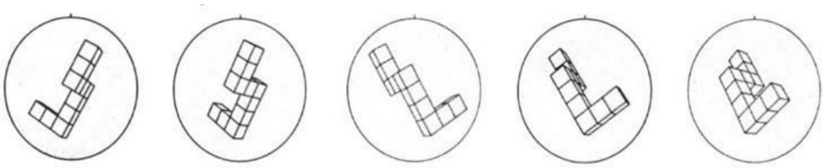
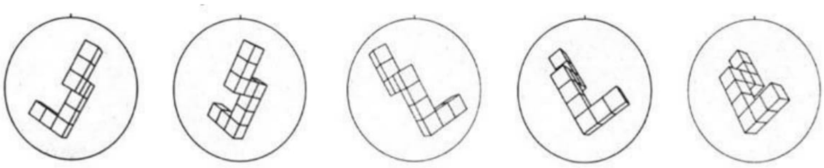
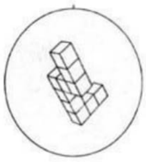
This page provides training for the first task.

Below, the same single object is given in 5 different positions. Please check for yourself that it is the same object only presented at different angles



Now check that the object at the bottom is NOT identical to the upper objects:





Now, you are to determine which 2 of the 4 objects to the right are identical to the object in the green circle. 2 objects are always identical and 2 are not. You are to mark the 2 identical objects. Below, the 2 identical objects are already marked. The other 2 are mirrored or different in another way. Please check the

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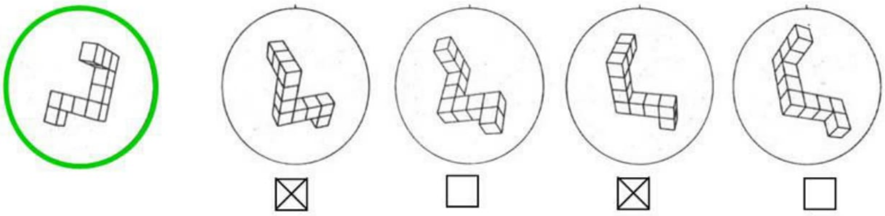
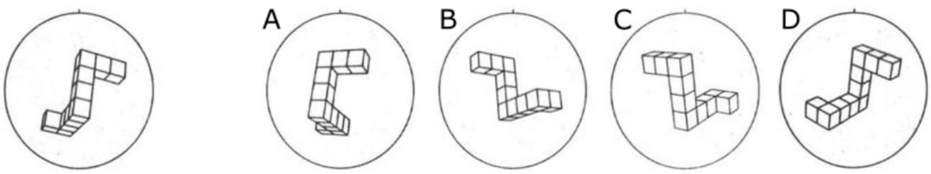
following images:



Now let's do a sample task

Choose the 2 objects that are identical to the figure on the left

- ☐ A
- ☐ B
- ☐ C
- ☐ D



Mental rotation test - info

In the next section, there are 20 questions. The questionnaire will automatically

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progress forward to the following section after 6 minutes. Please solve all the questions that you can within this 6-min limit. Remember that there are always TWO (and only two) correct answers per question.

Please click the forward arrow signs at the lower right corner of the screen to continue.

Mental rotation test

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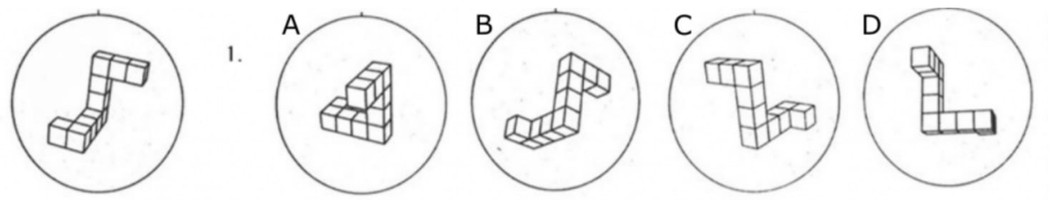
1. Choose the 2 objects that are identical to the figure on the left

- ☐ A
- ☐ B
- ☐ C
- ☐ D



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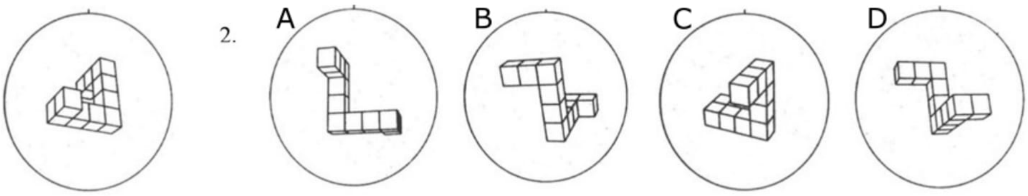
2. Choose the 2 objects that are identical to the figure on the left

- ☐ A
- ☐ B
- ☐ C
- ☐ D



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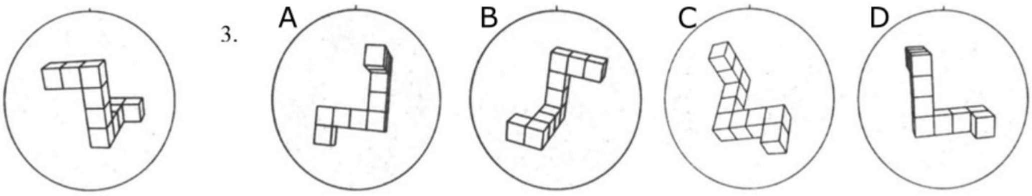
3. Choose the 2 objects that are identical to the figure on the left

- ☐ A
- ☐ B
- ☐ C
- ☐ D



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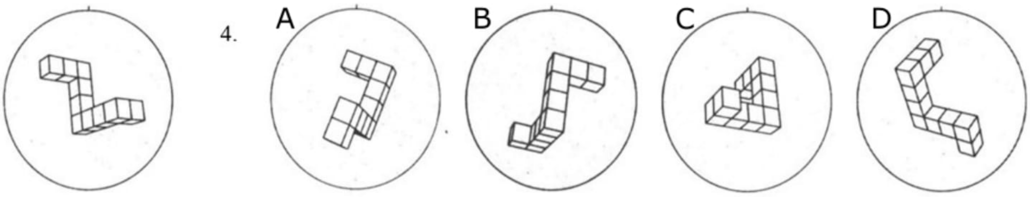
4. Choose the 2 objects that are identical to the figure on the left

- [ ] A
- [ ] B
- [ ] C
- [ ] D



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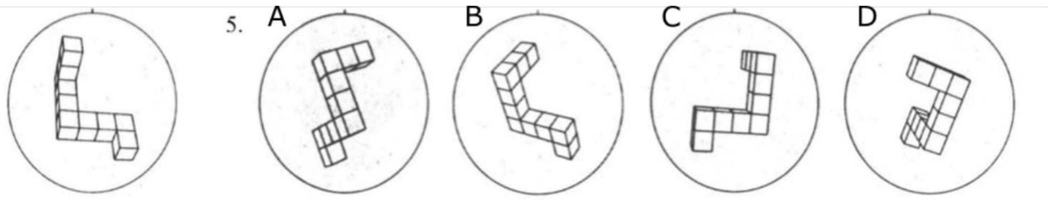
5. Choose the 2 objects that are identical to the figure on the left

- [ ] A
- [ ] B
- [ ] C
- [ ] D



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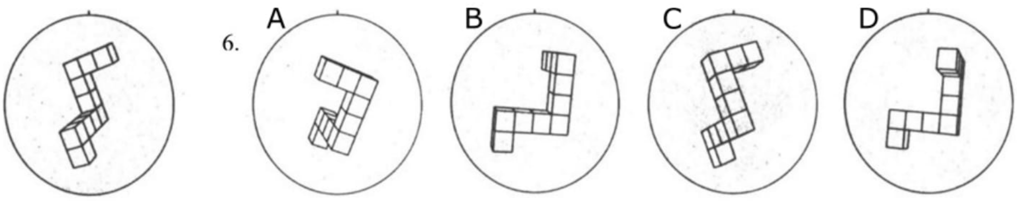
6. Choose the 2 objects that are identical to the figure on the left

- [ ] A
- [ ] B
- [ ] C
- [ ] D



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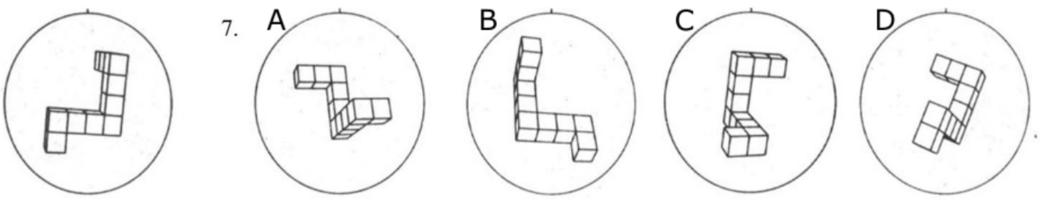
7. Choose the 2 objects that are identical to the figure on the left

- [ ] A
- [ ] B
- [ ] C
- [ ] D



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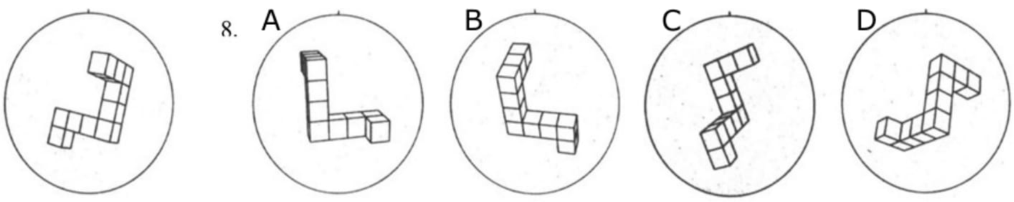
8. Choose the 2 objects that are identical to the figure on the left

