The influence of visualisation type on decision-making

A comparative evaluation of 2D, 3D and combined 2D/3D geovisualisations for urban planning decisions

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Abstract

The advance in information technology has led to an increase in 3D models. In this thesis, we investigate the comprehensibility and utility of 3D visualisations compared to 2D and combined 2D/3D visualisations in regard to urban planning. For this purpose, the impact of the different visualisation types on the decision-making process was examined through a user study with 40 participants. The participants were asked to solve three urban planning related tasks with the aforementioned visualisations. Additionally, the visualisations were rated based on preference, usability and satisfaction. To further explore the efficiency of the different visualisation types, users' eye movements were recorded with a Tobii TX300 eye tracker device. This enabled us to examine which features of the visualisations the participants were looking at as they performed the tasks. The results showed that participants changed their decision when solving the tasks with different visualisation types. The findings indicate that the different visualisation types provided the individuals with distinct information, which seemed to influence their decision. The oblique 3D visualisation appeared to be the preferred visualisation type and was rated easiest for making urban planning decisions. Participants explained that it provided a good overview of the whole scene and they valued its natural representation of information. This thesis is contributing towards the overarching goal of establishing whether a particular visualisation type is more suitable than others for specific planning related activities.

Keywords: 3D visualisation, 2D visualisation, combined 2D/3D visualisation, eye tracking, decision-making, urban planning

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1 Introduction

1.1 Motivation

The number of 3D city models and their use in geographic information science (GIS) seems to be growing immensely. Due to the technological developments and data availability, the production of such models has become more feasible (Batty et al. 2000). As a consequence, a vast amount of 3D visualisations are available. They differ in size, degree of realism, interactivity and immersion. Additionally, they serve numerous purposes, for instance analysis, communication, exploring or decision-making. The increasing popularity of 3D visualisations may be an indicator of their relevance.

One spatial application field related to geography where 3D representations are prevalent is urban planning. In recent years, there has been a growing interest in the combination of GIS and urban planning, as demonstrated by the growing number of professional efforts and scientific conferences under the umbrella term *geodesign* (Goodchild 2010). This is partly because significant improvements in information technology have empowered planners to make use of the visualisations and in turn allowed citizens to take part in the planning process. Steinmann et al. (2005) discuss that GIS is important for the public participation planning process, as it facilitates the involvement of citizens in the decision-making process.

There are various arguments that support the use of 3D models for decision-making in urban planning. For example, Coors & Ewald (2005) suggest that 3D city models are intuitive for the viewers and can therefore make urban planning more transparent and comprehensible. Herbert & Chen (2014) state that 3D visualisations may help to understand the context that a building is situated in. According to Pleizier et al. (2004), 3D displays provide a more realistic view of the impact of changes in comparison to 2D representations. Despite these suggested advantages, 3D models may not be the most efficient or effective visualisation type for a specific task. For instance, Tory et al. (2007) express that the occlusion in 3D visualisations can make it difficult to interpret data. As a consequence, it is important to analyse which visualisation type is most suited for a particular task. Yet, this question relating to the use of 3D has so far not been commonly studied in a systematic manner.

Several studies have discussed the usefulness of 2D and 3D visualisations for different purposes. However, much of the literature relating to the utility of specific visualisation types for urban planning tasks is generally not based on empirical evidence but on theoretical assumptions and observations. It is consequently useful to test the statements with empirical methods, such as the use of a controlled user study. In addition, the effects of 2D and 3D representations on the decision-making process are not yet fully explored. There are different decision-making theories that try to explain how decisions are made and what factors influence the decisions. Nevertheless, there seems to be a research gap in describing to what degree a visualisation type can change a decision and why.

For that reason, this thesis aims to explore how different visualisation types, specifically 2D and 3D, influence decision-making in regard to urban planning. For this purpose, selected neighbourhoods of a fictitious city model are visualised in 2D, 3D and combined 2D/3D visualisations. We try to examine which representation type is favoured for three urban planning related activities and analyse if decision-making changes when individuals are presented with different visualisations.

1.2 Research questions

To analyse different visualisation types in regard to decision-making and usefulness, the following leading question is proposed:

Do tested visualisation types lead to a different decision in urban planning? If yes, why?

More specifically, following research questions are investigated:

1. Do the decisions change, based on visualisation type? If yes, why?
   - For a site selection task
   - For a scenario selection task

2. Which visualisation type is rated the easiest and why?
   - For a site selection task
   - For a scenario selection task
   - For a distance estimation task

3. How do the preference ratings before task execution compare to the satisfaction ratings after the task completion?

1.3 Thesis structure

The remainder of the paper is organised as follows. In chapter 2, related literature is reviewed and discussed. The focus is on public participation and different visualisation types, more specifically 2D and 3D visualisations. A brief introduction to decision-making is also presented. Chapter 3 is devoted to the experimental design and methods that were used to conduct the user study. The results of the experiment are described in chapter 4. In chapter 5, the research questions are discussed in regard to the results of the user study and related research. Furthermore, limits of the study are presented. Finally, the last chapter gives a short conclusion of the thesis and implications for future research are proposed.

2 State of the art

2.1 Dimensionality of visualisation

2.1.1 2D versus 3D

The role of 3D visualisations has changed immensely in the last decades. Batty (2000) states that in the early stages of 3D urban modelling, the focus was simply on getting the 3D visualisations going. However, this changed drastically as the technology to create them improved. Once the resources were advanced enough, the emphasis of sophisticated models became on improved rendering, faster fly-through and greater realism (Batty 2000). The rendering of complex geometries became embedded in standard hardware, which enabled the vast production of 3D visualisations (Shiode 2000). This advancement in technology along with a supply of adequate data has played a key role in the development of more informed 3D visualisations. While in the past, designers had to use “crude aggregate socio-economic data” mixed with local intuition to create plans, they now are able to work with data at a local scale (Batty et al. 1998, 2). The supply of remotely sensed data is increasing and thus the creation of urban models is more feasible (Batty et al. 2000). Besides remote sensing data, new developments in photogrammetry have also been mentioned as an important step in data capture (Köninger & Bartel 1998). This availability of fine scale, high-resolution data in digital form has thus added to the fast development of 3D models.

To test the efficiency of 3D models, it is reasonable to compare those “new” 3D visualisations with older visualisation types, as for example 2D models. Even though 3D models have become fairly popular, the 2D format is still useful. Some studies have shown that using 3D has led to a better performance in specific tasks, whereas other studies argue that 2D representations lead to better results, as discussed by several authors (for example St. John et al. 2001, Chen 2006, Shepherd 2008). In short, it can be said that the appropriate dimensionality of a representation is dependent on the task. In the following, some user studies and literature analyses regarding the efficiency of 2D and 3D visualisations will be reported.

The real world as we know it is comprised of three dimensions. The advantage of 3D is therefore that we can see the world as it is. This natural depiction of the world can make it easier for users to interpret the visualisation (Çöltekin 2002; Shepherd 2008; Lai et al. 2010). Another advantage of 3D visualisations concerns the amount of objects that are displayed. A 3D representation may enable the visualisation of more information compared to a 2D representation (Shepherd 2008).

The results of the user study of St. John et al. (2001) showed that a 3D view helped to understand shapes as well as the layout of scenes. The ability of 3D displays to show all three dimensions simultaneously may be a possible explanation for this (St. John et al. 2001). The authors further suggest that 3D is more beneficial for shape-understanding than 2D because it provides depth cues such as shading or occlusion. Rase (2003) agrees with this notion and adds that even though height information can be stored in a 2D map with visual variables, some users struggle to extract the height information. The author is thus presenting the usefulness of showing the scene in a 3D view. Besides giving depth cues, shadows can also be useful for other purposes. In a controlled experiment, Drettakis et al. (2007) tested the influence of realistic features in a visualisation. They formulated that users liked having shadows to judge sun/shadow coverage. Furthermore, they came to the conclusion that shadows, along with the depiction of realistic vegetation and human figures, seemed to provide a sense of scale.

That being said, there are also some problems that come with 3D displays. One is that they are distorted, or in other words, distances and angles are not represented truthfully. Jobst & Döllner (2008) discuss the effects of distortions and point out that expanding the field of view leads to a higher degree of perspective distortions. St. John et al. (2001, 80) state that it can be problematic to judge relative positions in 3D displays as "the projection of objects tilted toward the line of sight in a 3D view is compressed". Consequently, they argue that 2D views may be better suited for tasks where distances and angles between objects must be judged. Similarly, Lind et al. (2003) express that 3D visualisations are ineffective for tasks where Euclidean distances are important. They recommend using other visualisation types if users are expected to make metric judgments. This is in agreement with individuals' perceived usefulness of 2D visualisations for measurement-based tasks, as the study by Herbert & Chen (2014) showed.

Another disadvantage of 3D models is that they can be distracting. Architect Mike Rosen explains that when he gave planners a 3D model, they spent an extended amount of time looking at it and got lost in the details (as discussed in Delaney 2000). Michael Sherman, CAD Manager for the National Capital Planning Commission (NCPC), also states that individuals may become too "enthralled" with 3D models, lose focus and thus spend too much time with it (Delaney 2000). It is consequently of importance to only choose 3D visualisations if it is beneficial for the task.

A further problem of 3D visualisations is that some objects are hidden by other objects. Tory et al. (2007) argue that the occlusion in 3D visualisations increases the complexity level and makes it harder for the user to understand the display. In a first-person perspective, the front buildings override most of the content of the visualisation. This hinders the perception of reference points which in turn complicates orientation (Jobst & Döllner 2008). There are various techniques to deal with this issue. For instance, Elmqvist & Tsigas (2007) present 25 techniques for occlusion management. Dealing with occlusion is not the focus of this master thesis and for that reason it will not be discussed further.

Besides this problem of occlusion, an additional problem comes from the complexity of 3D models. Bleisch & Dykes (2006) tested in a user study the efficiency of 3D maps for information extraction, such as estimating the length or steepness of specific features. The results showed that participants performed rather poorly in those tasks when using that visualisation type. The authors assumed that participants have trouble understanding the nature and scale of a landscape in a 3D representation and thus cannot interpret it accurately. However, they found that if users spent more time inspecting the visualisation, the usefulness of 3D visualisation increased. Similarly, Borkin et al. (2011) yielded the same results. They reason that 2D views are more efficient than 3D if users have to "read" the visualisation and extract information in a systematic manner. Cockburn & McKenzie (2002) propose another argument that explains why 2D can be more useful than 3D views. They found that 3D visualisations seem to be too cluttered for sparse information retrieval tasks, which in turn can lead to a negative impact on the effectiveness of the visualisations.

In a different study, Hegarty et al. (2009) examined the relationship between users' preference and performance with different visualisations. They observed that individuals tend to prefer realistic representations, such as 3D models, over non-realistic visualisations. Yet, the authors found that the favoured visualisation types were not always the ones that led to the highest efficiency. This concept of dissociation between preference and performance is termed *naïve realism* (Smallman & John 2005).

As this discussion about the utility of 3D visualisations shows, the efficiency of 3D is dependent on the task and the purpose. Herbert & Chen (2014) conducted a study to compare the usefulness of 2D and 3D representations among planners. In their study, participants noted that they preferred the 3D visualisations for providing context and the 2D visualisations for tasks where measurement was involved. Thus, their findings are adding to the literature which explains that the value of a specific visualisation type is related to the task that it is used for. If the visualisation type is matched to the tasks, users might understand the site better, evaluate the impacts better and therefore can make more informed decisions (Herbert & Chen 2014).

