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

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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 geovisualizations 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 geovisualization for planning in South Africa. Results will inform guidelines for the appropriate use of these non-traditional technologies for development planning.

1. 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 (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 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 (South Africa, 2013). The graphical representation has the goal to simplify the technical aspects, and assist non-technical stakeholder 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 visualizations. Bayram (2005) 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 & 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 platform for various spatial data (Hildebrandt & Döllner, 2009). Reportedly, 3D city models have been successfully used to communicate new planning developments in public participation projects (Chen, 2011, Isikdag & Zlatanova, 2010, Wu et al., 2010). 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, personal communication, November 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.

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 (NPC, 2012) which emphasises the need for instruments and capabilities needed for the effective spatial governance of development. The remainder of the paper is structured as follows: in Section 2 provides a brief background on map literacy and the planning process; in Section 3 the methodology is described; in Section 4 the preliminary results are presented and discussed; Section 5 presents the experiment design; Section 6 offers conclusions.

2. Background

2.1. Map literacy

A number of map reading skills are required to understand and interpret a map. Board (1975) defined three main groups of map reading actions, namely: navigation, measurement, and visualization. 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 1. He suggested that these complex map reading tasks can be broken down into elementary task, and that we use a combination of these elementary tasks to complete an action.

Table 1. 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	

2.2. 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 & 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 organizations. 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.

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 (Paar & Rekittke, 2011, Chirowodza et al., 2009). 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 geovisualizations can have a negative effect on this process.

3. Methodology

3.1. 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 (Morgan, 1998, Kitzinger, 1995, Courage & Baxter, 2005). 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, 2008).

3.2. Study design

A within-subject participant assignment was used, meaning that all participants were assigned the same questions (Martin, 2008). 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 impediment. The learning effect is present if participants’ behaviour is affected by exposure to earlier levels of the manipulated variable (independent variable) (Martin, 2008).

An independent variable is an element/variable that is manipulated during the experiment (Martin, 2008). 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 geovisualization*, namely, 2D maps, 3D non-photorealistic landscapes, and 3D realistic city models (e.g. Figure 1, 2 and 3). 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 2) 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 3.2). 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.

3.3. 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 1 for an example).

Figure 1. Land use map of central Pretoria, South Africa

The Ordnance Survey Minecraft[1] 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 2). The Philadelphia redevelopment 3D model was used for the 3D realistic city models. The model was developed using ESRI CityEngine[2], and the model is freely available for download (ESRI, 2012).

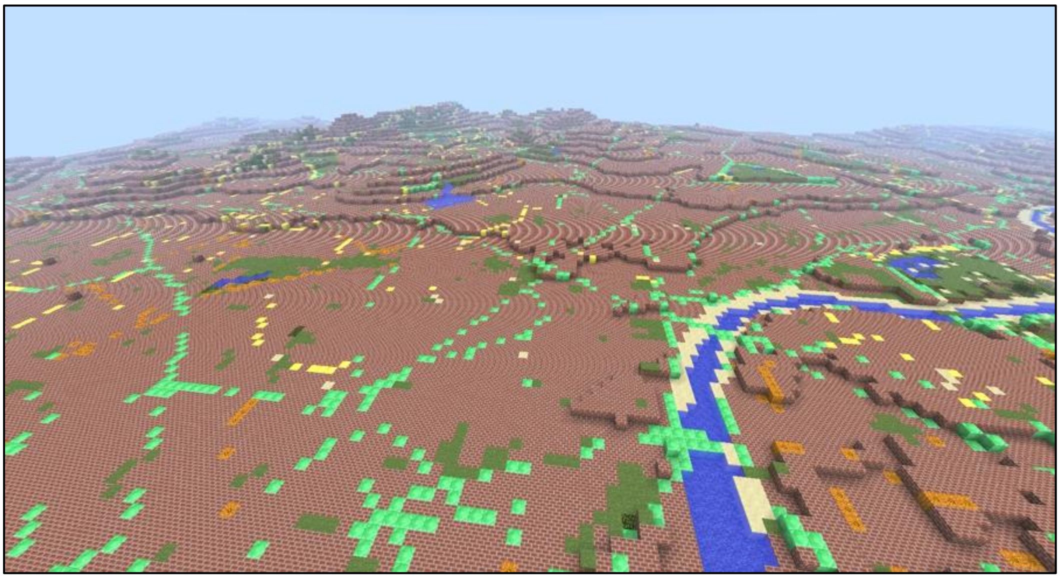

Figure 2. Minecraft model of London, United Kingdom. Courtesy of Ordnance Survey (2013)

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

[1] https://minecraft.net/
[2] http://www.esri.com/software/cityengine

4. Results and discussion

In this section the preliminary results of the experiment are presented and discussed. Twenty-one University of Pretoria undergraduate students (ten males, eleven 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. The graph is depicted in Figure 4.