- ☐ A
- ☐ B
- ☐ C
- ☐ D



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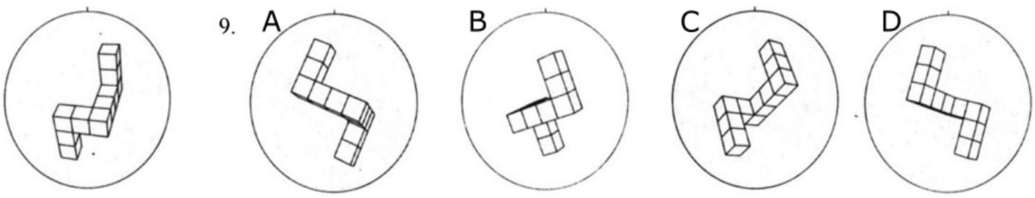
9. Choose the 2 objects that are identical to the figure on the left

- ☐ A
- ☐ B
- ☐ C
- ☐ D



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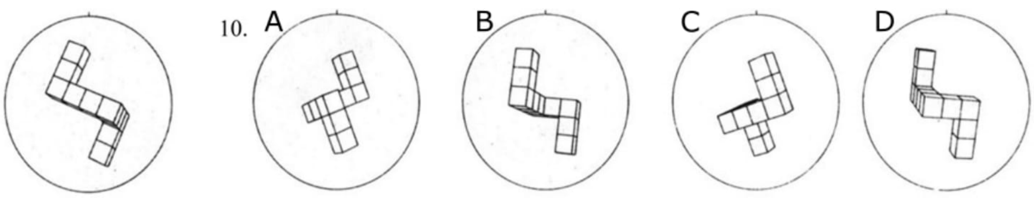
10. Choose the 2 objects that are identical to the figure on the left

- ☐ A
- ☐ B
- ☐ C
- ☐ D



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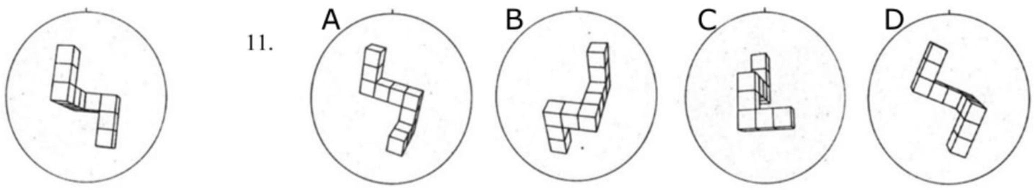
11. Choose the 2 objects that are identical to the figure on the left

- ☐ A
- ☐ B
- ☐ C
- ☐ D



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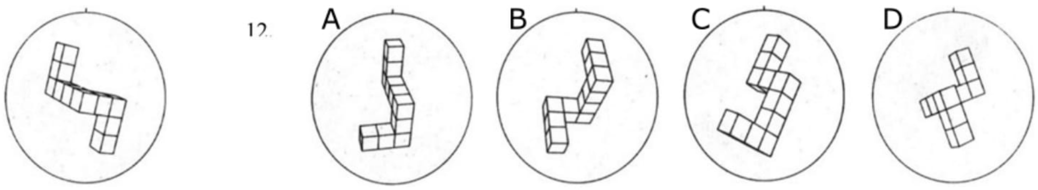
12. Choose the 2 objects that are identical to the figure on the left

- ☐ A
- ☐ B
- ☐ C
- ☐ D



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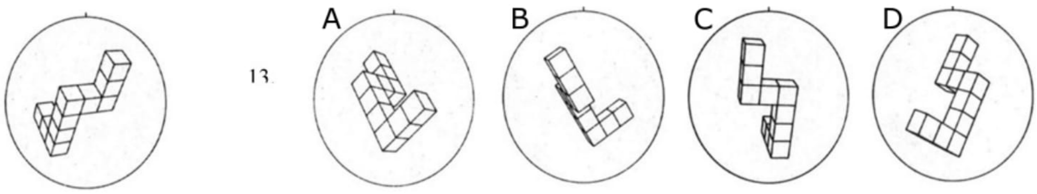
13. Choose the 2 objects that are identical to the figure on the left

- ☐ A
- ☐ B
- ☐ C
- ☐ D



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14. Choose the 2 objects that are identical to the figure on the left

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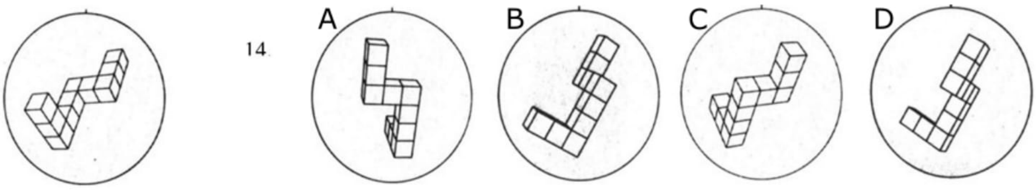
- [ ] A
- [ ] B
- [ ] C
- [ ] D



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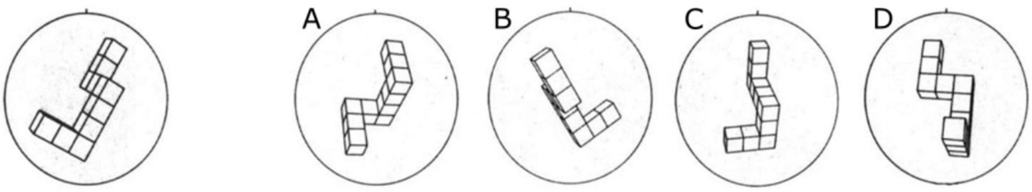
15. Choose the 2 objects that are identical to the figure on the left

- [ ] A
- [ ] B
- [ ] C
- [ ] D



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16. Choose the 2 objects that are identical to the figure on the left

- [ ] A

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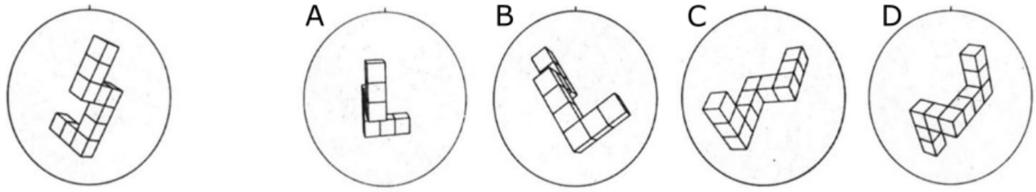
- [ ] B
- [ ] C
- [ ] D



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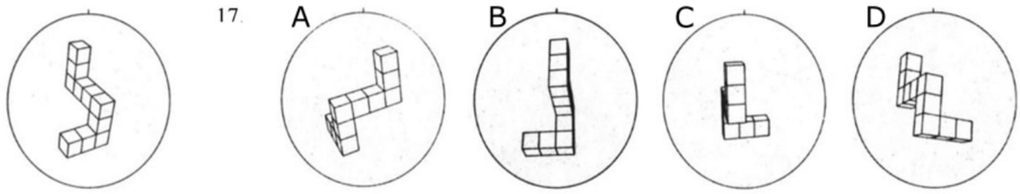
17. Choose the 2 objects that are identical to the figure on the left

- [ ] A
- [ ] B
- [ ] C
- [ ] D



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18. Choose the 2 objects that are identical to the figure on the left

- [ ] A
- [ ] B

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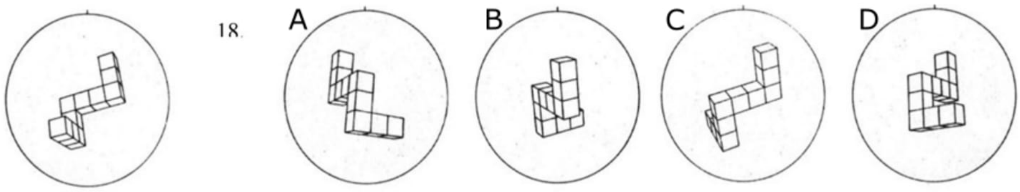
☐ C
☐ D



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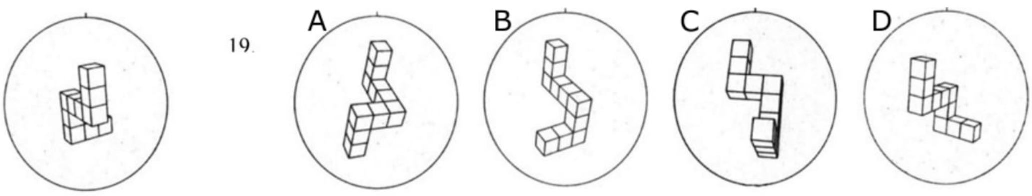
19. Choose the 2 objects that are identical to the figure on the left

☐ A
☐ B
☐ C
☐ D



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20. Choose the 2 objects that are identical to the figure on the left

☐ A
☐ B
☐ C

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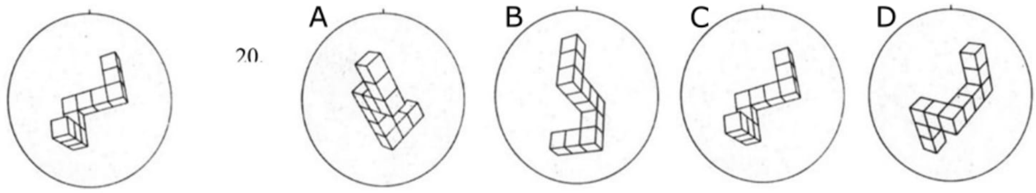
☐ D



Intro to next section

In the next section, you will be presented with various maps and asked to complete some map reading tasks.

Please click the forward arrow signs at the lower right corner of the screen to continue.

Question 3 - name the feature (1.1)

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Which of the following best describes the feature inside the red circle?