Instead of deciding between 2D and 3D visualisations, there is the option to have a combined view. This may avoid the problem of finding the most appropriate visualisation type, meaning 2D or 3D, for a task. Tory et al. (2004) claim that it is becoming more common to combine 2D and 3D views. They tested the usefulness of visualisation types for different tasks (see also Tory et al. 2006). Their results showed that combined 2D/3D visualisations are better suited for relative position estimation tasks than strict 2D or 3D views as they reduced error and evoked higher confidence. Mixed representations can also be helpful for other purposes. With a combined view, individuals can use the best-suited strategy for solving a task based on their needs, as they can switch attention between the 2D and 3D view and use the one that is more appropriate for the specific task (Tory et al. 2004). Another example of the combined 2D/3D visualisation analysis is the paper by Bleisch & Nebiker (2008). They argue that combined 2D/3D visualisations improve performance and lead to a better understanding of the situation, as they combine the strengths of the two views. 2D and 3D views serve different purposes and therefore a combination of both may help to overcome their individual shortcomings. Providing a 2D view next to a 3D view makes it possible to compare different ideas side-by-side, which can further simplify analysis and data exploration (Bleisch & Nebiker 2008). The findings of Herbert & Chen (2014) indicate that users not only perform better with a combined view, they also prefer to use it. After analysing different visualisation types, they concluded that participants preferred to use the 2D and 3D visualisations together for most of the analysed planning tasks. This is further stressing the benefits of the combined visualisation. Nevertheless, Herbert & Chen (2014) found that for certain tasks (assessing recession planes, shadow impact or building setback), the strict visualisations were preferred over the combined visualisation.

As discussed, there are several studies that compare different visualisation types. Each of the three mentioned types, 2D, 3D as well as combined 2D/3D visualisations, has their strengths and weaknesses, depending on the purpose of the task. In the next section, the efficiency and role of 3D visualisations in urban planning are discussed.

2.1.2 3D visualisations in planning

A number of authors discuss the increasing interest in producing 3D models of the urban and built environment and their importance in the urban planning processes (Batty 2000; Hanzl 2007; Gröger & Plümer 2012). One of the areas of interest that is starting to emerge is the combination of GIS with design principles, as discussed by Goodchild (2010). The author uses the umbrella term *geodesign* to describe the concept of connecting the complex technology of GIS with cartographic principles to create efficient, science-based visualisations that can support planning. 3D visualisations can be used in various areas of urban planning. Uses include analysis of the present situation, planning and control, decision support and presentation (Ranzinger & Gleixner 1997).

There are different ways to generate 3D models. According to Wu et al. (2010), the current 3D representations in urban planning are mostly based on Virtual Reality Markup language (VRML). Çöltekin (2002) also mentions the importance of VRML in generating online 3D graphics. Another way to generate 3D visualisations is to use existing models and adapt them. For example, NASA developed technology to create 3D elevations from 2D photographs (Delaney 2000). The extrusion of height from 2D maps is also used frequently to generate 3D applications (Wu et al. 2010).

When creating visualisations, the designer can use visual variables to represent data effectively and appropriately. Bertin (1983) proposed a set of graphic variables (shape, size, location, orientation, colour value, colour hue and texture) that can be used to present the relevant information of a display more salient. In addition to those typical variables, 3D visualisations have some 3D specific variables like animation, light sources and camera views (Herbet & Chen 2014). Thanks to the manipulation of those variables, 3D models can be presented in numerous ways. For example, designers can choose the viewpoint and angle at which a visualisation is shown. The angle can reach from perspective to orthographic views (Jobst & Döllner 2008). The standard perspective views used in most virtual 3D city models, as defined by Jobst & Döllner (2008), are shown in Figure 1.

Figure 1: Standard perspective views of 3D city models (Jobst & Döllner 2008).

Once the designer has chosen an angle, they have to make further decisions about the visualisation's attributes including field of view, camera distance and orientation within the 3D display (Jobst & Döllner 2008).

Geertman (2002) analysed the usefulness of planning support systems (PSS). The results show that generally, 3D visualisations are considered helpful tools in the planning process. Workshop leaders expressed that 3D models are more appropriate in later stages of the planning process when the plans are more definite, in comparison to early stages where the sketches are vague. This suggests that 3D visualisations might only be brought into the planning process after first decisions have been made and the plans are a bit more developed and certain.

A lot of authors discuss the benefits of 3D models for non-experts. For instance, Rase (2003) reasons that 3D representations are especially valuable for people in urban planning who have little experience in map reading. 3D representations may provide a more intuitive view than 2D images and may therefore be easier to understand and work with (Rase 2003; Coors & Ewald 2005; Wu et al. 2010). This is supported by Wanarat & Nuanwan (2013), who report that 3D visualisations seem to help the public understand the planning processes better, which in turn can lead to faster decision-making and better feedback from the participants. This can ultimately lead to a better plan. Wu et al. (2010) report that the public expects planning proposals to be visualised in three dimensions because they think of a city as a three dimensional edifice. Rase (2003) also expresses that because we are used to seeing in three dimensions, 3D visualisations can be understood more intuitively than 2D representations. This is supported by many studies that have explored the benefits of 3D models. As an example, Pleizier et al. (2004) enunciate that with a 3D view, the impact of changes that may come with a new plan will be presented in a more realistic manner, which could result in a better understanding of the plans. Barton (2007) also comes to the same conclusion. He found that several participants appreciated to see the information in a 3D visualisation and stated that the third dimension was a valuable and beneficial addition to the representation. Köninger & Bartel (1998) describe 3D visualisations as a tool that enables users to evaluate complex spatial circumstances. Bleisch & Nebiker (2008) suggest that the 3D view might help to gain new insights into the data. Herbert & Chen (2014) assume that this visualisation type should be especially useful for understanding the context that a building is situated in. Ranzinger & Gleixner (1997) identify at least three benefits from 3D city planning: more involvement of the citizens, planners can present their ideas more fully and politicians feel more secure about their decisions. Similarly, Hanzl (2007) names three goals that may be achieved with the new technologies: providing a platform for communication in a non-professional context, enabling distant contacts and empowering a participatory planning process.

There are different aspects of a visualisation that not only have an impact on the effectiveness but also on the user’s opinion about the presented area. Rohrmann & Bishop (2002, 327) state that “it is generally assumed that the quality of a representation will influence how favorable a building or environment is judged”. They studied the effect of lighting as well as sound in a suburban environment visualisation. They found that visualisations with foggy conditions were rated least favourable and had the lowest perceived realism rating compared to sunny daytime and nighttime visualisations. Their findings show that night and day visualisations were perceived as valid and thus suggested using both representations of a situation. Moreover, they found that sound in a simulation is perceived as valuable and slightly increases the liking of the visualised area.

Another author that looked at 3D visualisations is Delaney (2000). He examined several 3D models and asked planners about their experience with them. He found that developers preferred 3D representations for modelling the urban environment and the planners would even use more advanced 3D models if the costs were not as high. The high costs of development are still regarded as a major obstacle in the development of realistic models in recent literature (see for example Herbert & Chen 2014). Another constraint of 3D models mentioned was that they are time-consuming (Delaney 2000).

Shiode (2000) asserts that 3D visualisations especially play a crucial role in community planning and public participation. A general overview of public participation along with some of its benefits and concerns are presented in the next section.

2.2 Public participation

2.2.1 Overview

In the last decades, there have been growing efforts to actively involve the public in the decision-making process. The idea of fostering public participation corresponds with the wider societal trend of supporting partnership working and challenging traditional democracy (Richards et al. 2004). Including citizens in policy making is a method that is widespread (Bulkeley & Mol 2003) and used in various areas. When looking at literature from the most recent years, it can be seen that public assistance is popular in numerous fields, particularly within environmental and urban planning issues. This is most likely dependent on the politics and authorities that govern a city or other governmental units, as discussed by Wiedermann (1993). He mentions that government officials have become more willing to enforce public cooperation due to the many protests and lawsuits that have occurred in recent years.

It was this change of attitude and acceptance of public engagement that enabled the empowerment of the public. However, just as important as the change in society and the politics was the advance in technology. Several authors observed that GIS and other spatial analysis tools have played an important part in the development of public cooperation in the planning process. Pleizier et al. (2004), for example, argue that the improvement in technology has led to a bigger number as well as more advanced tools for public participation, such as 3D models. According to them, geovisualisations can improve the interaction and communication with citizens. Therefore, possibilities for including the public in planning issues seem to increase as techniques for the visualisation of plans improve (Pleizier et al. 2004).

One of the focuses of GIS over the last few decades was how GIS can support spatial decision-making and handle large amounts of data (Harris & Weiner 2003). This discussion then led to a focus on how GIS production and use can incorporate public input. The term public participation GIS (PPGIS) has become popular after the "GIS and Society" workshop in 1993 sponsored by the National Center for Geographic Information and Analysis (NCGIA) (Obermeyer 1998). The aim of the workshop was to focus on the relationship of GIS and society and analyse how access to GIS can be improved for individuals and non-governmental organizations (Obermeyer 1998).

Besides GIS tools, the internet can lead to an encouragement of public involvement. The number of people involved may increase and a broader audience could be reached, as it is possible to simultaneously share plans with a wider audience (Pleizier et al. 2004). Harris & Weiner (2003) also discuss the significant impact the internet has on participatory GIS, saying that it provides access and enables the use of GIS. Online public participation is especially beneficial as it is location- as well as time-independent.

After this overview of public cooperation and its history, different types of public participation are presented in the next section.

2.2.2 Types of public participation

The term public participation is highly generic and describes a broad spectrum of public involvement. The planning outcomes can depend heavily on the amount of assistance or intervention from the public. Consequently, planners have to think about what type of participation they want to use for the planning process. As Pleizier et al. (2004) state, the planners define the degree to which the public will be involved in a plan before the consultation of the public. This means that already at an early stage, planners will make decisions about how much and what type of influence the citizens will have. Further, the level of engagement should be appropriate to the context and objectives of the planning process (Reed 2008). Accordingly, every planning operation will be adapted individually and may differ from other processes. Nevertheless, there has been some effort to distinguish different types of involvement. The most well-known is Arnstein's (1969) ladder of participation. He identifies eight levels of involvement, which can be seen in Figure 2. Each rung represents a type of public contribution, ranging from low degree (lowest rung) to high degree of citizen participation (highest rung). The first two levels, *manipulation* and *therapy*, describe levels of non-participation. In these levels, citizens are solely educated by the planners about the projects, but they are not enabled to influence the planning outcome. Level 3 and 4 are *informing* and *consultation*. Citizens can take part in the decision-making process, but it is not assured that their opinions will be taken into account. Level 5, *placation,* is a higher level of tokenism. Participants can advise, but power holders still have the authority to make the final decision. Furthermore, participants are often not given enough information about the proposals to make a decision and are unaware of their rights. Level 6, *partnership,* enables the public to negotiate and engage, meaning they have an increasing degree of influence. The final two levels are *delegated power* and *citizen control*. They describe processes with the highest degree of citizen participation. In fact, citizens have a dominant decision-making role over public officials. Participants can be in full charge of a plan and have the power to determine the outcome.

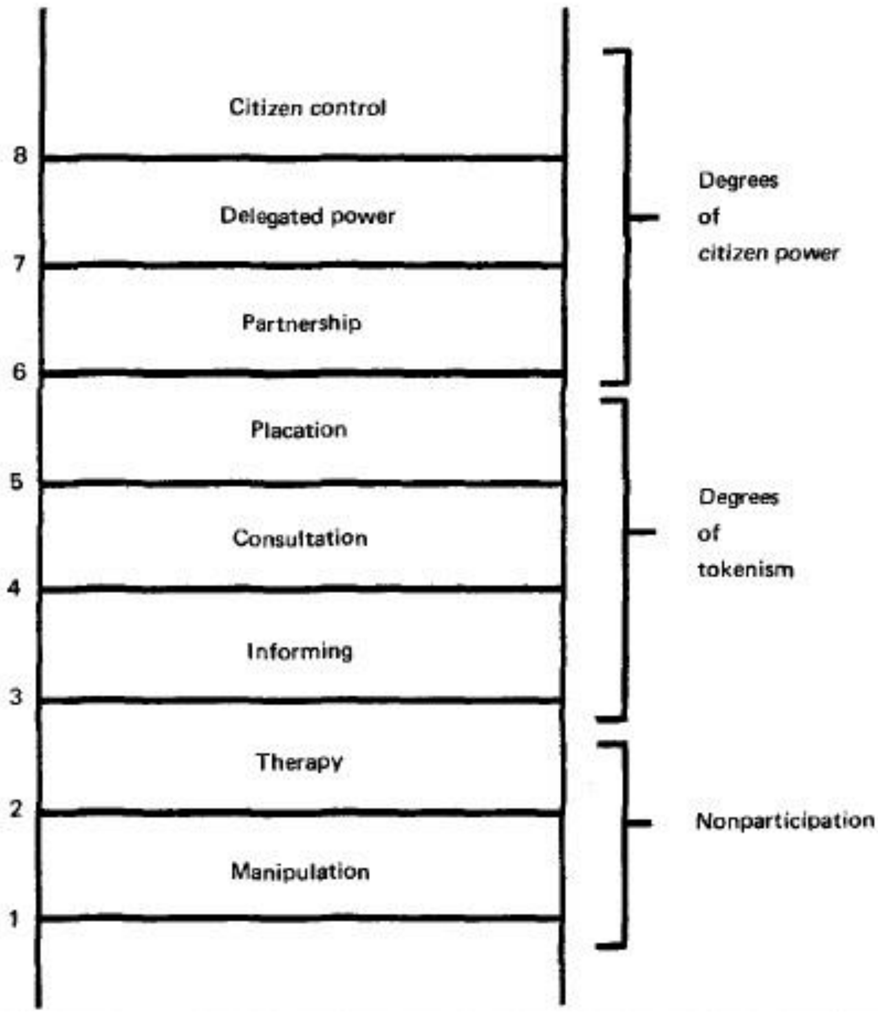


Figure 2: Eight levels of citizen participation (Arnstein 1969).