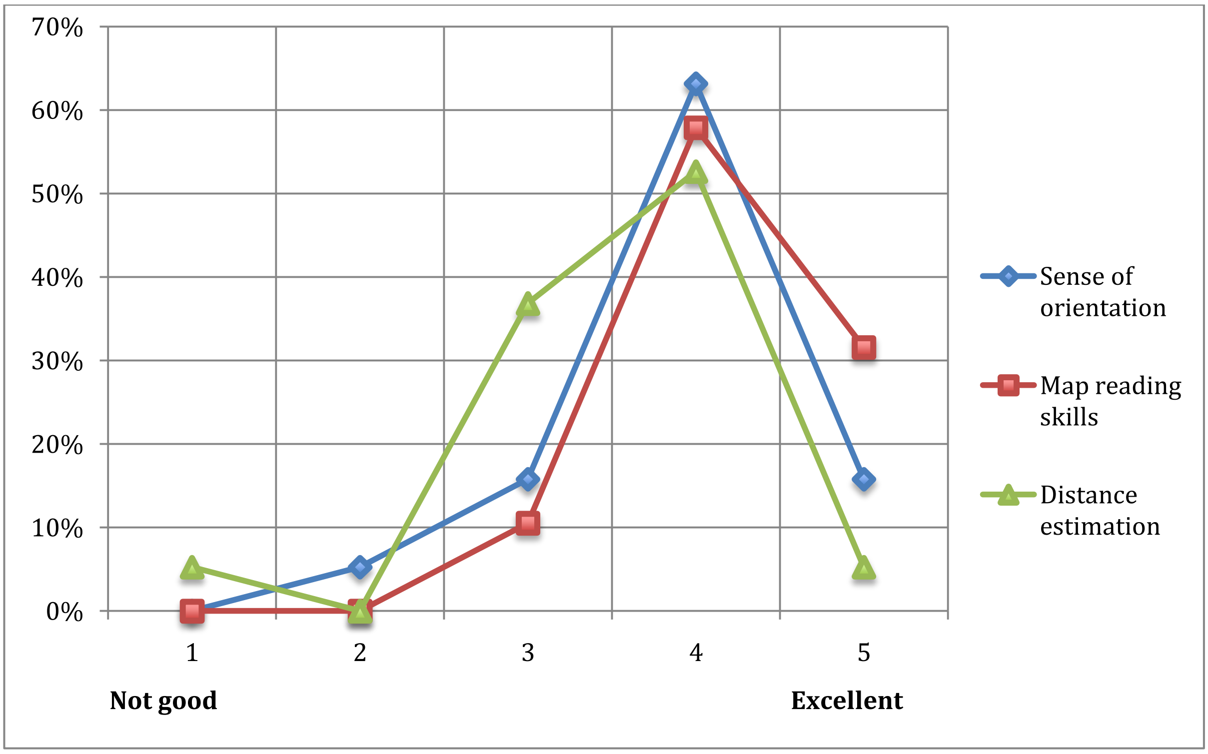

Figure 4. Participants' self-evaluated map reading skills

For all tasks, the participants were exposed to 6 maps and models (two for each type of stimuli). The results are summarised in Figure 5 and 6. 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.