- ○ Footpath
- ○ Gravel road

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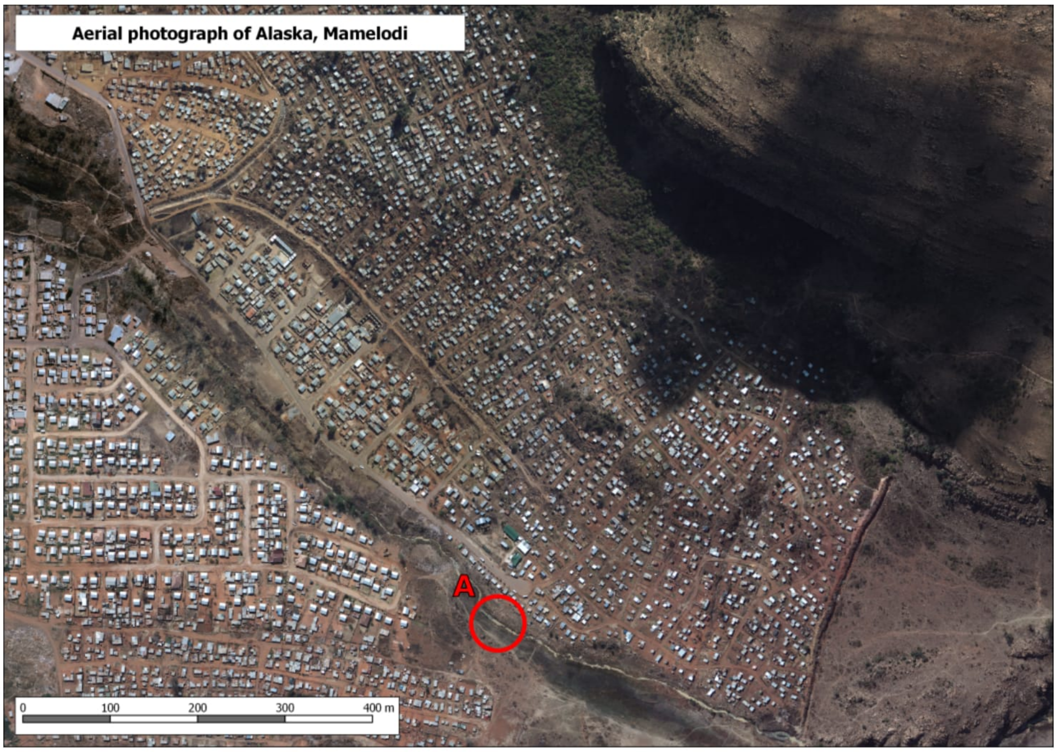
- River or stream
- Tar road
- Wetland



	0	10	20	30	40	50	60	70	80	90	100
Please indicate your confidence with this answer											

Question 4 - name the feature (1.1)

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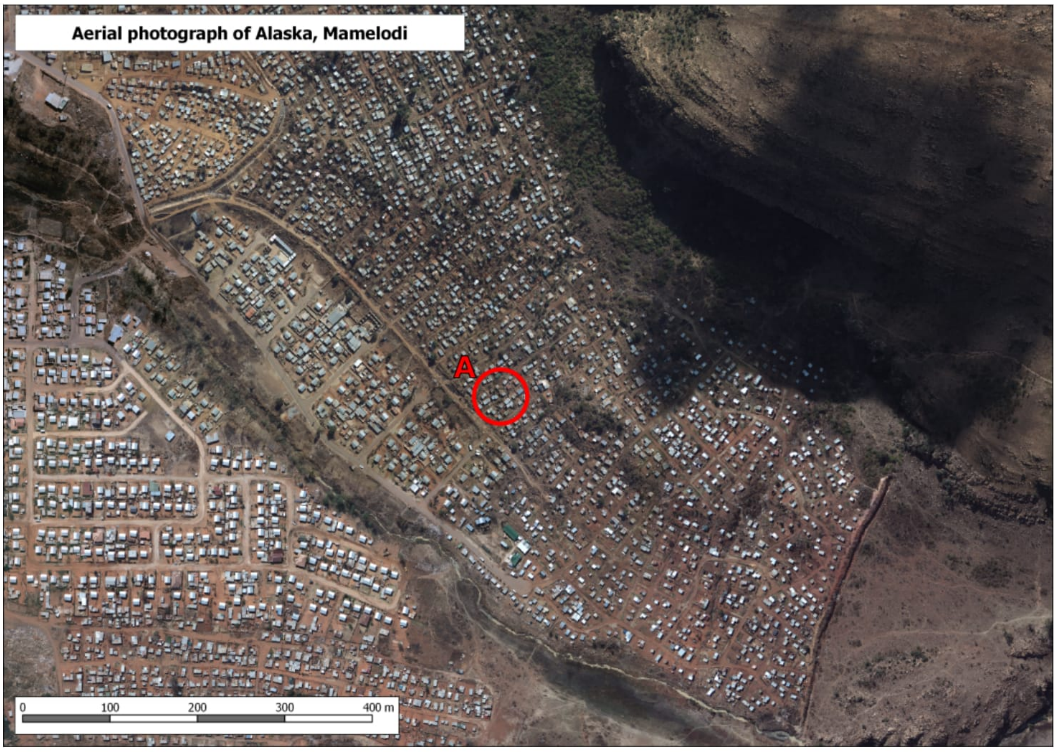
Last Click: *0 seconds*

Page Submit: *0 seconds*

Click Count: *0 clicks*

Which of the following best describes the feature inside the red circle?

- Formal dwelling
- Informal dwelling
- Land parcel
- RDP house
- Tuck shop



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	0	10	20	30	40	50	60	70	80	90	100
Please indicate your confidence with this answer											

Question 9 - difference btw features (1.2)

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Page Submit: *0 seconds*

Click Count: *0 clicks*

Which of the following best describes the features represented in A and B?

A

B

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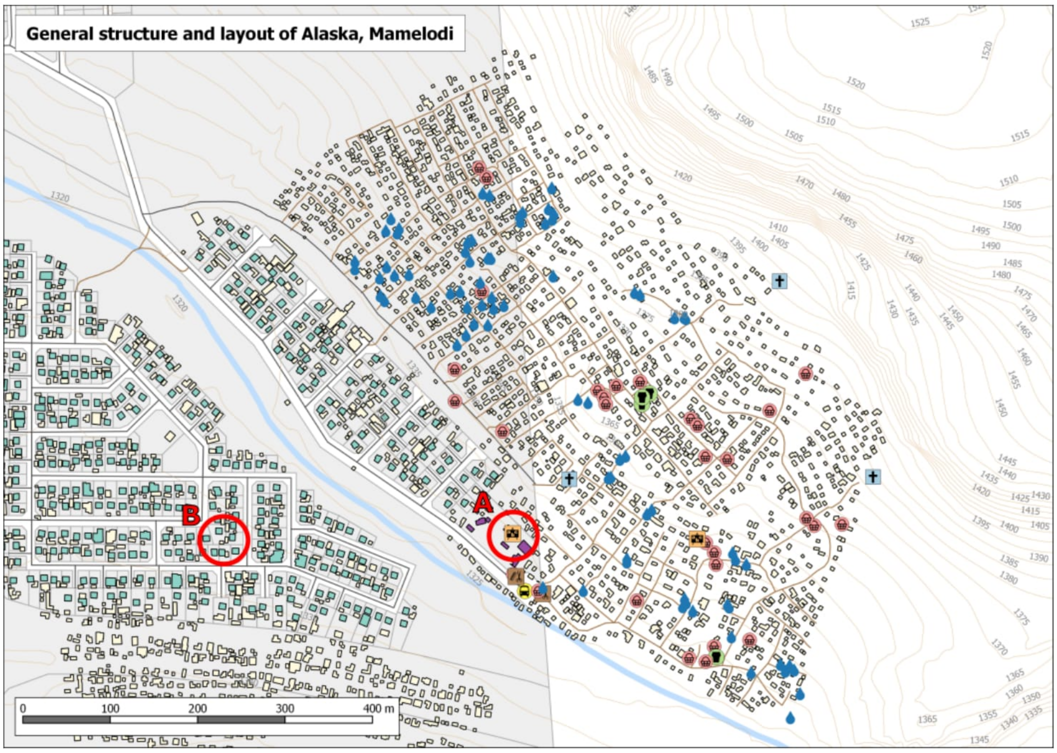

	0	10	20	30	40	50	60	70	80	90	100
Please indicate your confidence with this answer											

Question 14 - difference btw features (1.2)

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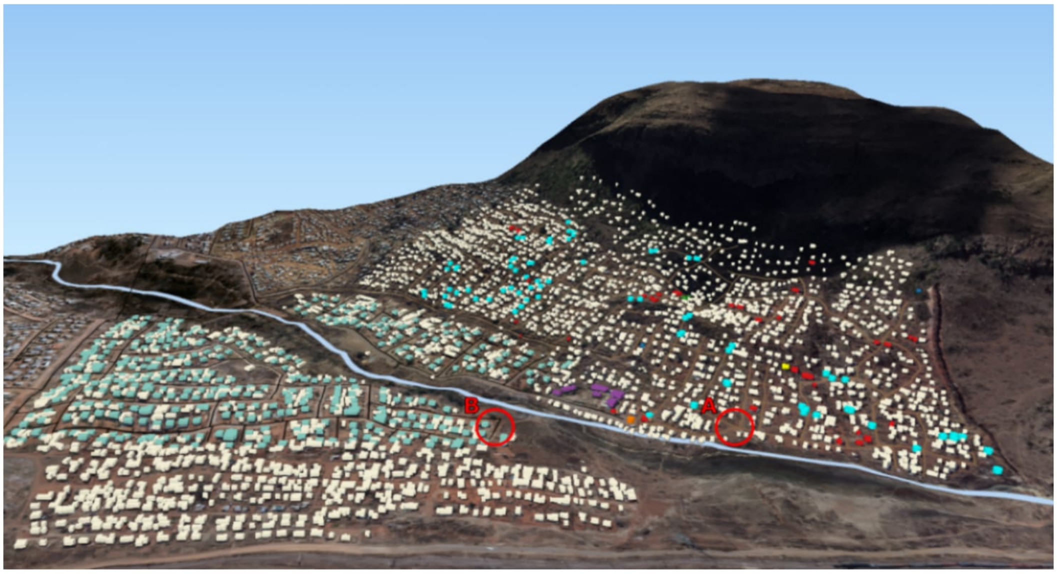
Which of the following best describes the features represented in A and B?