The type of participation that will be used depends on the authorities, the context and the purpose of the planning process. For this thesis, a high degree of public involvement will be analysed.

2.2.3 Benefits

There are many attempts to foster public involvement and support non-governmental collaboration in the planning process. Some of the benefits that come from citizen cooperation are described in the following.

According to recent literature, the community can give valuable input to the decision-making process. Individuals at the local level often look at an issue from another perspective that differs from the experts. Therefore, including the local community can make it possible to look at the issue from various viewpoints (Richards et al. 2004) and possibly develop new ideas from it (Carver 2001). Further, Barndt (1998) assumes that community representatives draw upon personal experience and usually incorporate a wider range of qualitative and quantitative information into the decision-making. The benefits of merging the local knowledge with expert knowledge can thus be large. Reed (2008) also stresses this point and suggests that an integration of local and scientific knowledge provides a more inclusive view on socio-ecological systems and processes.

It is further argued that public participation can lead to more effective planning outcomes. For example, Reed (2008) suggests that enabling the public to express their opinion about a plan may result in more efficient outcomes, as interventions can be better adapted to local needs and conditions. Thanks to the involvement of the community during the planning process it may be ensured that decision-making and planning procedures take the needs and interests of the affected communities into account (Sayce et al. 2013). Due to this, chances of community approval are increased (Richards et al. 2004). Richards et al. (2004) give another argument that demonstrates how public involvement can lead to better results of the planning process. He assumes that incorporating a broader range of agents might aid in understanding the intertwined nature of problems that can arise. In turn, it may be possible that there will be a more positive planning outcome (Richards et al. 2004). Another benefit of engaging the public is that it may help increase people's trust in the final decision, as it shows the authority's willingness to listen and acknowledge various and opposing opinions (Richards et al. 2004).

2.2.4 Disadvantages/Concerns

All the above-mentioned positive arguments make it clear why it is important to empower citizens and include them in the decision-making process. Nevertheless, there are also some concerns that come with public engagement. As discussed in the last chapter, it might be beneficial to include citizens in the planning process. However, even though there are numerous ways and methods to foster public participation, it cannot guarantee full and fair empowerment of the public. Carver (2001) mentions, for example, that meetings are held at times which are inconvenient for some individuals, thus they are excluded from the participation process. This can be avoided if the participation is held online, for example via a survey or online discussion. Yet, there is still a restriction because not everyone has physical access to the required technology to take part. This means that even with the internet as a tool to reach more citizens, some groups are still excluded (Stadtentwicklung Zürich 2013). This can lead to a selective participation where less powerful individuals are not included (Harris & Weiner 1998). Additionally, it is hardly possible to get a representative group of individuals and consequently it must be kept in mind that the results may not be valid for the whole population (Stadtentwicklung Zürich 2006).

Besides this inequality of access, large ranges of knowledge or technological competence can also hinder the empowerment of the public. Carver (2001) states that the public's knowledge and rationality regarding decision-making is often overestimated. According to the author, the public's thinking process about uncertainties is often rather simple, which may lead to errors and thus can cause problems during the decision-making process. Consequently, concerns over the usefulness of people's opinion might be raised and it is doubtful how effective they are.

Carver (2001) also addresses the issue that lay people may have difficulties using a GIS. He reports that without special training, it may be hard to work efficiently with the technology and the interpretation of the data can be problematic. Consequently, GIS alone does not guarantee a successful integration of the public in decision-making, as they do not have the necessary knowledge to use the system. Wiedemann & Femers (1993) also formulate that collaborative public engagement is only useful if the public has sufficient technological knowledge to use the information that is handed to them. It is thus important to not only ensure that the public has physical access to a GIS, but also the necessary knowledge to work with it.

Models are a representation of reality and therefore they can never perfectly emulate the real world. The accuracy of the model depends heavily on the designer. Consequently, this means that the creators of the model have the power to change the representation according to their own desires and manipulate it to reach their goals (Bulmer 2001). Harris & Weiner (1998) discuss the subjective influence that underlies data representation. Even though they talk about GIS, their reasoning can be applied to any kind of visualisation tool. They argue that choices must be made regarding the coverage and attributes that are visualised, the scale of the visualisation, how the data will be analysed and the decisions that will follow the analysis. Besides the designer themselves, other parties can also manipulate what the public sees. The stakeholders can decide which and how much information they want to present to the public, which leads to restrictions for the public (Bojórquez-Tapia et al. 2004). Additional to the conscious manipulations of the visualisation there are also unconscious misrepresentations. Barndt (1998) states that maps can distort reality and that it is important to identify those distortions.

Along with this difficulty that comes from the representation, a further problem with public involvement relates to the people themselves. For a planning task, the context and background of individuals might affect how they make decisions and must therefore be taken into account. However, Elwood & Leitner (1998) point out that there exists a big diversity between and within groups. This means that the context that the participants work in, e.g. the geographic, economic, political and social context can vary between individuals. This heterogeneity of individuals' contexts can lead to diverse and neighbourhood-specific feedback from the public, as shown by Elwood & Leitner (1998).

Another problem regarding the people is discussed by Krek (2005) and Carver (2001). According to them, the ignorance of individuals concerning the planning process may be a large problem. The theory behind this rational ignorance is that people have to put a lot of time into the planning process but the perceived reward is relatively low. Hence, the perceived effort is not justifiable by the end result. This causes an imbalance and as a consequence individuals are dissatisfied. In a similar context, Richards et al. (2004) talk about consultation fatigue. He found out that more people are asked to take part in decision-making. However, the return is small and as a result individuals' willingness to take part declines. Consequently, it is important to find new ways to entice the public to participate. He further states that people's reluctance to take part is especially large if they are uncertain of their suggestions being taken into account for the final decision.

Innes & Booher (2004) report that one of the downfalls of public cooperation is that it causes delays. This may be due to the fact that finding enough participants can be difficult and thus the data collection is prolonged. Moreover, if more individuals are being included in the decision-making process, the analysis and evaluation of all the answers and comments will be more time-consuming than with smaller representative groups.

2.3 Decision-making

As public urban planning progresses through its stages, the public eventually is required to make decisions in regard to the proposed plans. The decision problems can have various forms that can include but are not limited to approving or declining a plan, evaluating different scenarios or choosing between alternative locations. Therefore, this chapter is dedicated to exploring decision-making theories. First, a framework of decision-making is presented. Second, different decision-making models are reviewed. In addition, the strategies that individuals use to make a choice are examined. Various components that are part of the decision-making process are also discussed. Finally, the importance of how information is visualised in regard to reaching a decision is presented.

Hastie & Pennington (1995) discuss that there are two components of the decision-making process that should be kept distinct: the decision task and the cognitive process. The decision task is directly linked to the external world whereas the cognitive process describes the decision maker's thought process (Hastie & Pennington 1995). The relationship between the two is strong and both components should be taken into consideration when making assumptions about how a conclusion is reached. In reference to the cognitive process, the concept of *Bounded Rationality* has been mentioned as a central aspect for analysing decision theory (Payne et al. 1995; Dillon 1998). It is based on the belief that all rational behaviour occurs within certain boundaries, i.e. with limitations. It is used as an explanation for why an individual's actions can deviate from that of a rational decision maker. Humans have limited processing capacity and therefore can only make judgments based on their cognitive skills. One way to deal with cognitive limitations is to use tools that support decision-making. Carsjens & Ligtenberg (2007) express that decision-makers need a tool that enables them to analyse environmental impacts of a new plan rapidly and provides the option to look at alternative scenarios iteratively. They further state that exploring more alternatives can lead to better decision-making.

Following this short overview of the decision-making framework, different decision-making models are reviewed. According to Dillon (1998), a vast number of theories have been developed in the past to describe the decision-making process. He classifies them into three decision-making models: normative, descriptive and prescriptive. Normative models describe what people should do theoretically. However, the theoretical actions of individuals do not coincide with real life situations and thus descriptive models are required. They are based on observations and are used to describe exact actions of individuals (see Dillon (1998) for more information on the descriptive models). Recently, prescriptive models, which are based on normative and descriptive models, have been added to the decision-making categories. They describe what people should and can do and are adjusted to the specific decision-making scenarios as well as the decision maker's needs. Tsoukiàs (2008) suggests using the prescriptive model when the decision maker exhibits intransitive preferences. Tsoukiàs (2008) also includes another decision-making category: the constructive approach. This model is used when the problem is not as apparent and therefore the construction of the problem and its solution occurs simultaneously. Dillon (1998) concludes that it is nearly impossible to create a model that describes all observed decision-making processes. He explains that decision-making depends on various variables and as a consequence, a uniform model is not applicable.

After the description of some decision-making models, strategies for decision-making are explored. Payne et al. (1995) discuss how people use a number of diverse information processing strategies to make choices. They state that the task as well as the context can influence the strategy type that will be used, which in turn highlights different aspects of the problem and thus can lead to different preferences. Another important factor in choosing which strategy to use, as identified by Payne et al. (1995), is the personal repertoire of decision strategies. From former decisions, people have acquired a repertoire of strategies that can help them decide which strategy to use, based on their experience with each strategy. Furthermore, the cognitive effort can influence an individual's choice of strategy. The strategy that minimises the amount of cognitive effort required to make a decision is often the most preferred (Payne et al. 1995). Finally, Payne et al. (1995) assume that individuals use the strategy that they believe is best suited for a task.

Another approach to describe decision-making is proposed by Zeleny (1982). He presents a diagram that serves as a basic model that can and should be modified to the specific context of a decision. He defines decision-making as a dynamic process that consists of a pre-decision, decision and post-decision stage. The stages are highly interrelated and influence each other. The pre-decision stage starts with the gathering of information and evaluation of different alternatives. If all alternatives are equally attractive and there is a small divergence of values, the decision-making becomes more difficult and there is a sense of conflict. To go from pre-decision to post-decision stage, individuals go through a process of partial decisions. Unsuitable alternatives are discarded and criteria are added or removed. This step is characterised with an iterative re-evaluation of all alternatives. The amount of possible alternatives diminishes and the dissonance that emerged from the decision problem is reduced. In the post-decision stage, the attractiveness of preferable options is enhanced and finally, the decision is made. More information is collected to increase the decision maker's confidence in their decision and to minimise regret. Zeleny (1982, 94) further states that the decision is embedded in the social framework and is consequently at least to some extent dependent on it: "Other people, their values, objectives, and constraints, interact with the individual decision-making process." In other words, our decisions are interdependent with those of others. Thus, decisions must be regarded in a bigger social context.