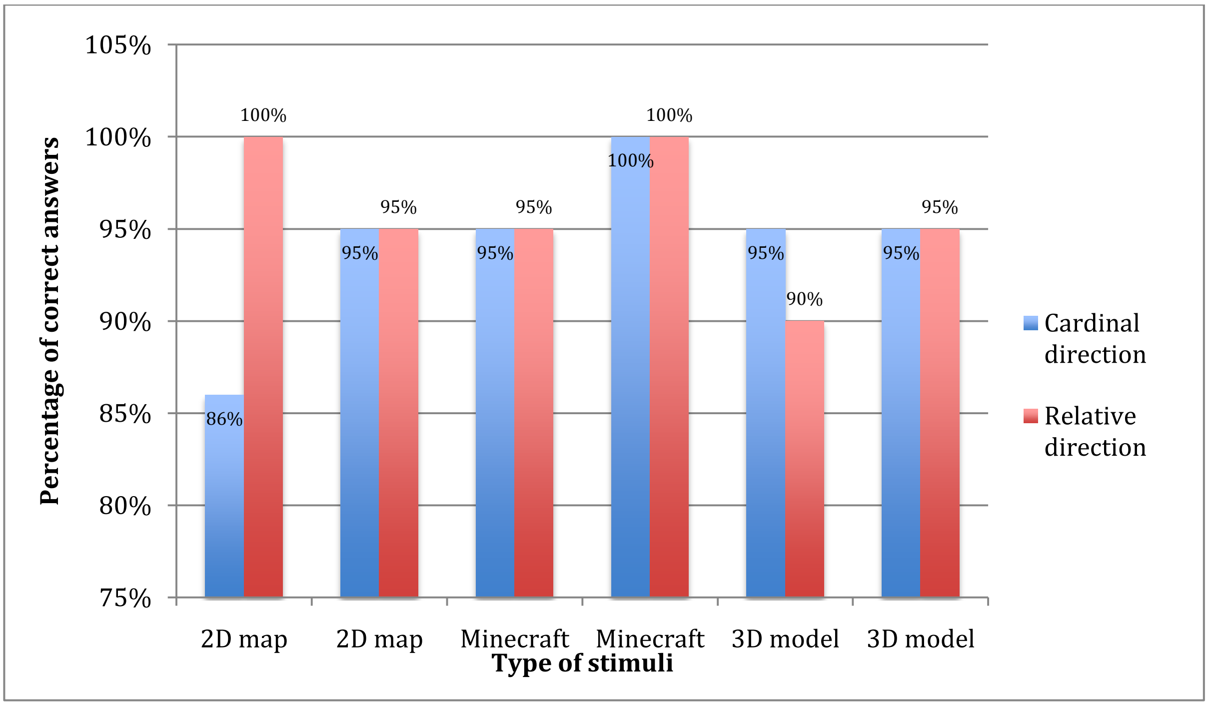

Figure 5. Correct answers for Task 1 (cardinal direction) and Task 2 (relative direction)

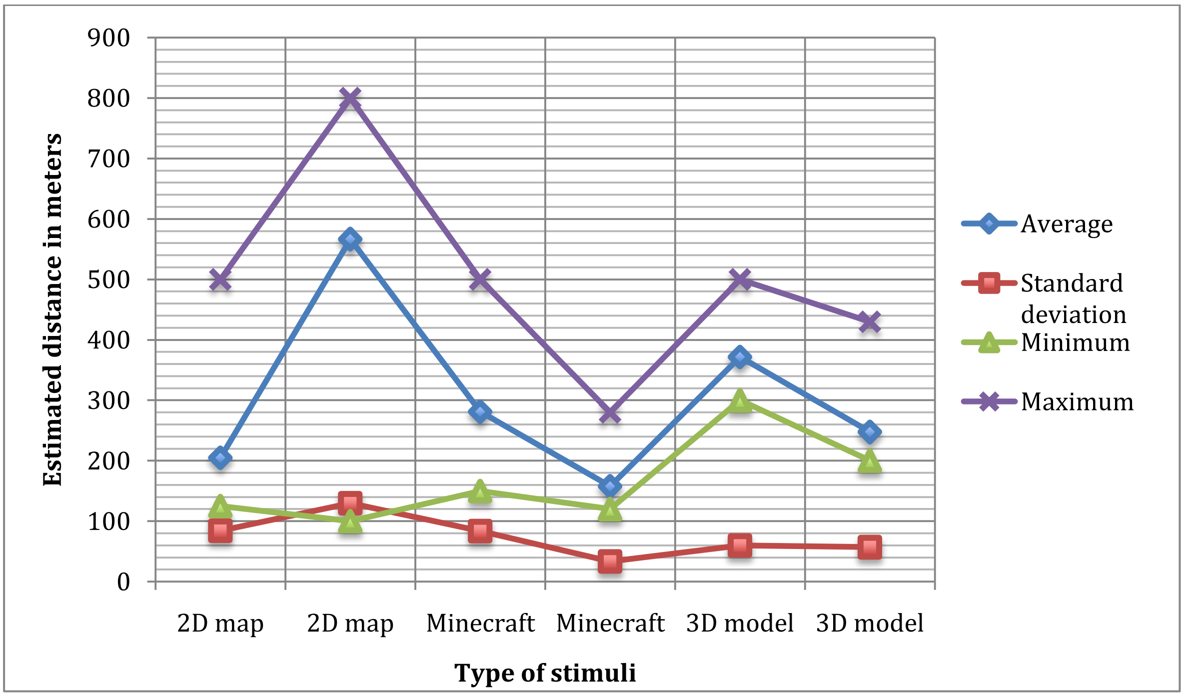

Figure 6. Basic statistical breakdown of Task 3 (distance estimation)

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 randomized. 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.