A

B



	0	10	20	30	40	50	60	70	80	90	100
Please indicate your confidence with this answer											

Question 17 - highest point (1.3)

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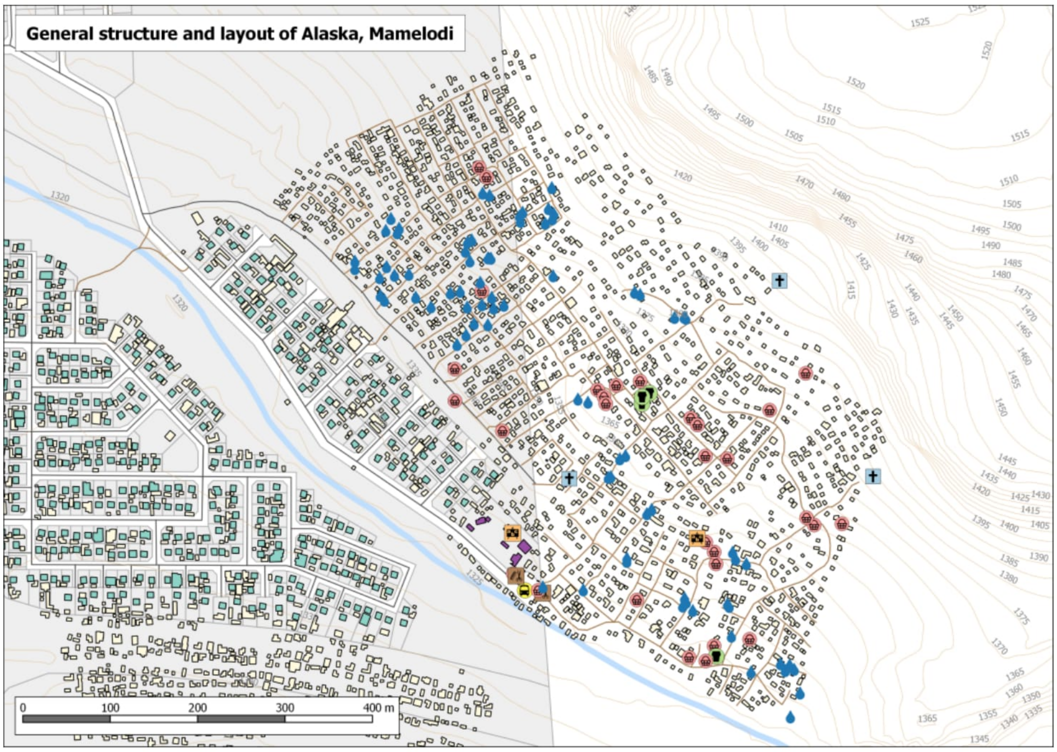
Indicate the highest point shown in the map below (click on the map).



0 10 20 30 40 50 60 70 80 90 100

Please indicate your

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confidence with this answer

Question 22 - lowest point (1.3)

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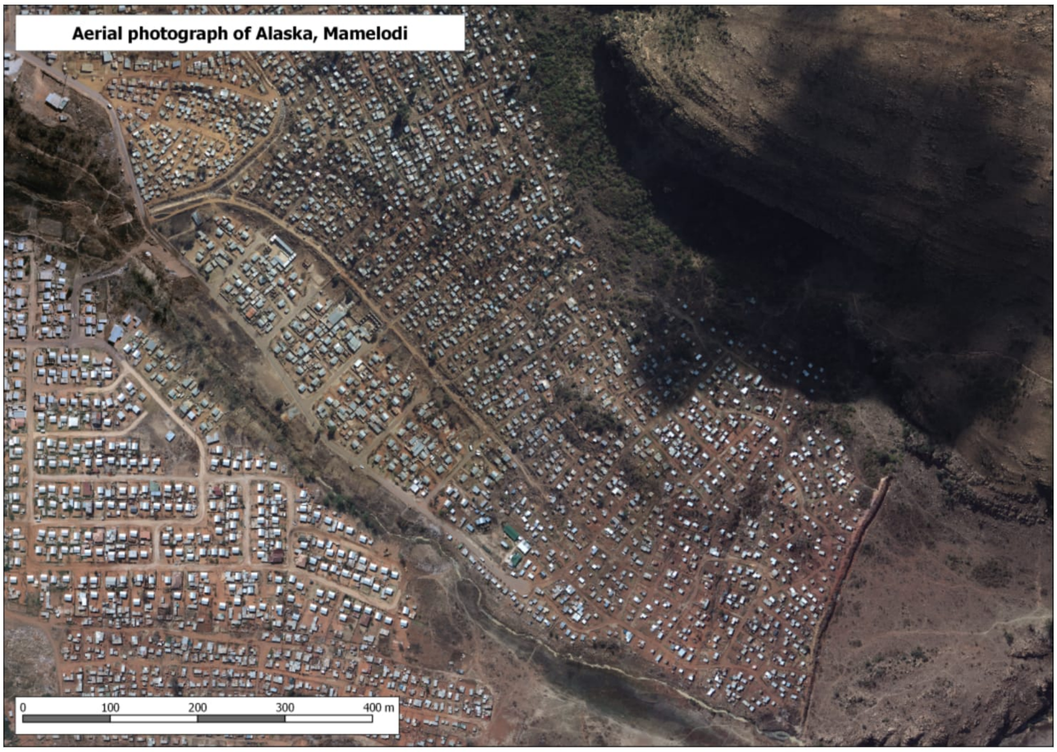
Indicate the lowest point shown in the map below (click on the map).



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	0	10	20	30	40	50	60	70	80	90	100
Please indicate your confidence with this answer											

Question 25 - steepest slope (4.1)

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Do you know and understand what slope is?

- Yes
- No

Slope is the change in elevation over a change in location, usually measured over some fixed interval, e.g. the change in height between two points 30 meters apart. Slope is usually reported as a percentage slope, or as a degree angle measured from horizontal.

In which area, A or B, is the slope the steeper?

- A
- B
- Slope is similar

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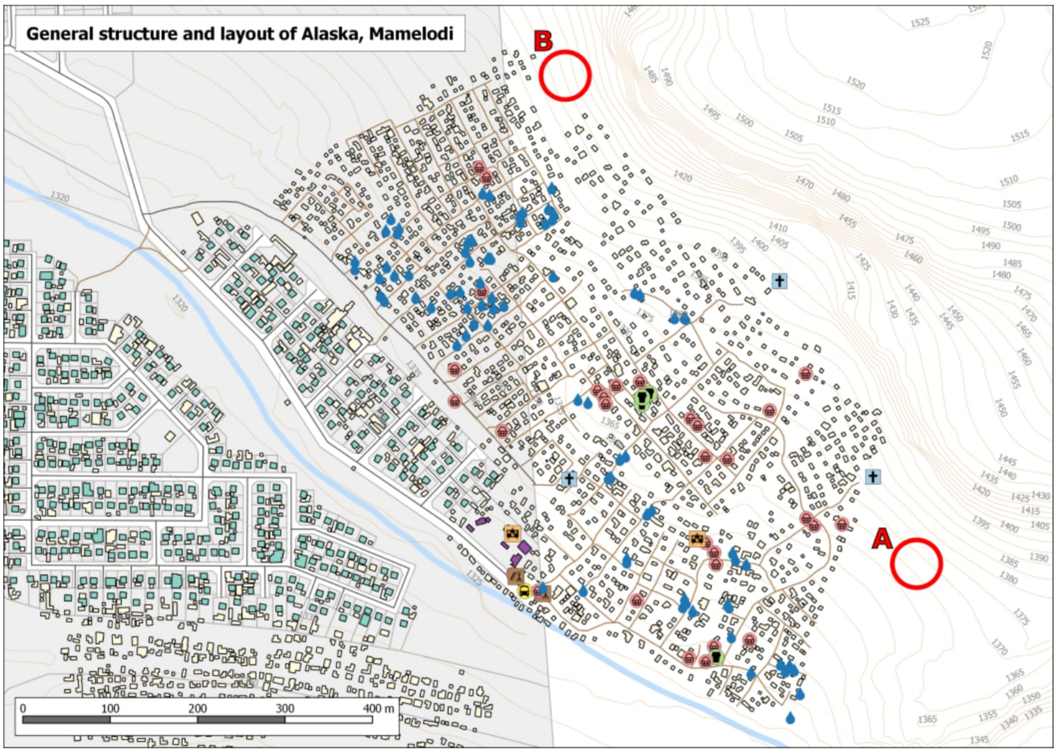

	0	10	20	30	40	50	60	70	80	90	100
Please indicate your confidence with this answer											

Question 19 - highest point (1.3)

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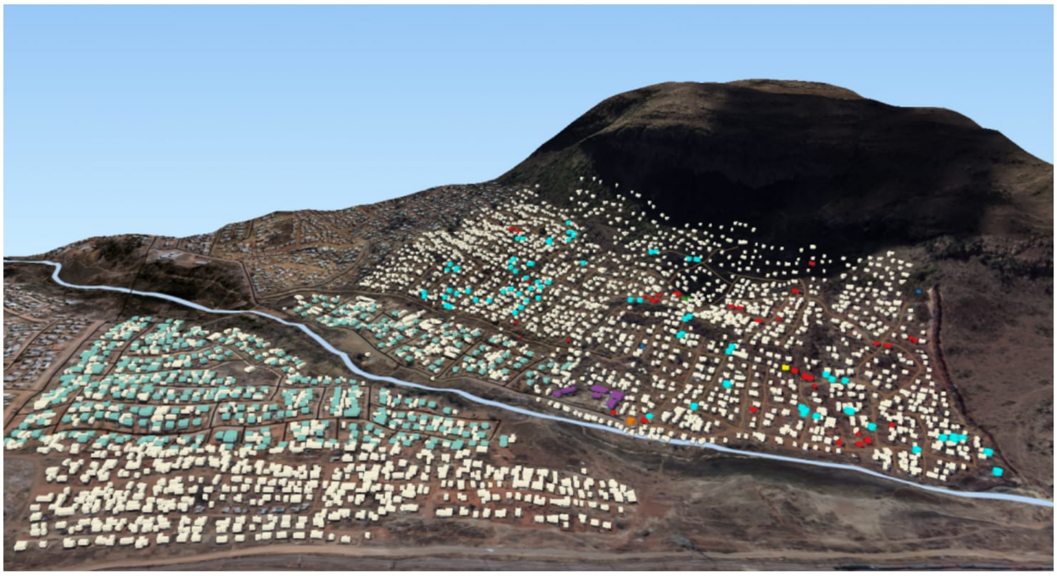
Indicate the highest point shown in the map below (click on the map).