A different way to model decision-making strategies is by utilising production systems, as discussed by Payne et al. (1995). The authors mention that every decision strategy consists of a sequence of elementary information processes (EIP). The following EIPs are used in decision strategy: read, compare, difference, add, product, eliminate, move and choose. According to Payne et al. (1995), EIPs can be described as operations that an individual can use to transform the initial problem stage of a decision problem into the final goal stage. Payne et al. (1995) suggest that the number of EIPs can be used to measure how big the cognitive effort is to make a decision with a specific strategy. The authors claim that strategies' usefulness depends on the task. Consequently, to reach low effort and high accuracy, a strategy should be chosen based on the task demands (Payne et al. 1995).

Resnik (2000) asserts that for characterising the decision problem, three components must be identified and analysed: acts, outcomes and states. The decision maker has to choose between one or more acts which then lead to an outcome. Furthermore, the whole decision problem is embedded in the state of the environment. This model can be represented in a decision table which consists of a number of acts (rows) and a number of states (columns). Each cell corresponds to an outcome. An example of a decision table with two actions, two states and four outcomes can be seen in Table 1.

	State 1	State 2
Act 1	Outcome 1	Outcome 3
Act2	Outcome 2	Outcome 4

Table 1: Decision table according to Resnik (2000).

From the table it is obvious that the outcome depends on the chosen acts and the state of the environment. One important message from this table is that "several problem specifications may pertain to the same decision situation" (Resnik 2000, 8). As a consequence, the decision maker must select the act and state carefully and consider the outcome.

Besides the three components that have been mentioned before (acts, outcomes and states), another factor that has been discussed in relation to decision-making is the role of intuition. For example, Simon (1987) distinguishes between logical and judgmental decision-making. The author describes that logical decision-making describes processes where goals and alternatives are made explicit and the consequences of the alternatives are compared and evaluated. On the other hand, judgmental decision-making is used when rapid decisions are required, which leaves little time to make a systematic analysis of the situation (Simon 1987). In the latter decision-making process, decision makers often cannot reason how or why exactly the choice was made. Simon (1987) explains that judgmental decision-making is used by experts when the problem is solved quickly and intuitively. According to the author, experts draw upon experience and make their decision mostly based on intuition and judgment. This behaviour can be described by a "recognition and retrieval process that employs a large number (…) of patterns stored in long term memory" (Simon 1987, 61). Nevertheless, that does not mean that analysis becomes insignificant. Simon (1987) stresses that both, intuition and analysis, are important aspects of decision-making and they complement each other to make an efficient decision.

Even though there are some known models and strategies that individuals use to make a choice, such as the ones previously mentioned, there are still some uncertainties regarding the decision-making process. Often, decision makers do not behave exactly as what a specific decision theory would suggest. Tsoukiàs (2008) gives a possible explanation for this. The author states that the way a decision problem is expressed and its setting can also influence the decision maker. This makes it difficult to predict the exact outcome of the decision-making process. In addition, individual factors can also influence decision-making (Payne et al. 1995). Thus, it must be taken into account that many factors have an impact on the outcome and it may be impossible to measure some of them.

One factor that seems to have an impact on the decision-making is the visualisation type. For that reason, to understand how individuals make a choice, it may also be important to analyse which information or presentation type works best for a specific purpose or facilitates decision-making. Dennis & Carte (1998) state that the result of a decision-making is influenced by how well the information presentation, the task and the decision processes match. They tested two information presentation types: map-based and tabular presentations. To test the performance of both representations, an experiment was conducted where participants had to solve geographic adjacency tasks and geographic containment tasks. Adjacency tasks require an understanding of the relationships between the areas, whereas in the containment tasks, the relationships among geographic areas are less important. The results showed that decision makers were faster to make a choice when they used map-based presentations compared to tabular illustrations. Additionally, map-based presentations were also more accurate for geographic adjacency tasks. They came to the conclusion that it is the type of information presentation that influences the selection of decision processes, rather than the task itself. These results imply that the type of information representation can have a large impact on how individuals make decisions.

From this discussion about the various models, strategies and components, we can comprehend the complexity of decision-making. To further examine the decision-making process we analyse different visualisation types and their influence on the decision-making process. The focus is on whether different types of visualisations lead to different decision outcomes and why.

3 Methods

3.1 Participants

The experiment was conducted with a total of 40 participants (21 females and 19 males). The majority of the participants (95%) were aged between 18 and 31 and two participants were aged between 32 and 45. They were recruited by e-mail or asked directly and were rewarded with a five CHF voucher for the cafeteria and chocolate. Most of the participants were geography students at the University of Zurich, with the others coming from other faculties. In the beginning of the experiment, participants were asked to give some information about their training in geography related areas. A five-point Likert scale was used, ranging from no training (1) to professional (5). The results are illustrated in Figure 3. An important note to mention is that most participants had little to no experience in urban planning.

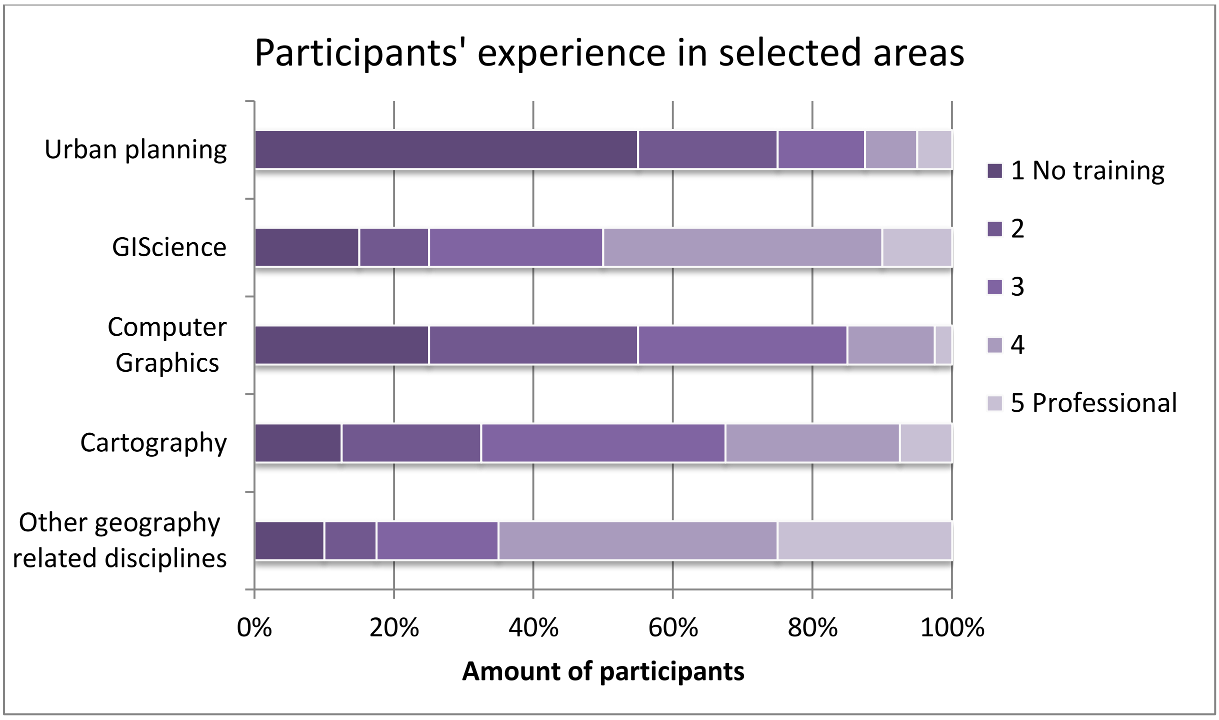


Figure 3: Level of experience of participants in selected areas.

Since urban planning is the context of this study, the participants were further asked to state how often they have been involved in some urban planning related activities, such as decision-making, workshop participation or online discussions. The findings show that most participants have not been involved in urban planning related activities (See Figure 4). Only one participant works within an urban planning environment. It can therefore be assumed that the results of the experiment are not influenced by expert knowledge.

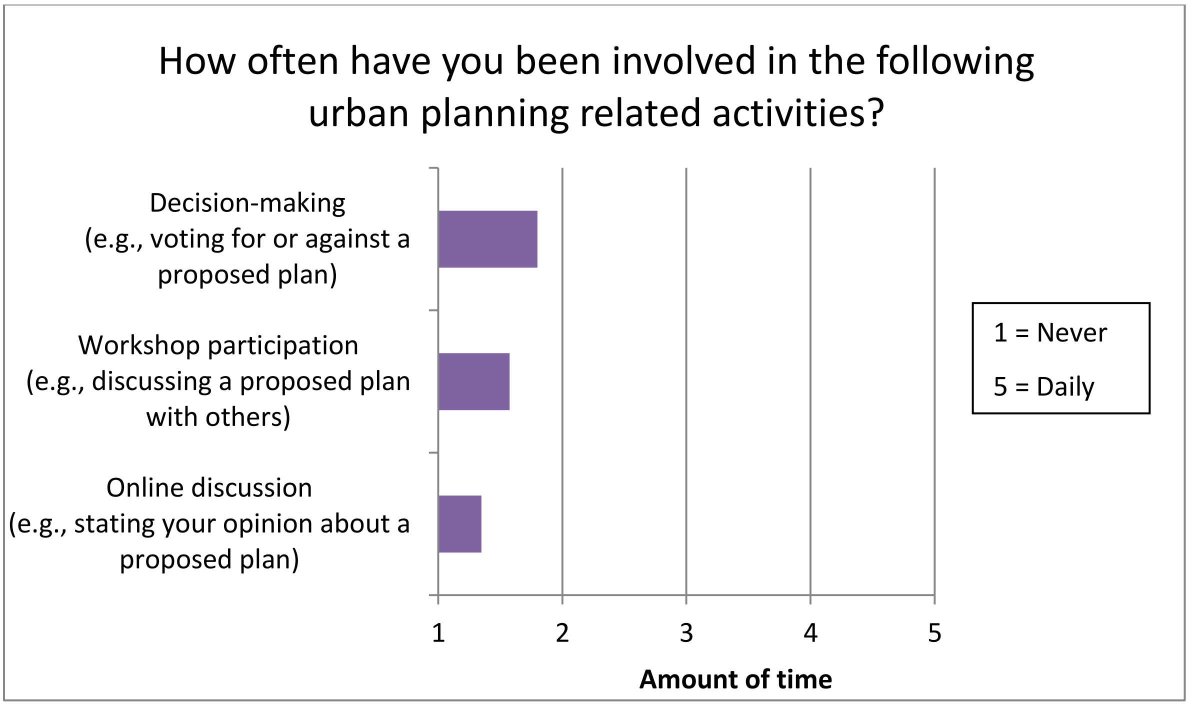


Figure 4: Frequency of participants' involvement in urban planning activities.

3.2 Apparatus

The experiment was conducted using the Tobii TX300 Eye Tracker. Gaze data was collected with a sampling rate of 300 Hz and an accuracy of 0.4 deg. The minimal fixation duration was set to 100 milliseconds. The eye-tracker was calibrated for each participant at the beginning of the experiment. Additionally, video and audio were recorded.

The Tobii Studio analysis software 3.2.1 was used to design and run the experiment as well as to analyse the data.

Further information on the technical specifications can be found on the department's website at http://www.geo.uzh.ch/en/units/giscience-giva/services/eye-movement-lab.

3.3 Material

The stimuli for the experiment were 2D, 3D and combined 2D/3D visualisations of city scenes. The modelled city was chosen to be fictional in order to prevent any possible relations to a real life city. This prevented any bias from the participants who may have been familiar with the city, had it been authentic. The scenes were created using Google SketchUp Make. To generate the 2D visualisations, the 3D model was changed to parallel projection and turned to top view. In addition, the shadows were turned off for the 2D view. For the combined 2D/3D visualisations, a 2D view was presented next to a first-person 3D view. Objects such as houses, benches, cars or trees were downloaded from SketchUp's 3D Warehouse and were slightly adapted to fit into the environment.

The online survey platform SurveyMonkey was used to collect and analyse responses. The survey can be found at the end of this thesis in Appendix B.