5. 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 4 provided valuable input into the design of the experiment.

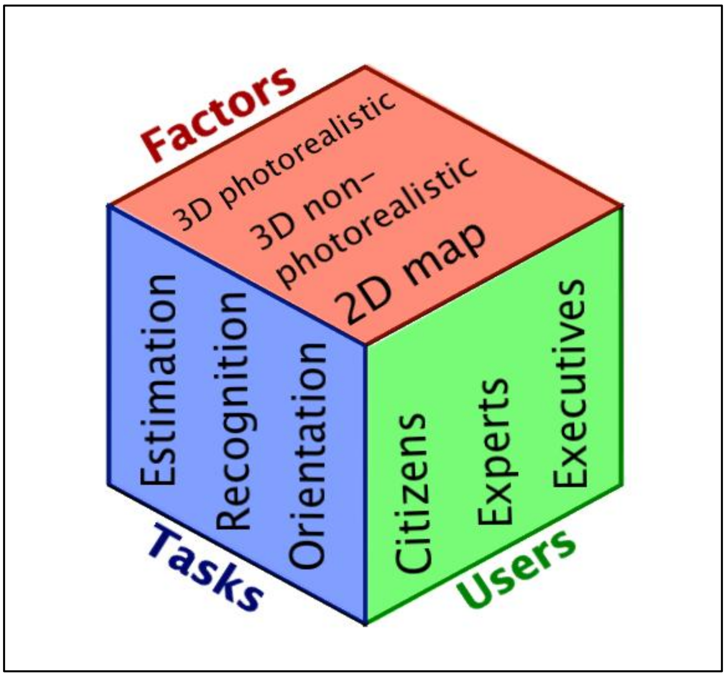

Figure 7. Map literacy factorial design matrix

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, 2008). The factorial design matrix for the map literacy experiments described above is depicted in Figure 7. The independent variable in revised experiment will remain the type of geovisualization: 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 inference. 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 & Hegarty, 2012). Spatial thinking skills allow us to manipulate mental representations of objects real or imagined.

As shown in the factorial design matrix (Figure 7) 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[3]. 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 Brittain), 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.

6. 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

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

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 geovisualizations despite the fact that these were from unfamiliar or foreign areas. The application of these geovisualizations 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.

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References

Abbott, J 2003, 'The use of GIS in informal settlement upgrading: its role and impact on the community and on local government', *Habitat International,* vol. 27, pp. 575 – 593.

Argawala, R 1983, *Planning in Developing Countries: Lessons of Experience*, World Bank Staff Working Papers, No 576, Management and Development Series, World Bank, Washington.

Bayram, S 2005, 'Naïve and Expert Geography Students' Perceptions on Digital Map Literacy', *Studies in Media and Information Literacy Education*, vol. 5, no. 4, pp. 1 – 11.

Board, C 1978, 'Map Reading tasks appropriate in experimental studies in cartographic communication', *Cartographica: The International Journal for Geographic Information and Geovisualization*, vol. 15, no. 1, pp. 1 – 12. .

Chen, R 2011, 'The development of 3D city model and its applications in urban planning' *19th International Conference on Geoinformatics*, Shanghai, China, 24 – 26 June 2011, pp. 1 – 5.

Chirowodza, A, van Rooyen, H, Joseph, P, Sikotoyi, S, Richter L, & Coates, T 2009, 'Using participatory methods and geographic information systems (GIS) to prepare for an HIV community-based trial in Vulindlela', *South Africa Journal of Community Psychology*, vol. 37, no. 1, pp. 41–57.

Clarke, D 2007, *Impact of map literacy on development in South Africa*, PhD dissertation, University of Stellenbosch, South Africa.

Cohen, C & Hegarty, M 2012, 'Inferring cross sections of 3D objects: A new spatial thinking test', *Learning and Individual Differences*, vol. 22, no. 6, pp. 868 - 874.