	0	10	20	30	40	50	60	70	80	90	100
Please indicate your confidence with this answer											

Question 11 - difference btw features (1.2)

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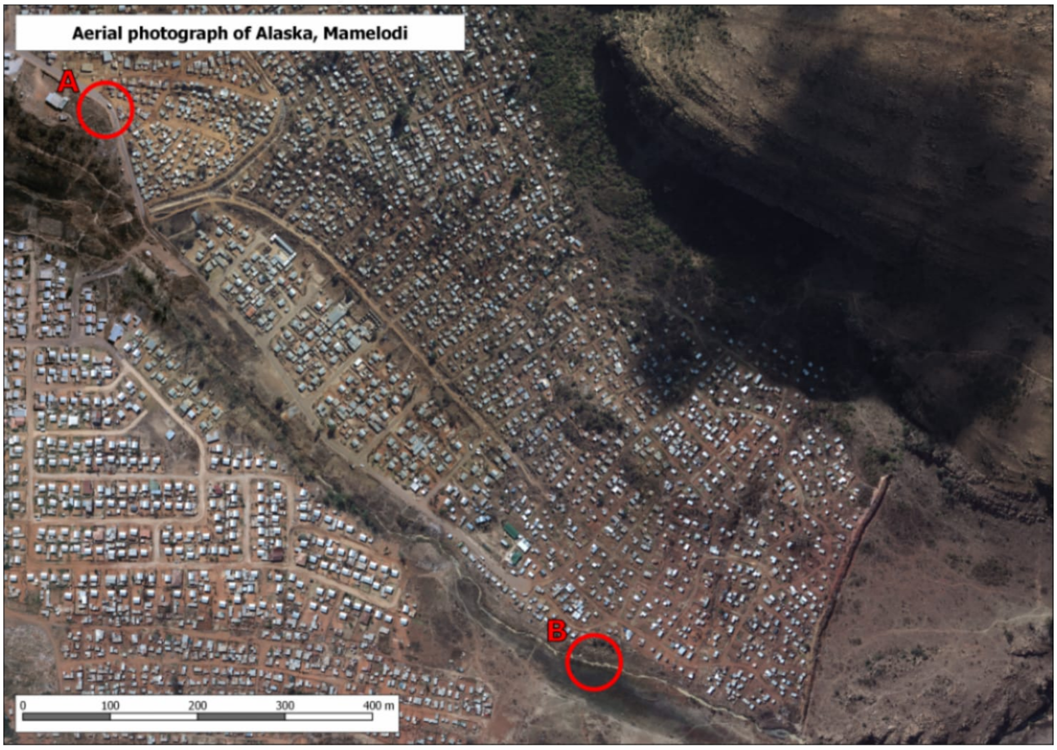
Which of the following best describes the features represented in A and B?

A

B



	0	10	20	30	40	50	60	70	80	90	100
Please indicate your confidence with this answer											

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Question 1 - name the feature (1.1)

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Which of the following best describes the feature inside the red circle?

- ◯ Formal dwelling
- ◯ Informal dwelling
- ◯ Land parcel
- ◯ RDP house
- ◯ Tuck shop

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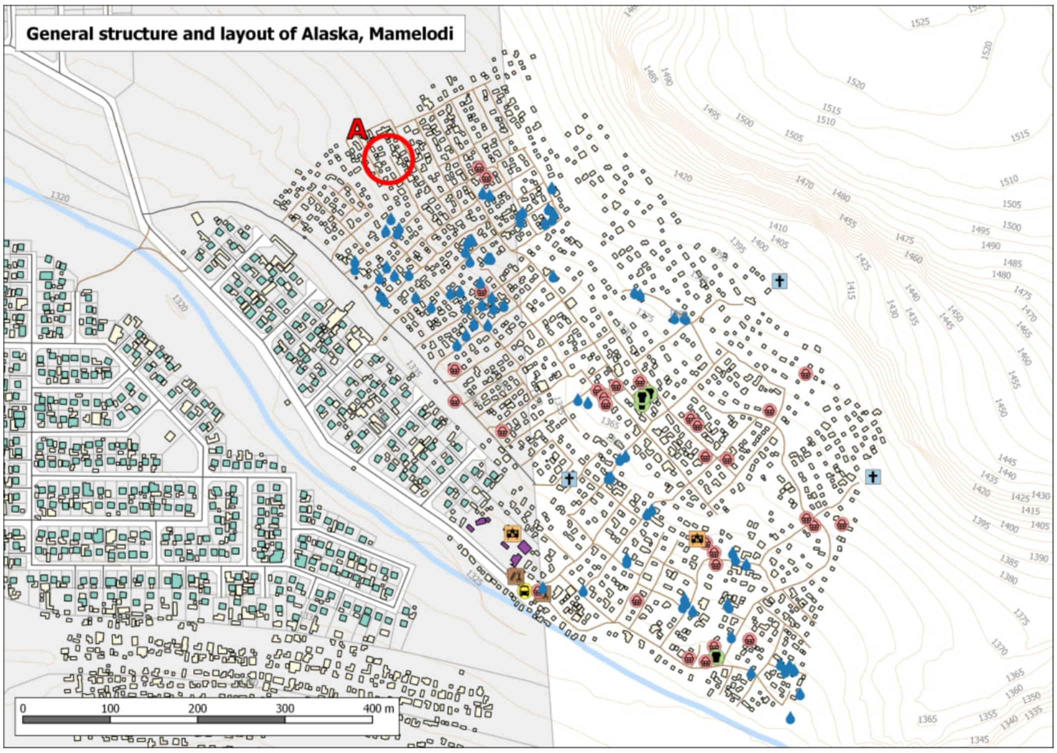

	0	10	20	30	40	50	60	70	80	90	100
Please indicate your confidence with this answer											

Question 30 - steepest slope (4.1)

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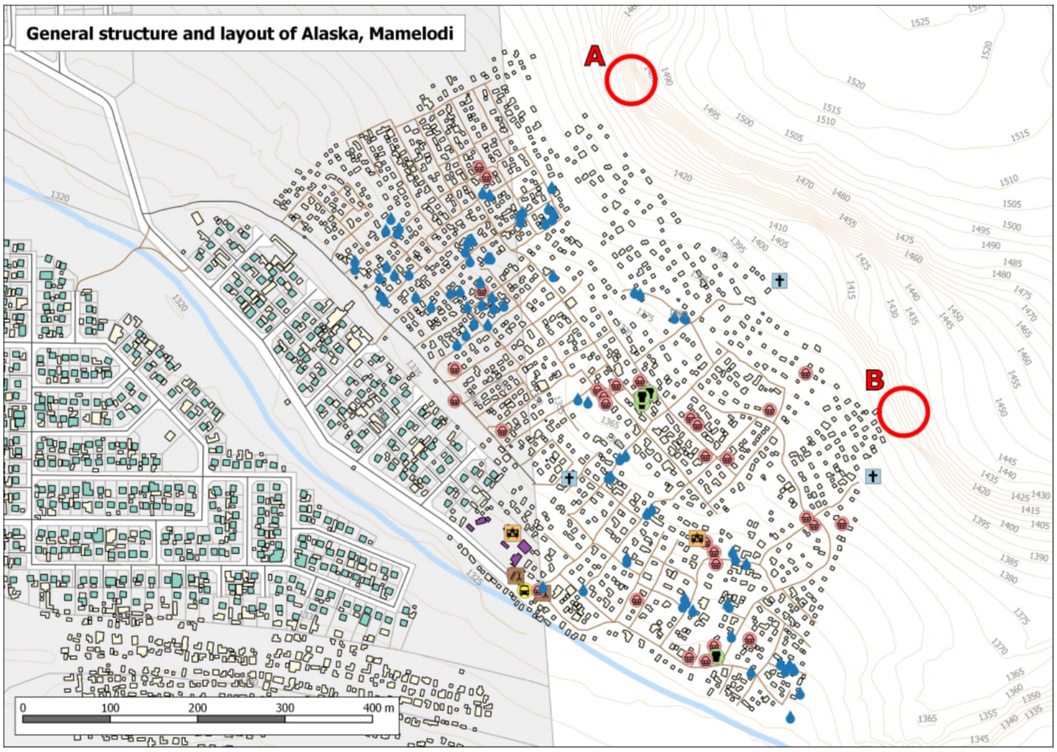
Click Count: *0 clicks*

Slope is the change in elevation over a change in location, usually measured over some fixed interval, e.g. the change in height between two points 30 meters apart. Slope is usually reported as a percentage slope, or as a degree angle measured from horizontal.

In which area, A or B, is the slope the steeper?

- A
- B
- Slope is similar



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	0	10	20	30	40	50	60	70	80	90	100
Please indicate your confidence with this answer											

Question 31 - steepest slope (4.1)

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In which area, A or B, is the slope the steeper?

- A
- B
- Slope is similar

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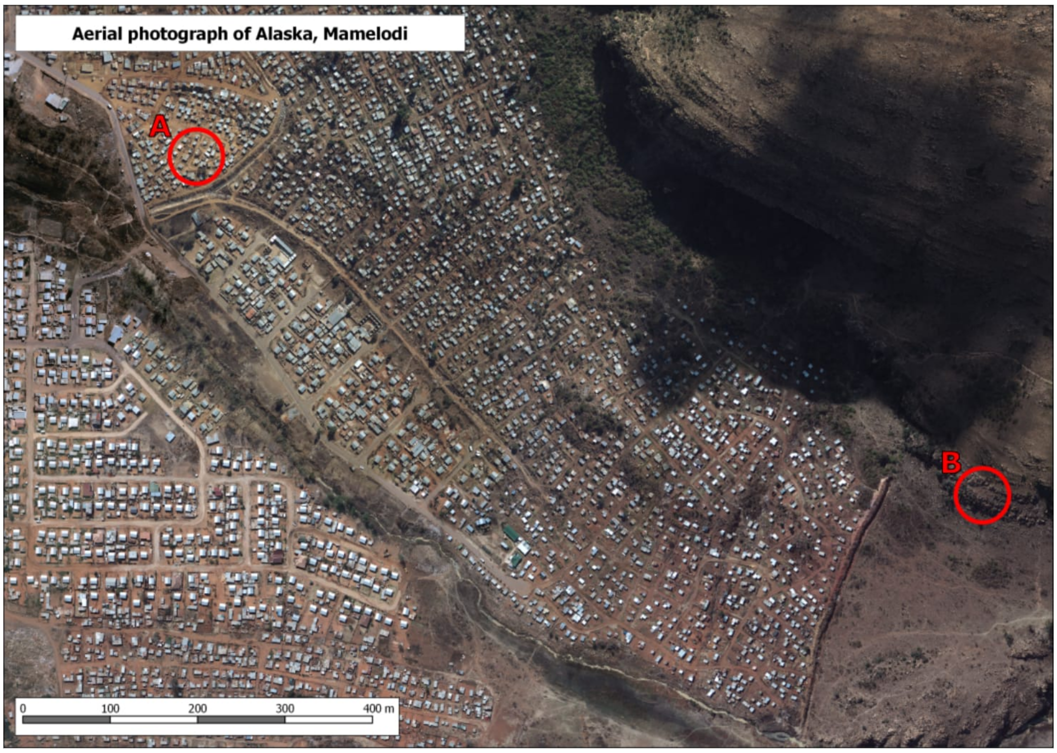