3.4 Experimental design

3.4.1 Within-Subject design

A within-subject design, also called repeated-measures design, was used for the experiment. This means that every participant had to solve all tasks and was exposed to all independent variables. The advantages of a within-subject design compared to a between-subject design are that fewer participants are needed and individual differences between the participants can be minimised (Martin 2008). The disadvantage, however, is that the order of the questions might influence participants' performance and responses. After being exposed to a stimulus, individuals are aware of what to expect for the next question and are familiar with the task (Field 2009). Besides this learning effect, fatigue can be another source of systematic variation. As the experiment progresses, participants may start to fatigue or become bored, which has an impact on the answers (Field 2009).

When designing the survey, it was important to reduce those order effects as much as possible. To do this, the order of the three tasks as well as the order of the visualisations within the tasks was counterbalanced. This means for example, some participants first solved the task with a 2D visualisation then with a 3D visualisation and vice versa. For the combined 2D/3D visualisations the positions of the 2D and 3D views were also interchanged. This randomisation ensures that a potential bias introduced by order effects is levelled out and a possible systematic variation is minimised (Martin 2008).

3.4.2 Variables

The **independent variables** are variables that the experimenter changes in order to examine participant's behaviours (Martin 2008). For this experiment, the independent variable was the visualisation type, i.e. the dimensionality of the visualisation. Oblique 3D visualisations were compared to 2D and combined 2D/3D visualisations. For one task, strict first-person 3D visualisations were also presented to the participants. We chose to use 2D, oblique 3D and first-person 3D views, as they are all very common in urban planning.

The **dependent variables** are a measure of participant's behaviour in response to the manipulation of the independent variables (Martin 2008). The following dependent variables were chosen for this experiment:

- Participants' *preference* for different visualisation types was measured before completion of the tasks
- A five-point Likert scale was used to measure participants' *satisfaction* with the different visualisation types after completion of the tasks
- A difficulty rating was carried out to see how *helpful* the visualisation types were

- The *accuracy* of participants' answers was tested with distance estimation tasks
- *Fixation durations* were derived from the eye-tracking gaze data

To test if the changes in the dependent variables were caused by the manipulation of the independent variables, all other circumstances and external factors must be kept constant and controlled (Martin 2008). Without those **control variables**, it cannot be assured that the dependent variables were solely influenced by the independent variables. Accordingly, this experiment was conducted in a controlled environment. Lighting conditions, the instructions and explanations that were given to the participants before the experiment and distance to the screen were constant and equal for all participants.

3.4.3 Procedure

The experiment was carried out in the eye movement laboratory at the University of Zurich. Before starting the experiment, participants were required to read and sign a consent form which informed them about the purpose of the study, test procedure, safety, privacy and their right to withdraw their consent. The consent form is attached in Appendix A. After the calibration of the eye-tracker, the experiment commenced. Participants had no time limit to complete the questionnaire and solve the tasks. On average, participants took around 30-45 minutes to finish the experiment.

The experiment consisted of three parts: a preference section, a task section and a satisfaction section. In the preference section, participants had to state whether they preferred a 2D or oblique 3D visualisation for a site selection, plan approval and route planning task. The same questions were asked again, but this time, the oblique 3D visualisation was compared to a combined 2D/3D first-person view. Every question included a comment field to provide the participants with the opportunity to describe the reasons behind their choice. The task section consisted of three central urban planning tasks for non-experts: site selection, scenario selection and distance estimation. For every task, participants saw the scenario through different visualisation types (2D, oblique 3D, first-person 3D and combined 2D/3D). The three tasks are discussed in further detail in the next sections. After each task, participants were asked about the ease of completion based on the visualisation, e.g. how helpful it was to make a decision with a specific visualisation type. A five-point Likert scale was provided to answer the question. Furthermore, a comment box was added so that participants could express their thoughts and feelings about the visualisation. In the satisfaction section, which was the last part of the experiment, participants were asked to rate each of the visualisation types (2D, 3D and 2D/3D combined view) individually, based on usefulness and attractiveness. Positive and negative statements were given to the participants, followed by a five-point Likert scale ranging from "strongly disagree" to "strongly agree". Additionally, participants were asked if they would use a visualisation type for a specific task.

3.4.4 Site selection

Steinmann et al. (2005) state that site location tasks are very common in public participation planning. The planner suggests alternative locations for a new building or another object (for example a bus stop) and the public can decide which one they prefer. In the experiment for this thesis, four different locations for a residential, high-rise building were presented to the participants. The task was repeated with another scene, again with four possible locations. Using two different scenes for this task allowed us to also observe the impact of the scene content on the decision-making.

The participants could choose the most suitable location, or, if they did not prefer one or the other, decide to give the answer "I don't know". This task was visualised successively with two representation types. The first one was a combination of 2D and 3D first-person view. In this combined 2D/3D visualisation, an overview of the city in 2D was displayed on one side and next to it was a close up of the respective location in a 3D first-person view. Four visualisations, one for each location, were shown per scene. In the 2D view, the position of the participant was marked with a red circle. Two examples of this combined view are shown below. Figure 5 is an example for the first scene and

Figure 6 for the second scene. The other combined 2D/3D views are attached in Appendix B.

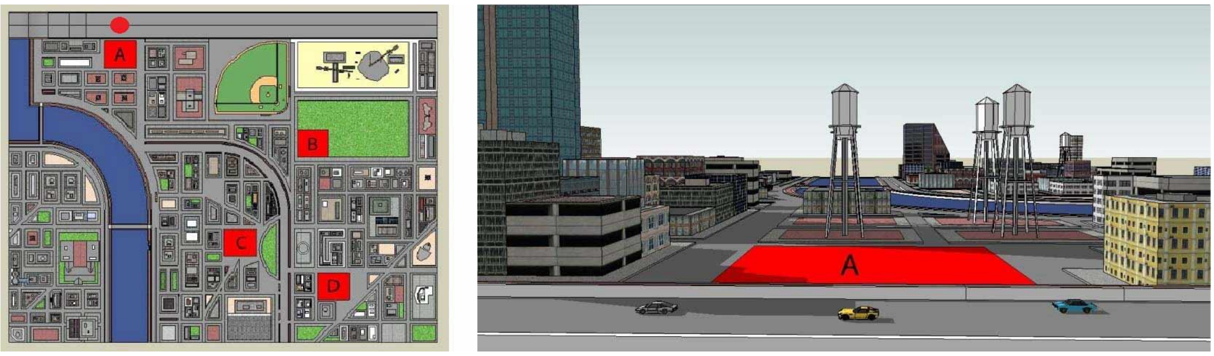


Figure 5: Site location task in combined view, scene 1.

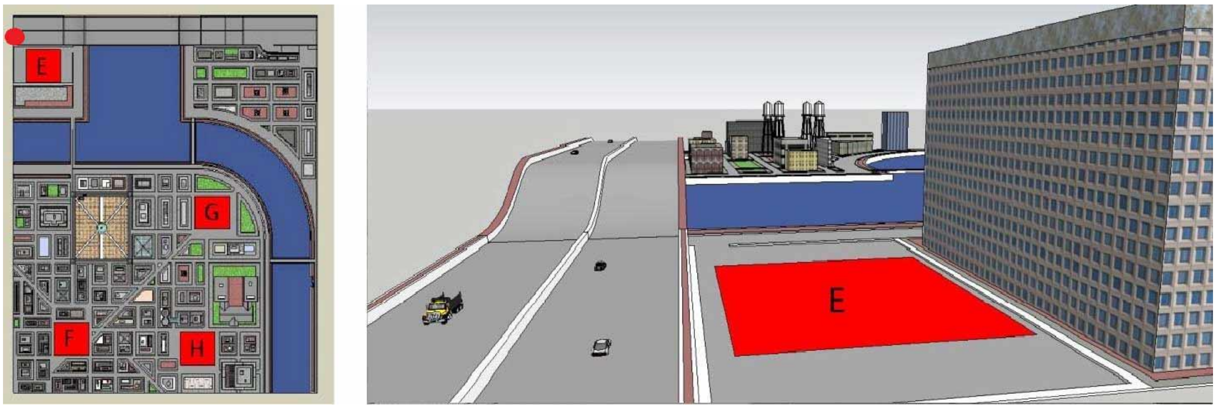


Figure 6: Site location task in combined view, scene 2.

The second visualisation type was an oblique 3D view. In this representation, the whole city was visible in one display from a top angle. It was made sure that the four possible locations were not completely occluded by buildings. The oblique 3D view for the first scene is shown in Figure 7 and the one for the second scene in Figure 8.

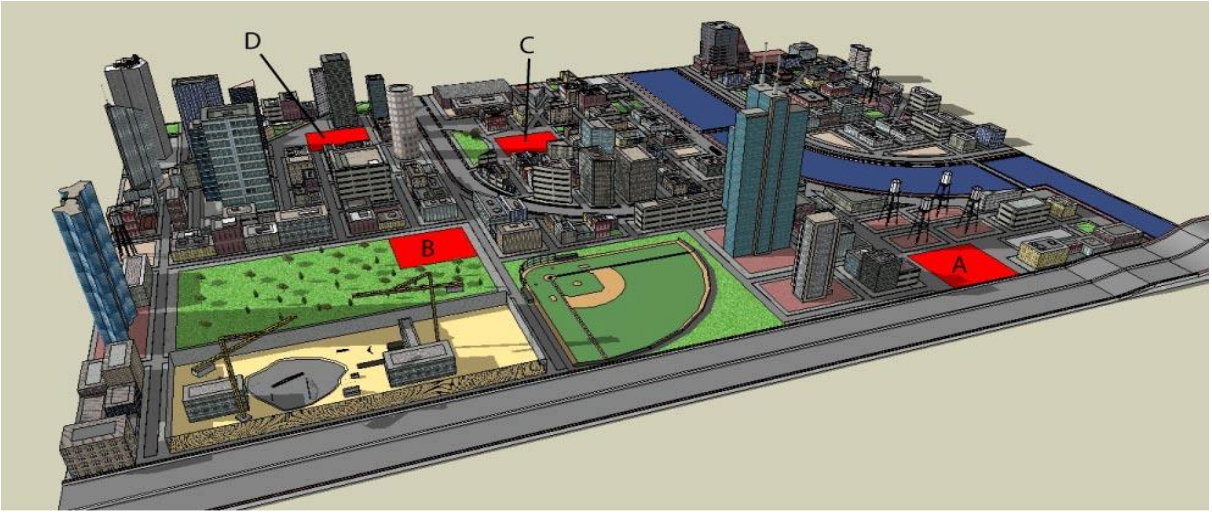


Figure 7: Site location task in oblique 3D view, scene 1.

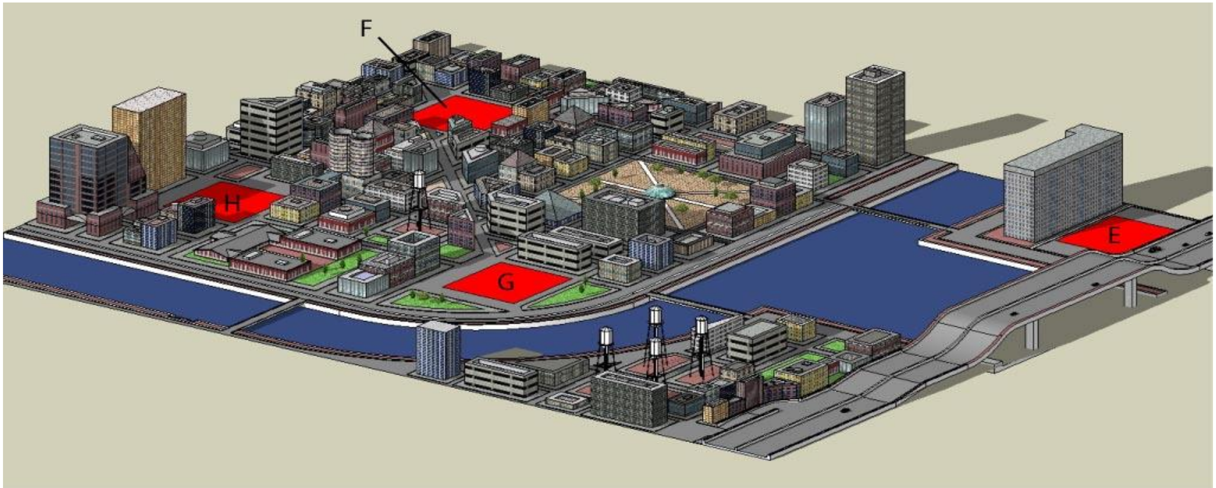


Figure 8: Site location task in oblique 3D view, scene 2.