Courage, C and Baxter, K 2005, *Understanding Your Users: A Practical Guide to User Requirements Methods, Tools, and Techniques*, Morgan Kaufmann Publishers, California, United States of America.

Engel, BP 2004, ‘Developing map use skills for planners and implementers of land reform in South Africa’, *GeoJournal*, vol. 60, pp. 183 – 189.
ESRI, 2012, *Philadelphia redevelopment 3D model*, available online at http://www.arcgis.com/home/item.html?id=78e67939ae7d42a294d734ee2fd427d0
Gröger, G & Plümer, L 2012, ‘CityGML – Interoperable semantic 3D city models’, *ISPRS Journal of Photogrammetry and Remote Sensing*, vol. 71, pp. 12 - 33.
Hildebrandt, D & Döllner, J 2009, ‘Implementing 3D Geovisualization in Spatial Data Infrastructures: The Pros and Cons of 3D Portrayal Services’, in W Reinhardt, A Kruger and M Ehlers (eds), *Geoinformatik*, 35, pp. 9 - 16.
Hjelmager, J, Moellering, H, Cooper, A, Delgado, T, Rajabifard, A, Rapant, P, Danko, D, Huet, M, Laurent, D, Aalders, H, Iwaniak, A, Abad, P, Düren U & Martynenk, A 2008, ‘An initial formal model for spatial data infrastructures’, *International Journal of Geographical Information Science*, vol. 22, no. 11-12, pp. 1295 – 1309.
Kitzinger, J 1995, ‘Qualitative Research: Introducing focus groups’, *British Medical Journal*, vol. 311, pp. 299 – 302.
Koontz, H, O’Donnell, C & Weihrich, H 1984, *Management*, 8th Edition. McGraw-Hill, Tokyo, Japan.
Kotze, HJ & Van Wyk, K 1986, *Politieke Konsepte*, Perskor Uitgewery, Johannesburg.
Isikdag, U & Zlatanova, S 2010, ‘Interactive modelling of buildings in Google Earth: A 3D tool for Urban Planning, Developments in 3D Geo-Information Sciences’, in *Lecture Notes in Geoinformation and Cartography*, pp. 52 – 70.
Martin, D 2008, *Doing Psychology Experiments*, Thomson Higher Education, USA.
Montgomery, D 2009, Design and analysis of experiments, Wiley, USA.
Morgan, D 1997, *The Focus Group Guidebook (Focus Group Kit)*, SAGE Publications, California, USA.
Morton, PJ, Horne M, Dalton RC, & Thompson, EM 2012, ‘Virtual City Models: Avoidance of Obsolescence’, *Digital Physicality – Proceedings of the 30th eCAADe Conference*, vol. 1, Technical University in Prague, Faculty of Architecture, 12-14 September 2012, pp. 213 - 224.
Morrison, JL 1978, ‘Towards a Functional Definition of the Science of Cartography with Emphasis on Map Reading’, *The American Cartographer*, vol. 5, no. 2, pp. 97 - 110.
Nahas, S & Washington, S 2013, ‘Challenges of Strategic Planning and Development in Nigeria’, *European Journal of Developing Country Studies*, vol. 14, pp. 2668 – 3687.
National Planning Commission (NPC) 2012, *National Development Plan 2030. Our future – make it work.* Pretoria, South Africa.
Ordnance Survey 2013, *Minecraft map of Great Brittain*, available online at http://www.ordnancesurvey.co.uk/innovate/developers/minecraft-map-britain.html
Paar, P & Rekittke, J 2011, ‘Low-Cost Mapping and Publishing Methods for Landscape Architectural Analysis and Design in Slum-Upgrading Projects’, *Future Internet*, vol. 3, pp. 228 – 247.
Semmo, A, Trapp, M, Kyprianidis, JE & Döllner, J 2012, ‘Interactive Visualization of Generalized Virtual 3D City Models using Level-of-Abstraction Transitions’, *Eurographics Conference on Visualization (EuroVis)*, vol. 31, no. 3, pp. 885 – 894.
Sliuzas, R 2003, ‘Opportunities for enhancing communication in settlement upgrading with geographic information technology-based support tools’, *Habitat International*, vol. 27, pp. 613–628.
Spatial Planning and Land Use Management Act, 6 of 2013, South Africa.
Wu, H, He, Z & Gong, J 2010, ‘A virtual globe-based 3D visualization and interactive framework for public participation in urban planning processes’, *Computers, Environment and Urban Systems*, vol. 34, pp. 291 – 298.