	0	10	20	30	40	50	60	70	80	90	100
Please indicate your confidence with this answer											

Question 32 - steepest slope (4.1)

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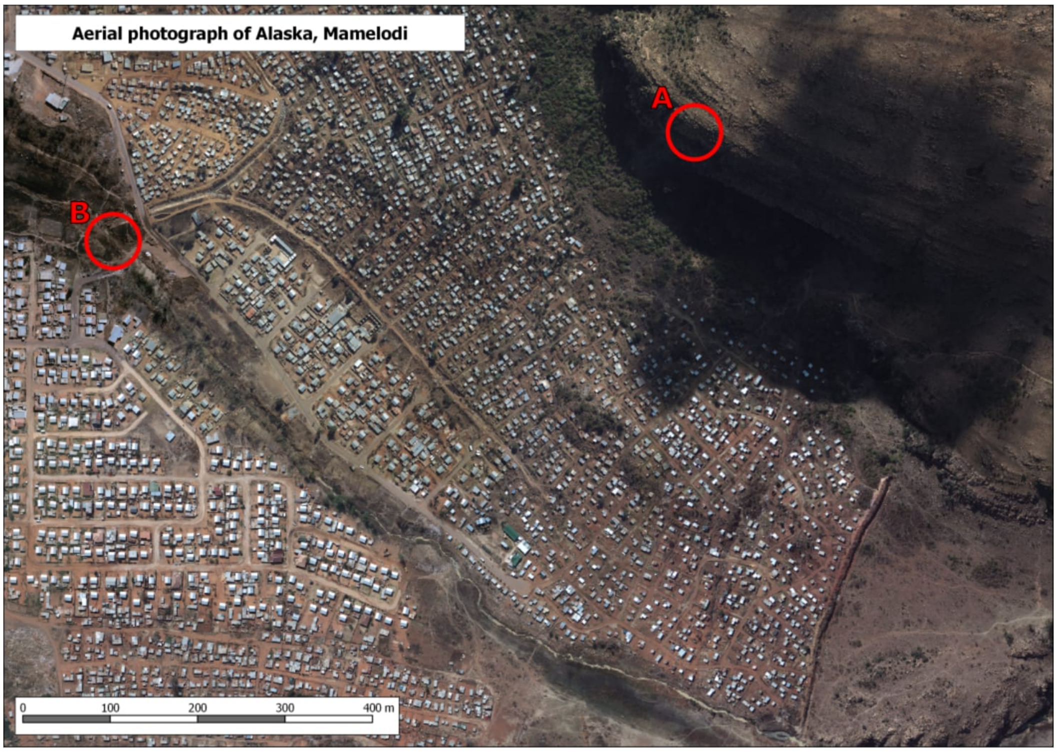
In which area, A or B, is the slope the steeper?

- ○ A
- ○ B
- ○ Slope is similar



	0	10	20	30	40	50	60	70	80	90	100
Please indicate your confidence with this answer											

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Question 33 - steepest slope (4.1)

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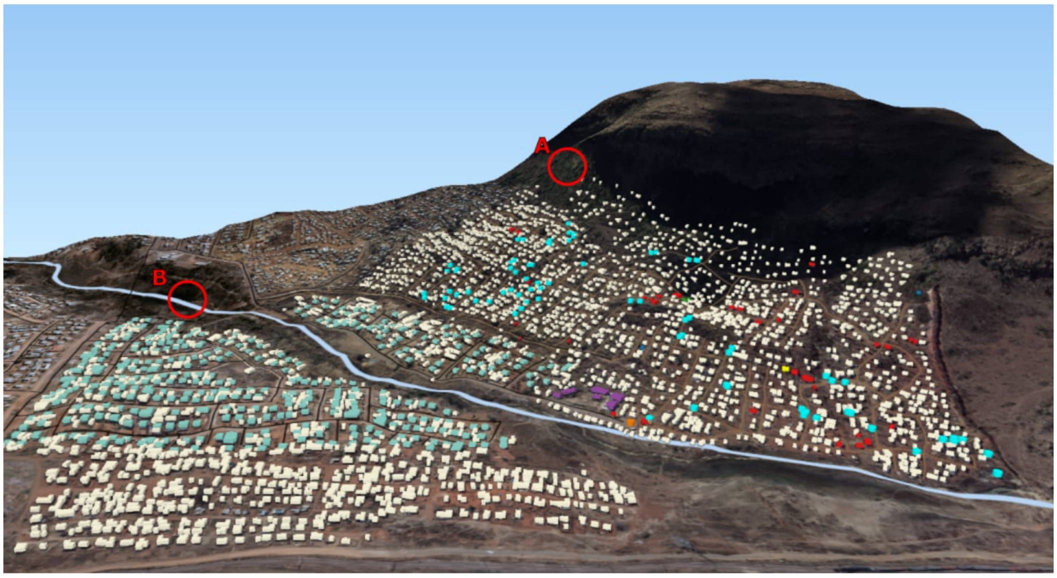
In which area, A or B, is the slope the steeper?

- A
- B
- Slope is similar



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	0	10	20	30	40	50	60	70	80	90	100
Please indicate your confidence with this answer											

Question 34 - steepest slope (4.1)

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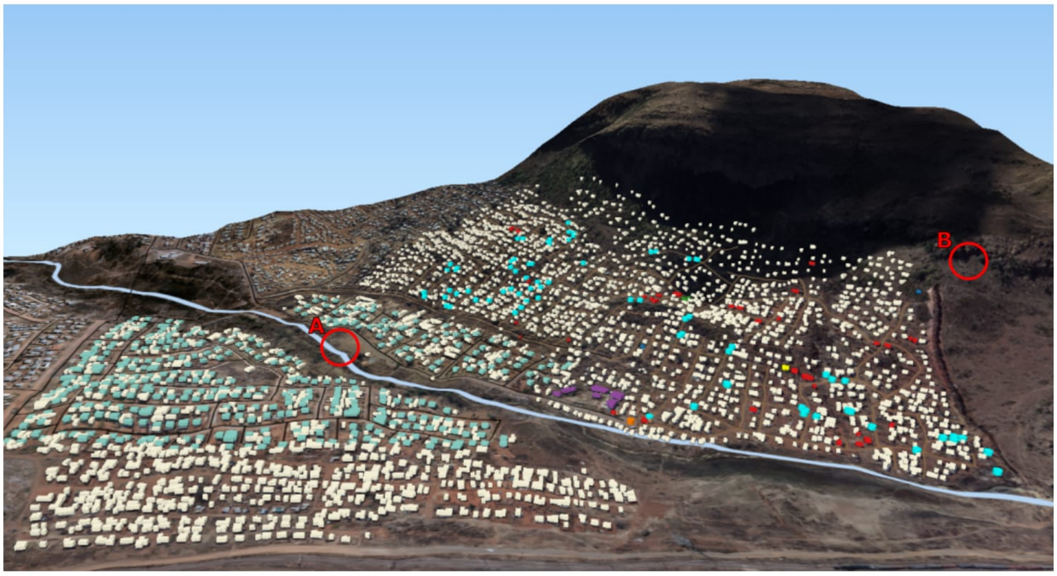
In which area, A or B, is the slope the steeper?

- A
- B
- Slope is similar



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	0	10	20	30	40	50	60	70	80	90	100
Please indicate your confidence with this answer											

Question 23 - lowest point (1.3)

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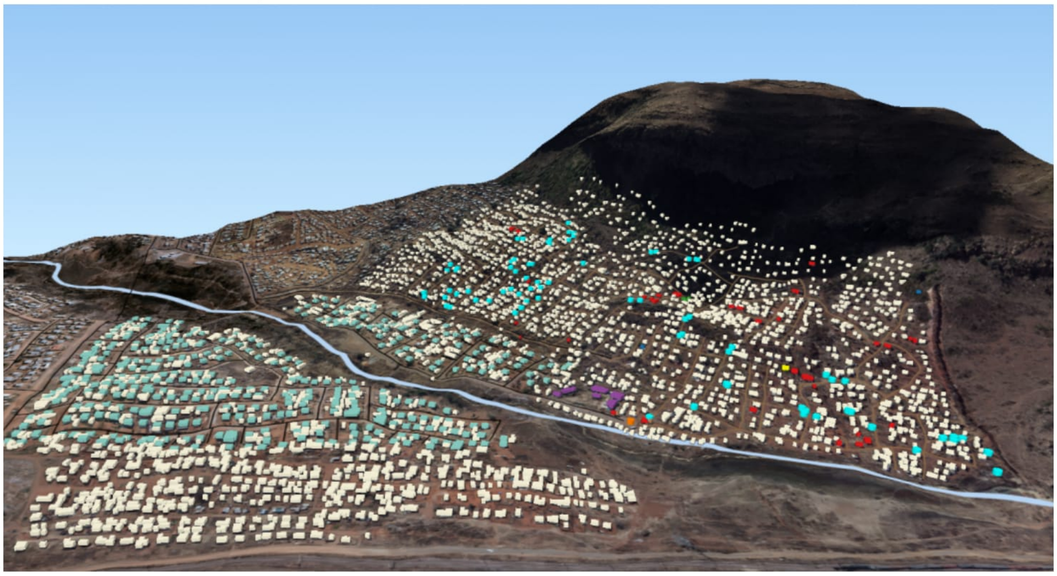
Indicate the lowest point shown in the map below (click on the map).



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	0	10	20	30	40	50	60	70	80	90	100
Please indicate your confidence with this answer											

Question 21 - lowest point (1.3)

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Indicate the lowest point shown in the map below (click on the map).