The task was stated as follows:

> *"Imagine that this is your neighbourhood. A new residential, high-rise building (skyscraper) will be built. Four alternative locations are proposed. Please choose the location that you think is best suited for the building. Possible locations are indicated with a red square and the letters A-D (or E-H).*
>
> *Where should the new high-rise building go? Choose A, B, C or D (or E, F, G or H)."*

3.4.5 Scenario selection

Scenario selection tasks, where individuals are required to choose between different scenarios, are also often used in urban planning. For this task, participants had to vote for two different scenes, namely a park and a playground. This enabled us to observe the contribution of the scene content to the decisions. Two different scenarios for each scene were represented and participants had to state which one they preferred. Both of the scenarios had the same objects but they were arranged differently. The visualisations were shown as a 2D and 3D oblique view. The 2D visualisations are displayed in Figure 9 and Figure 11, the oblique 3D representations in Figure 10 and Figure 12.

Figure 9: Scenario selection task in 2D view, scene 1 (park).

Figure 10: Scenario selection task in oblique 3D view, scene 1 (park).

Figure 11: Scenario selection task in 2D view, scene 2 (playground).

Figure 12: Scenario selection task in oblique 3D view, scene 2 (playground).

The task accompanying the visualisations was:

> *"Your neighbourhood park (or playground) is being redesigned. You will now see two alternative proposals for your new park design. You, as a citizen, can decide which of the two alternatives should be realised through a vote.*
>
> *You visit this park often to play sports with your friends. Which proposal would you choose for the new park?"*

3.4.6 Distance estimation

The third task was a distance estimation task. This is not a direct urban planning decision task as the aforementioned. However, measurement-based examinations are also central in urban planning. Participants can only interpret and evaluate a proposal correctly if they are able to understand the scale of the plan. Furthermore, distance often plays an important part in urban planning. For example, the distance of a new building to the train station may influence citizens' opinion about it. Therefore, this task was included.

Two locations were marked with a red circle (Point A and point B) and participants had to estimate the walking distance in meters to get from one point to the other. A scale was provided next to every visualisation, but no additional tools were allowed to measure the distance. The participants had to solve the task with three different visualisation types: 2D, first-person 3D view and oblique 3D view. For every visualisation type two scenes were used, e.g. there were a total of six visualisations. Three of the six visualisations are presented in Figure 13 to Figure 15. The other visualisations can be found in the survey which is attached in Appendix B.

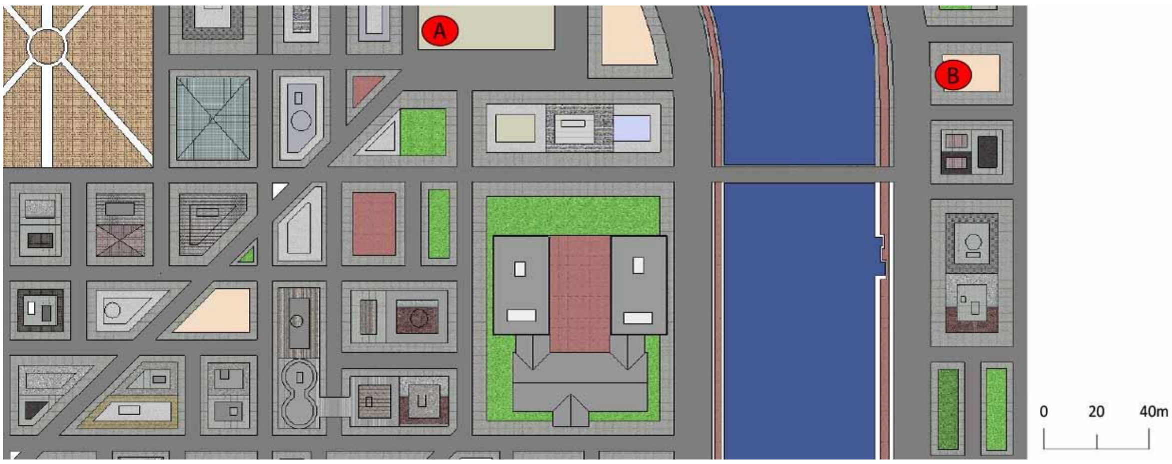


Figure 13: Distance estimation task in 2D view.

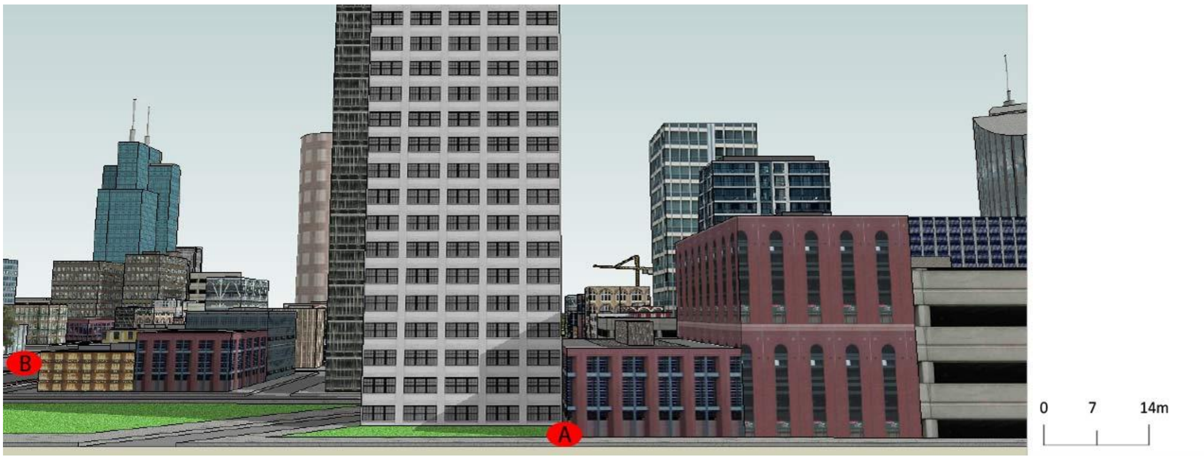


Figure 14: Distance estimation task in first-person 3D view.

Figure 15: Distance estimation task in oblique 3D view.

The task was stated as follows:

> *"What is the walking distance from point A to point B?"*

4 Results

In this chapter, the most important findings and results of the user study are presented. First, general observations are described. Afterwards, the results for each of the three tasks are analysed individually and the difficulty ratings are discussed. Then, the preferences as well as the satisfaction ratings are examined. Finally, the fixation durations that were derived from the eye tracker along with other gaze data are evaluated.

4.1 General observations

Participants were asked how often they used 2D visualisations (maps, plots, other graphics...) and 3D visualisations (city models, terrain models, software such as Google Earth…). The results, which are visualised in Figure 16, showed that on a scale from never (1) to daily (5), participants used 2D visualisations more frequently (Mean (M) = 4.2, Standard Deviation (SD) = 0.8) than 3D visualisations (M = 2.9, SD = 1.0).

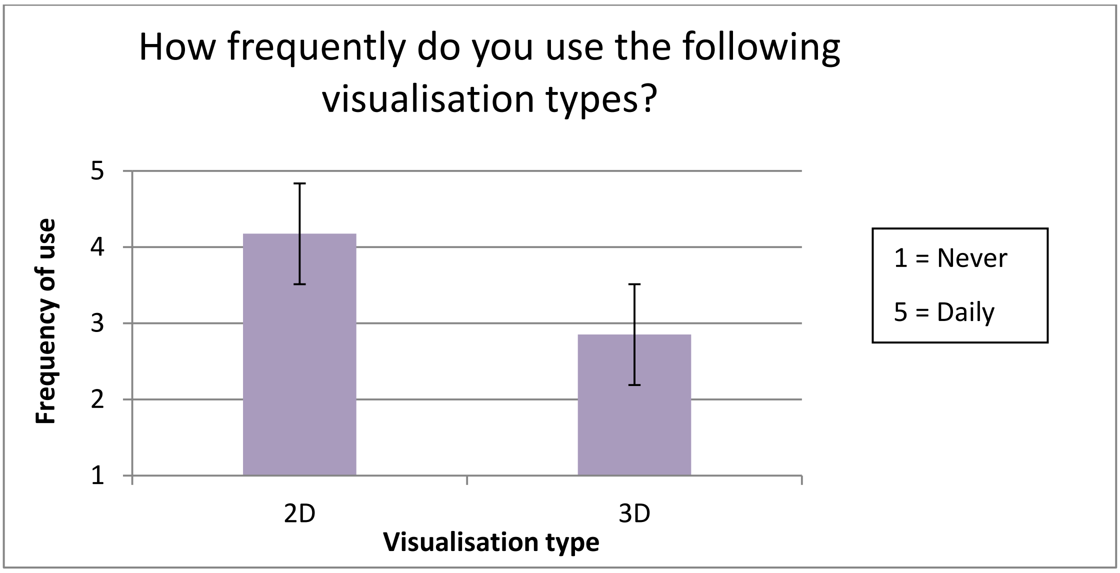


Figure 16: Frequency of use of 2D and 3D visualisations. Error bars: ± Standard Error (SE).

4.2 Tasks

4.2.1 Site selection

For the site selection task, participants were asked to choose the best out of four locations for a proposed high rise building, using a combined 2D/3D and an oblique 3D visualisation (see Section 3.4.4 for the exact wording). Two different scenes were used for this task (Figure 5 - Figure 8). There were some apparent differences between the two scenes for the site location task. Therefore, they are described and analysed separately.

For the first scene (Figure 5 for combined 2D/3D, Figure 7 for oblique 3D), the site selection decisions between the two visualisation types were not significantly different. In both representation types, location D was the most favoured with 90% of the votes in the combined view and 85% of the votes in the oblique 3D view. Location A was observed to be slightly more popular in the oblique 3D visualisation compared to the combined 2D/3D visualisation. Location B had the same amounts of votes for both visualisation types and finally, location C had one vote in the combined view but none in the oblique 3D view. None of the participants chose the option “I don’t know”. The results are displayed in Figure 17. In total, 10% of the participants shifted their decision after seeing the scene with a different visualisation type.

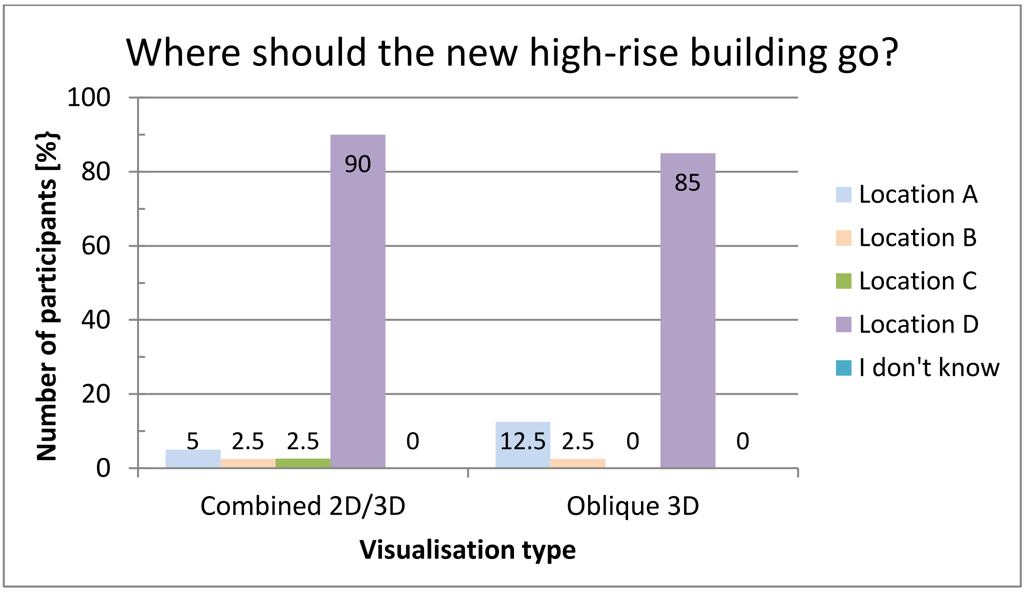


Figure 17: Results of site location task, scene 1.