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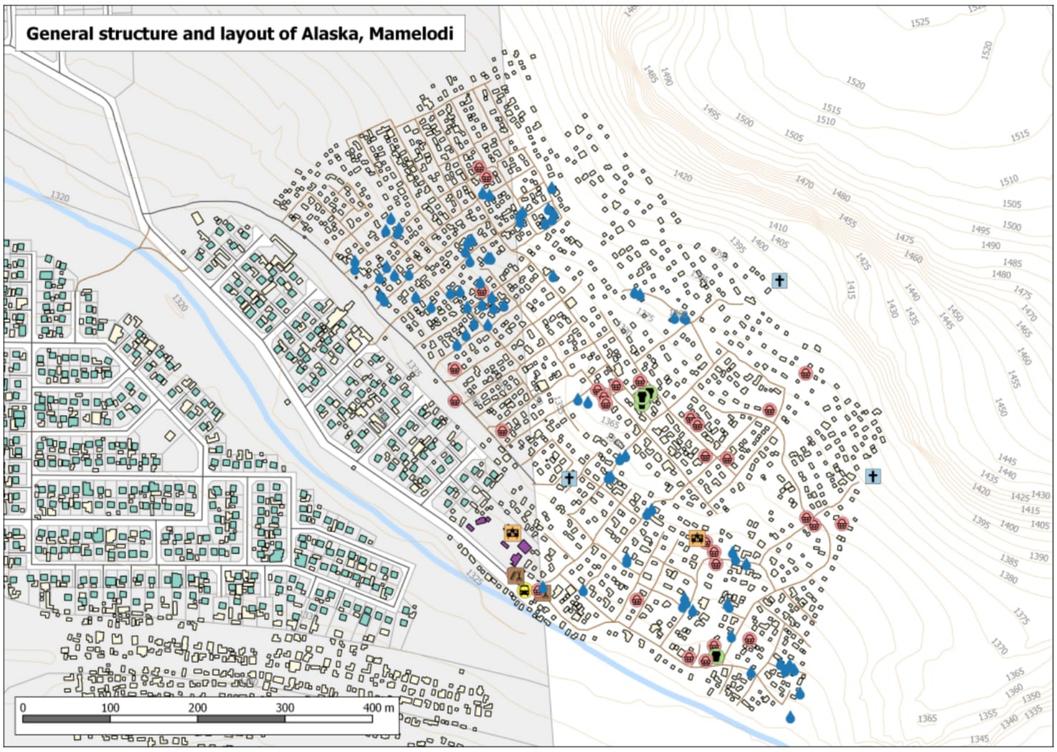

	0	10	20	30	40	50	60	70	80	90	100
Please indicate your confidence with this answer											

Question 18 - highest point (1.3)

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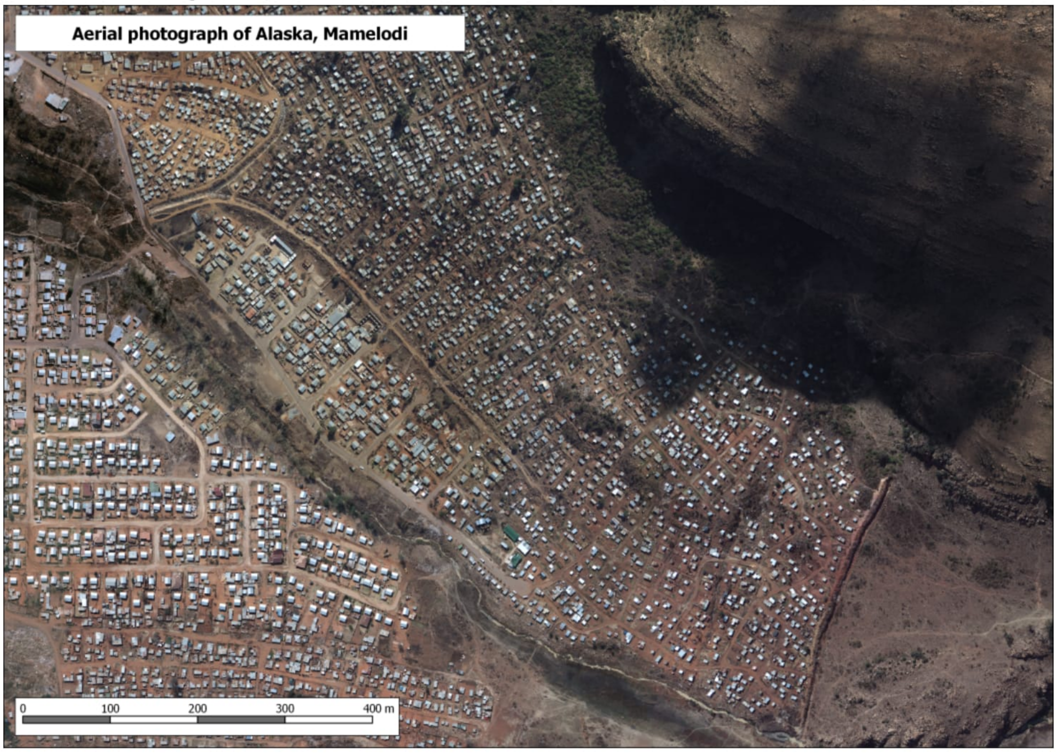
Indicate the highest point shown in the map below (click on the map).



	0	10	20	30	40	50	60	70	80	90	100
Please indicate your confidence with this answer											

Question 13 - difference btw features (1.2)

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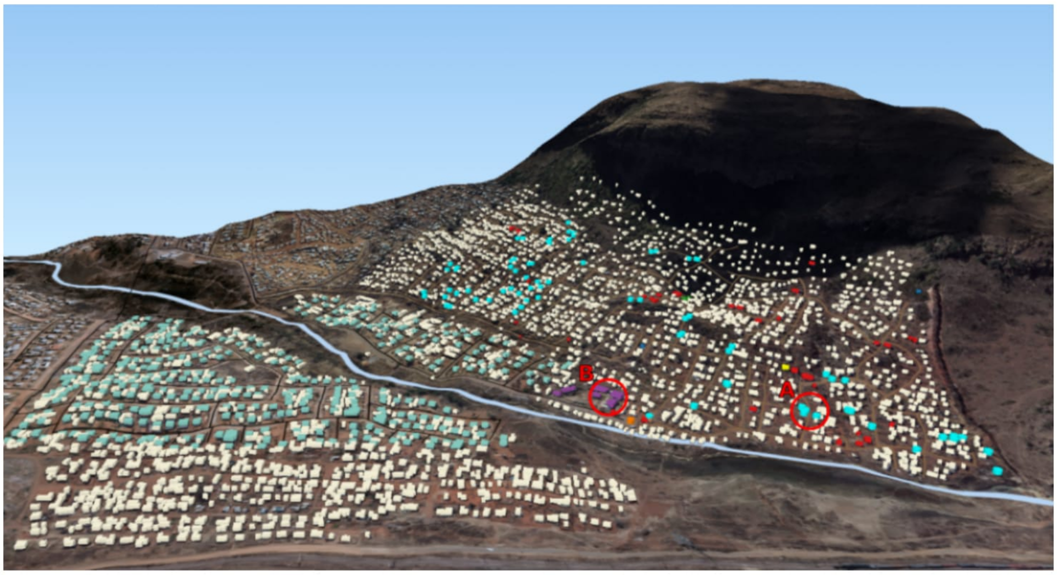
Which of the following best describes the features represented in A and B?

A

B



	0	10	20	30	40	50	60	70	80	90	100
Please indicate your confidence with this answer											

Question 12 - difference btw features (1.2)

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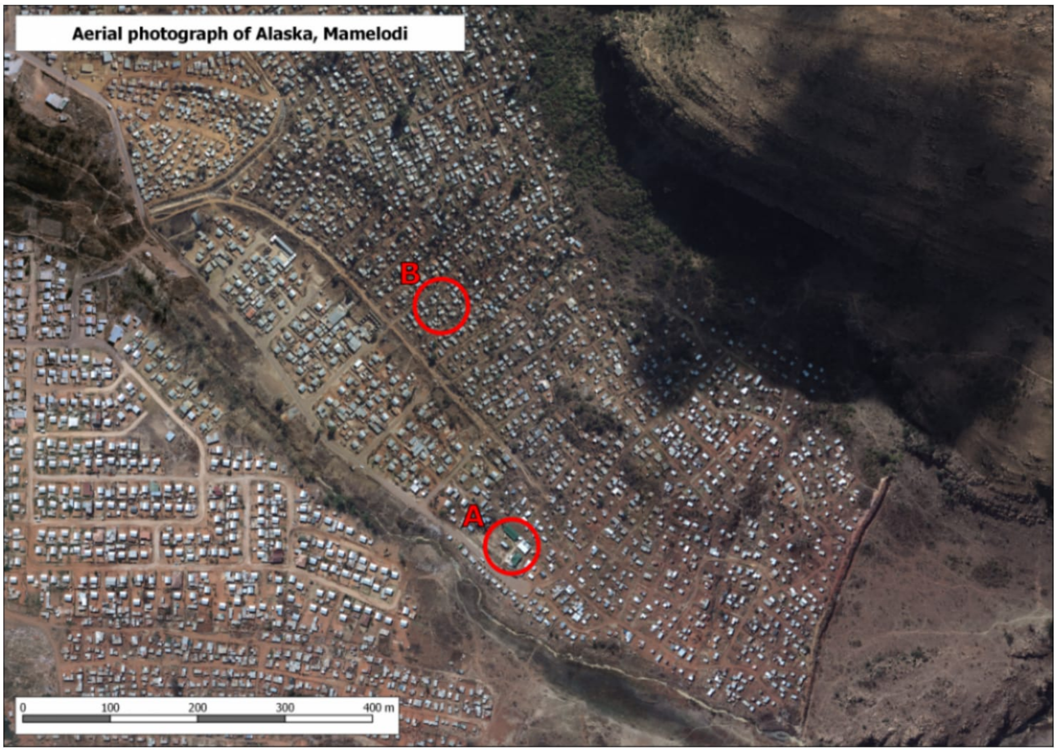
Which of the following best describes the features represented in A and B?