Participants were asked to give a reason after they voted for an option. According to their (qualitative) responses, the reason for choosing location D was mostly the number of high-rise buildings already present in this area. Many of them argued that a new high-rise building would fit perfectly in that neighbourhood and the city image would not be disturbed.

For the second scene (Figure 6 for combined 2D/3D, Figure 8 for oblique 3D), there were some large differences in participants' decision-making regarding the location between the combined visualisation and the oblique 3D visualisation, as can be seen in Figure 18. In the combined view, location F received the most votes and was closely followed by location E. However, in the oblique 3D view, location F was the second least favoured location and alongside location E, they both had considerably fewer votes than in the combined visualisation. Location H had more than double the amount of votes than the other locations in the oblique 3D visualisation and was the most popular for this visualisation type, whereas it was rather unfavourable in the combined view. Location G was the least voted for location and had the same amount of votes in both visualisation types. For this scene, the different visualisation types caused a decision shift in 42.5% of the participants.

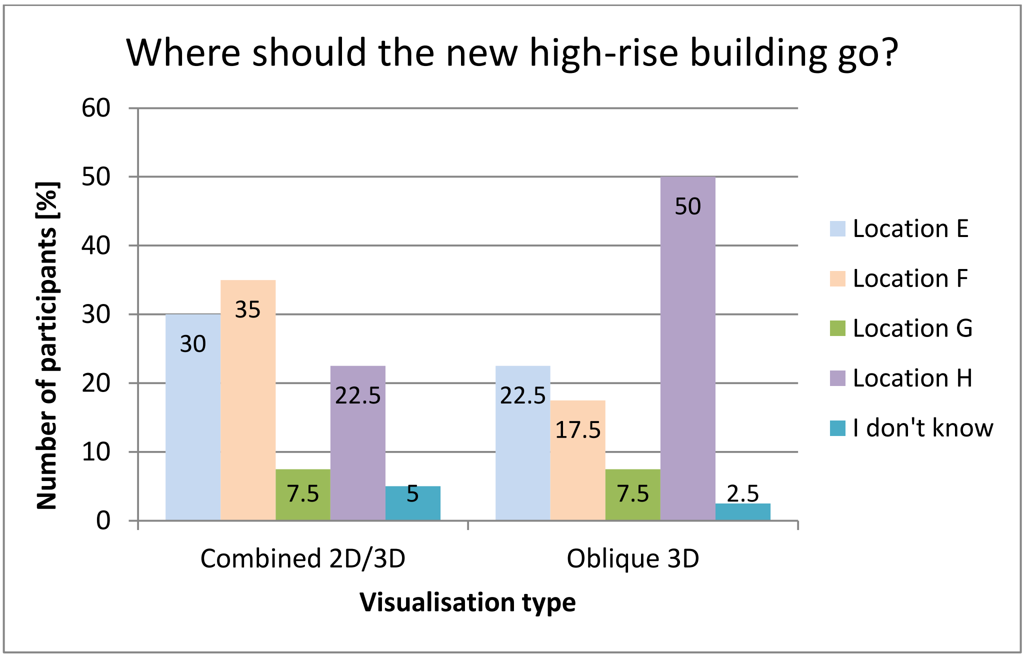


Figure 18: Results of site location task, scene 2.

In response to the qualitative question that inquired their reasons, participants expressed that they favoured location H in the oblique 3D view because of its proximity to other tall buildings. For the combined view, participants did not seem to perceive the surrounding buildings as high and thus decided against that location. Reasons for location F in both visualisation types were that it was in the middle of the city and it was more suited for the surrounding area. Furthermore, it did not affect the view of the river. While some participants chose E for its close connection to the road, others found that the location was too far from the city centre. Two out of 40 participants opted for the answer “I don’t know”, reasoning that the close up visualisation made it difficult to make a decision, as the viewing angle was too small and the perspective was too close to the ground.

4.2.2 Scenario selection

For the scenario selection, participants were asked to choose one out of two different scenarios using a 2D and a 3D visualisation. A more detailed description of the task can be found in Section 3.4.5. Similarly to the site selection task, the scenario selection task was executed using two different scenes

(Figure 9 - Figure 12). Therefore, as in the site selection task, the two scenes for the scenario selection task are also regarded separately.

For the first scene, participants were asked to decide between two alternative scenarios for a park (Figure 9 for 2D, Figure 10 for 3D). The results are displayed in Figure 19.

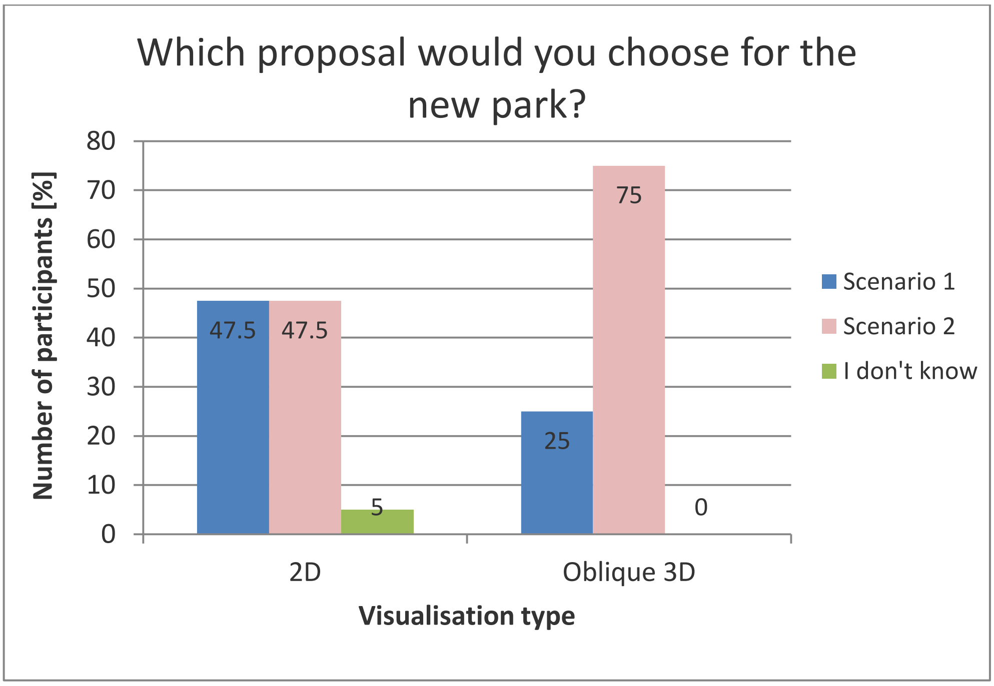


Figure 19: Results of scenario selection task, scene 1 (park).

For the 2D visualisation, scenario 1 and scenario 2 received the same amount of votes (47.5% each). Two out of the 40 participants chose the option “I don’t know”. Scenario 1 was mostly chosen because the soccer field was close to the kiosk while scenario 2 was chosen because the trees and fountain were located near the soccer field. When the scenarios were shown in oblique 3D, the decisions had changed to a large extent. We found that 27.5% of the participants shifted their decision after seeing the scene with a different visualisation type. In the oblique 3D, 75% of the participants chose scenario 2 as opposed to only 25% who chose scenario 1. Most participants asserted that they preferred scenario 2 due to the higher number of trees, which, apparently was not easily interpreted in 2D visualisation.

For the second scene, two alternative scenarios of a playground were compared (Figure 11 for 2D, Figure 12 for 3D) and participants were asked to vote for either of the two scenarios. Figure 20 shows the results of the task. This time, the visualisation type caused a decision shift for 22.5% of the participants.

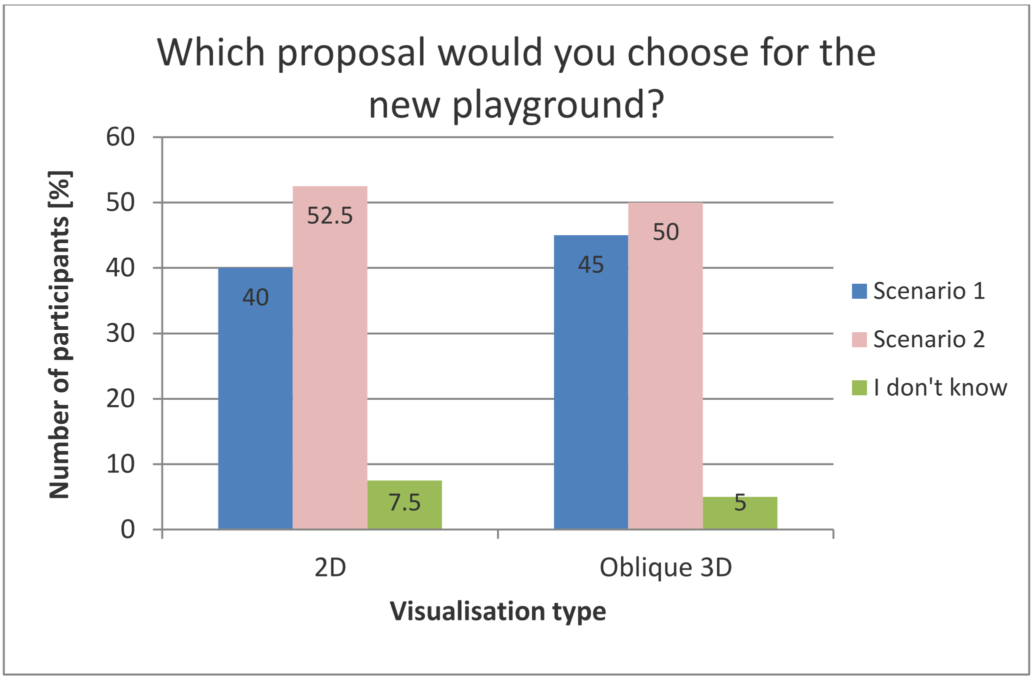


Figure 20: Results of scenario selection task, scene 2 (playground).

Reasons for choosing one scenario were in both visualisation types the arrangement of the playground facilities and the benches. Additionally, some individuals preferred to have the toilets in the corner of the park whereas others preferred to have them closer to the centre of the park. Furthermore, participants explained that they voted for one scenario or the other in the oblique 3D view because it looked “more spacious” or “more open“. However, as Figure 20 shows, in this particular scene, the voting patterns remained somewhat similar for the two visualisation types, unlike the big differences in the first scene (Figure 19). This further asserts the importance of the scene content.

4.2.3 Distance estimation

For the distance estimation task, participants were asked to estimate the distance to get from point A to point B, using a 2D, oblique 3D and first-person 3D visualisation (Figure 13 - Figure 15). The task is described in Section 3.4.6. When analysing the distance estimation questions, at the data pre-processing stage, we observed that one participant entered the value for the distance estimation incorrectly and put 1500 instead of 150. This value affected the results to a large extent when we calculated the means. Thus, before analysing the data, this outlier was removed from the data, as suggested by Field (2009). To see how participants performed with the different visualisation types, the estimated distances were compared to the actual distances and then grouped into three categories based on their accuracy: good (<11m), moderate (11-50m) and bad accuracy (>50m). The results are displayed in Table 2. As expected, participants had the highest accuracy when using the 2D visualisations. With the two 2D visualisations, 27.5% of the participants had a good accuracy and 37.5% a moderate accuracy. For the two first-person 3D visualisations, only 2.5% had a good accuracy and 22.5% had a moderate accuracy. The oblique 3D visualisations clearly showed to have the worst performance. Only 7.5% of the participants had a moderate accuracy and the rest achieved a bad accuracy. We further found that the differences between the genders were not significant ($p > .05$). This may indicate that the ability to estimate the correct distance is similar for both genders.