A

B



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	0	10	20	30	40	50	60	70	80	90	100
Please indicate your confidence with this answer											

Question 10 - difference btw features (1.2)

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Which of the following best describes the features represented in A and B?

A

B

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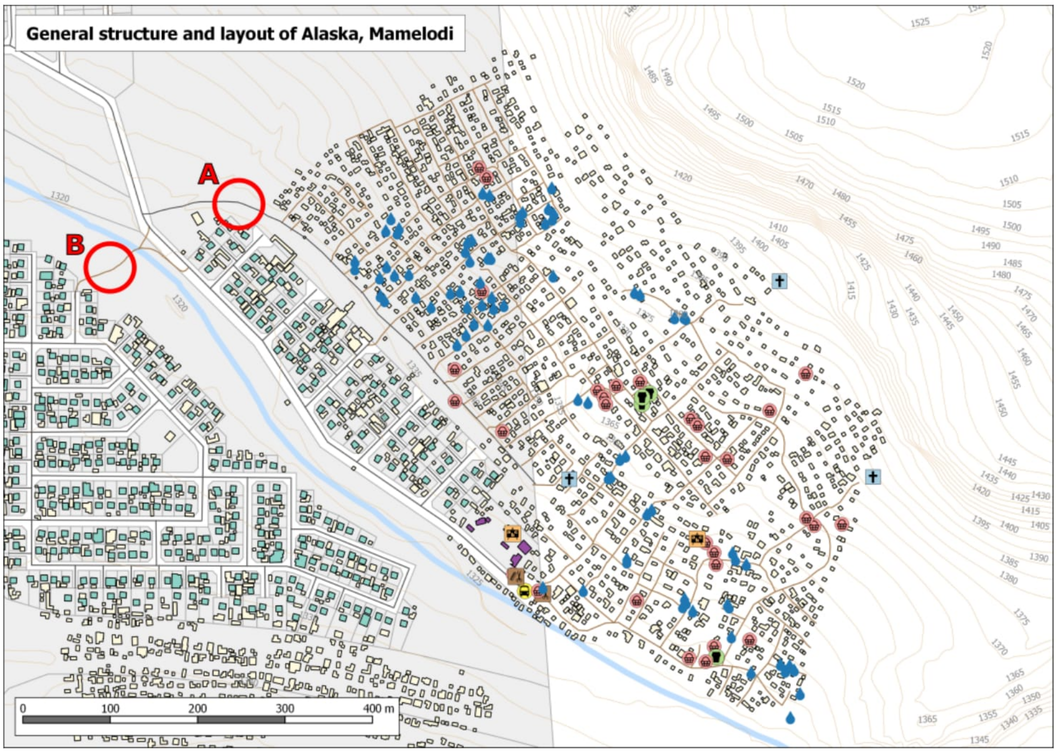

	0	10	20	30	40	50	60	70	80	90	100
Please indicate your confidence with this answer											

Question 6 - name the feature (1.1)

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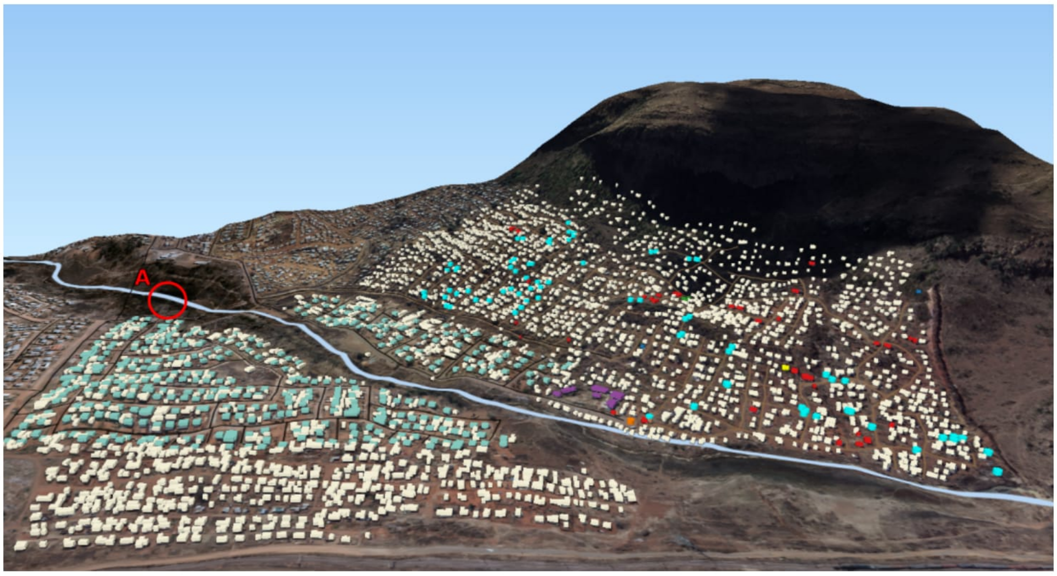
Which of the following best describes the feature inside the red circle?

- Footpath
- Gravel road
- Municipal border
- River or stream
- Wetland



	0	10	20	30	40	50	60	70	80	90	100
Please indicate your confidence with this answer											

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Question 5 - name the feature (1.1)

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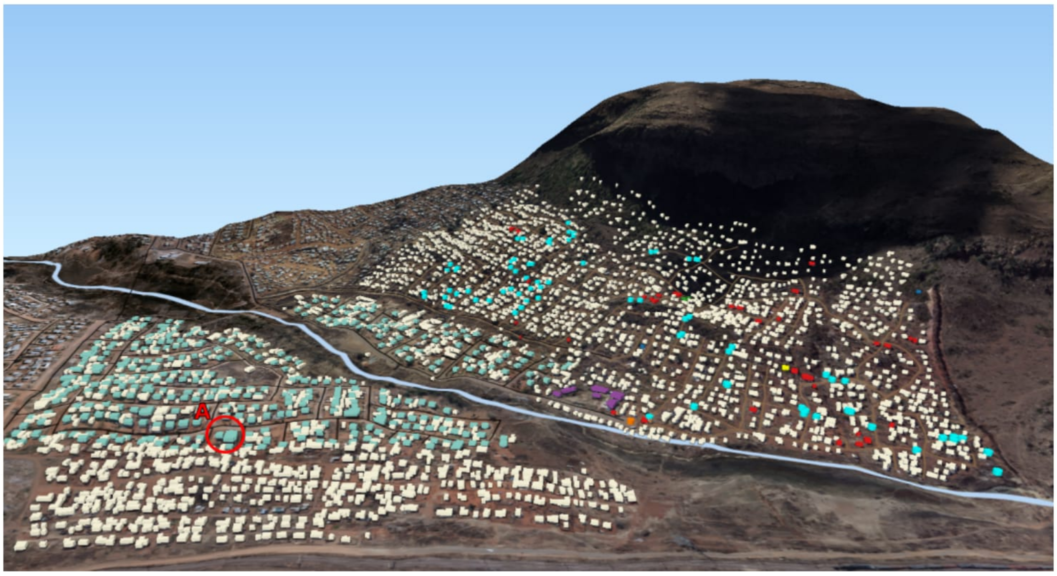
Which of the following best describes the feature inside the red circle?

- ○ Formal dwelling
- ○ Informal dwelling
- ○ Land parcel
- ○ RDP house
- ○ Tuck shop



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	0	10	20	30	40	50	60	70	80	90	100
Please indicate your confidence with this answer											

Question 2 - name the feature (1.1)

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Which of the following best describes the feature inside the red circle?

- ○ Borehole
- ○ Tap
- ○ Tavern
- ○ Tuck shop
- ○ Small lake

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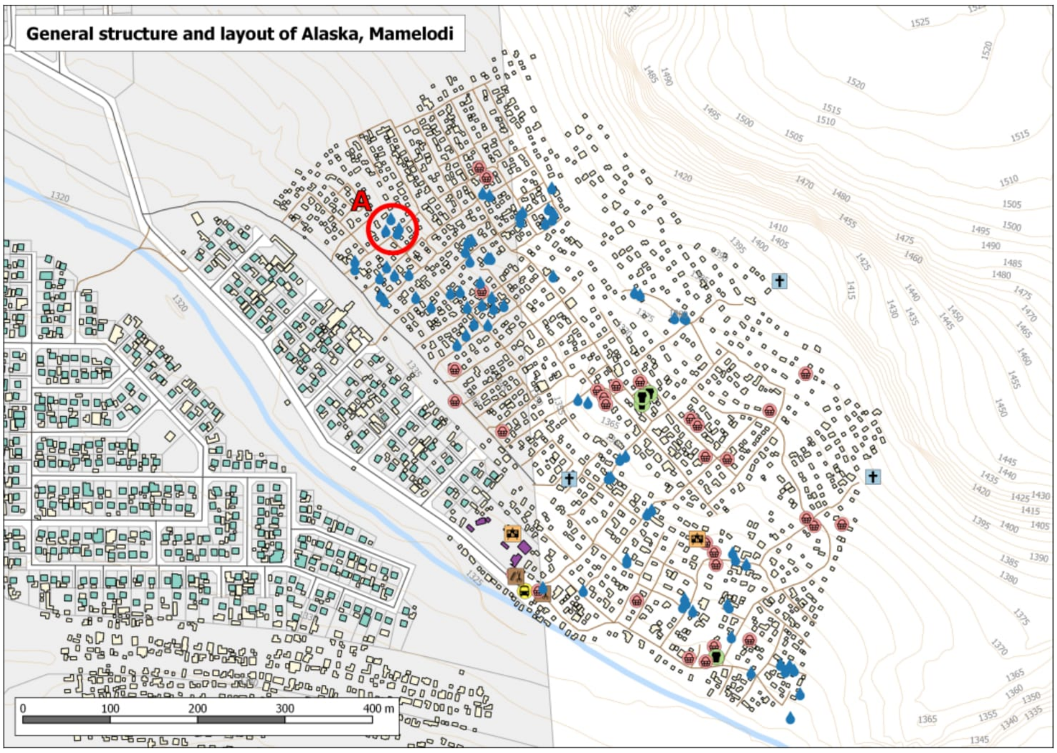

	0	10	20	30	40	50	60	70	80	90	100
Please indicate your confidence with this answer											

Thank you

Thank you for your participation.

Please contact Victoria Rautenbach (victoria.rautenbach@up.ac.za) if you have any questions.

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