	Visualisation type		
	2D	**First-person 3D**	**Oblique 3D**
Good accuracy	27.5%	2.5%	-
Moderate accuracy	37.5%	22.5%	7.5%
Bad accuracy	35%	75%	92.5%

Table 2: Accuracy of distance estimation task.

It may also be interesting to look at the estimated distances in more detail. With the 2D visualisation, 51% of the participants overestimated and 36% underestimated the distance. For the 3D first-person view, 6% overestimated and 94% underestimated the distance. The results for the oblique 3D view are very similar: 1% overestimated and the remaining 99% underestimated the distance. In short, overestimation was more common with the 2D visualisations whereas underestimation occurred more frequently with the 3D visualisations.

4.3 Difficulty rating

To get a closer insight into the usefulness of the individual visualisation types, it may help to look at the difficulty rating which took place after every task. Participants were asked to rate on a five-point Likert scale how easy it was to make a decision based on the visualisations. 1 indicated it was very easy whereas 5 indicated that it was very difficult to make a choice. The results from this difficulty rating, summarised over the two direct urban planning tasks (site selection and scenario selection), are shown in Figure 21.

The results for the site selection task (where participants worked with oblique 3D and combined 2D/3D views) show that on average, participants found it easier to make a decision based on the oblique 3D visualisation (M = 1.9, SD = 0.8) than the combined 2D/3D visualisation (M = 2.4, SD = 1.0). The main argument for the oblique 3D view was that all locations were displayed on the same map, as opposed to the first-person 3D view. The visualisation was further valued for its better overview of the whole area. Participants stated:

> “Every relevant location and their surrounding buildings are directly visible.”

> “I can make a decision much faster when I have a complete overlook like this.”

Opposed to this, comments about the combined 2D/3D visualisation hinted that this visualisation type was less helpful, as the relationship to the surrounding was not presented explicitly and needed to be extracted from the abstract 2D overview. As a consequence, it was difficult to imagine how the new building would fit into the neighbourhood. Furthermore, the matching of the two views in the combined visualisation was perceived as challenging and time-consuming. Additionally, it was reported that switching between the views caused some confusion. Nevertheless, participants found that the combined 2D/3D visualisation was still helpful to make a decision. Some participants argued that the combined visualisation was more helpful than the oblique 3D visualisation since it showed more details of the individual locations, which made it easier to decide for or against a location. As a particular advantage, participants mentioned that by using the combined visualisation, the same location could be viewed from two views. According to the participants, the 2D view provided a good overview of the context and the 3D view provided information on the height of the buildings and the sense of the place. Thus, the two images supported each other and offered a good foundation to make a decision. One participant commented on this by saying:

> "Both the 2D map and the 3D visualisation help to imagine the impact of the building in terms of the surrounding areas and buildings."

Another participant explained that the combination of both visualisations was important to form an opinion and added:

> "I probably would have made a different decision if I only saw the 2D or 3D maps."

The ratings for the scenario selection task were similar to the ones for the site selection task. The difficulty ratings showed that for the park and playground scenarios participants found it slightly easier to make a decision with the oblique 3D visualisation (M = 2.3, SD = 1.0) than with the 2D visualisation (M = 3.0, SD = 1.1). Participants stated that it was rather challenging to make a decision based on the 2D visualisations. Two of the participants mentioned that it was difficult to imagine how the scenarios looked in reality. However, in general, both visualisation types were considered less helpful to make a choice compared to the previous task.

In conclusion, for urban planning tasks (site and scenario selection combined), participants found that it was easiest to make a decision based on the oblique 3D visualisation (M = 2.1, SD = 0.7), followed by the combined 2D/3D visualisation (M = 2.4, SD = 1.0) (See Figure 21). Participants considered the 2D view less helpful for the decision-making process (M = 3.0, SD = 1.1). A repeated measures ANOVA was performed to compare the difficulty ratings for all visualisation types. The test revealed that the ratings for the three visualisation types were significantly different [$F(2, 150) = 22.049$, $p < .01$].

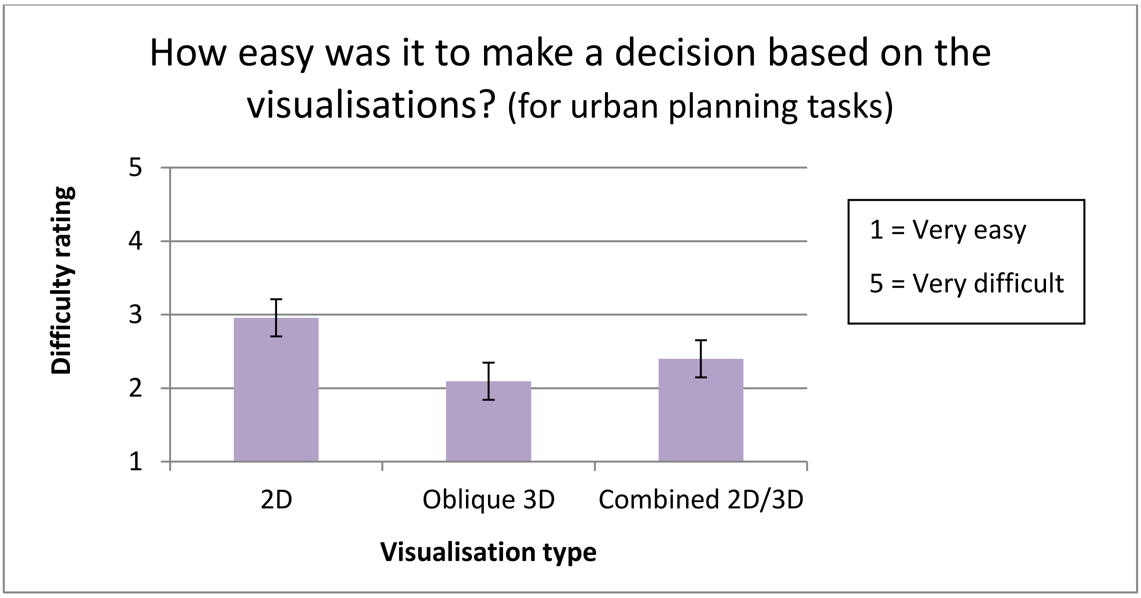


Figure 21: Results of difficulty rating for site selection and scenario selection tasks. Error bars: ± SE.

The difficulty ratings for the distance estimation task are shown in Figure 22. Again, the difficulty ratings were significantly different for the three visualisation types [$F(2, 158) = 88.307$, $p < .01$]. For this task, the 2D visualisation was clearly rated easiest (M = 2.5, SD = 0.8). As for the two 3D representations, participants stated that the oblique 3D image made the decision-making slightly easier (M = 3.8, SD = 1.0) compared to the 3D first-person view (M = 4.0, SD = 0.8). These findings contradict the performance results, which were discussed in Section 4.2.3.

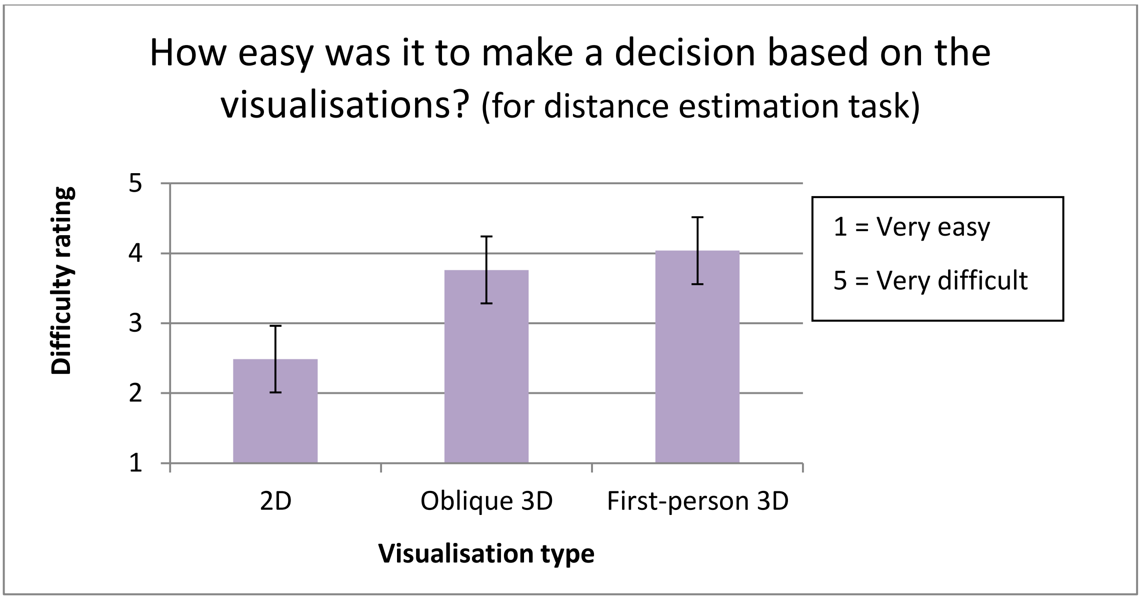


Figure 22: Results of difficulty rating for distance estimation task. Error bars: ± SE.

4.4 Preference and Satisfaction

At the start of the experiment, participants were asked to state their preference for different visualisation types for the three tasks route planning, site selection and scenario selection. The results of the overall preference ratings are presented in Figure 23 and Figure 24. The preference ratings showed that participants preferred each view to some extent and their preferences differed when the tasks varied. The analysis further showed that there were no significant differences in the preferences for a specific visualisation type between females and males ($p > .05$). Further findings are described per task type in the next sections.

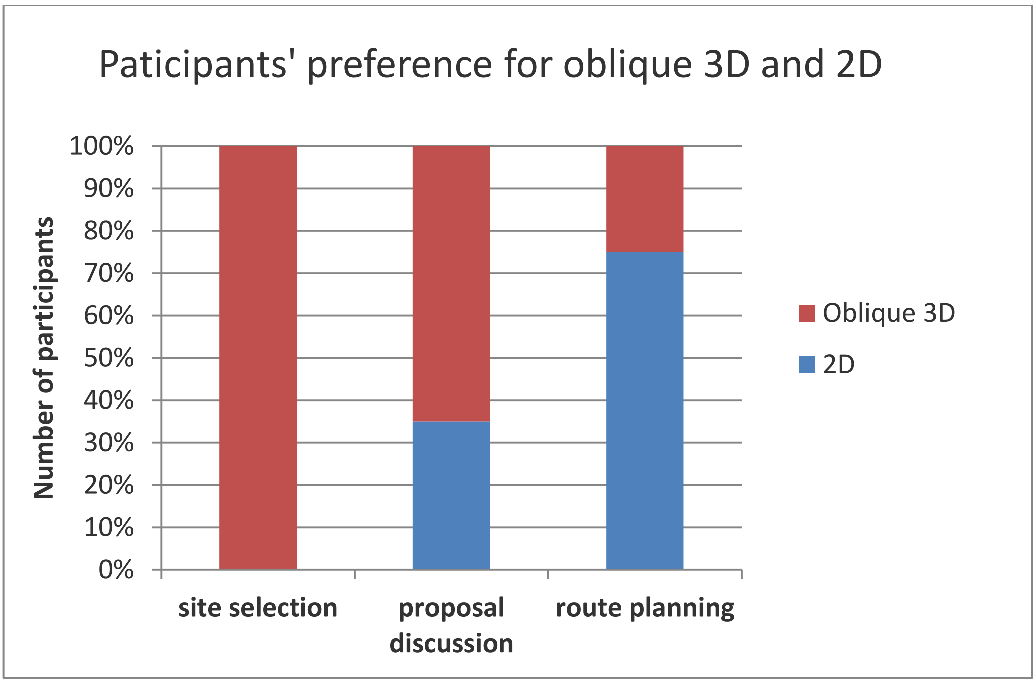


Figure 23: Preferences for oblique 3D and 2D for specific tasks before task completion.

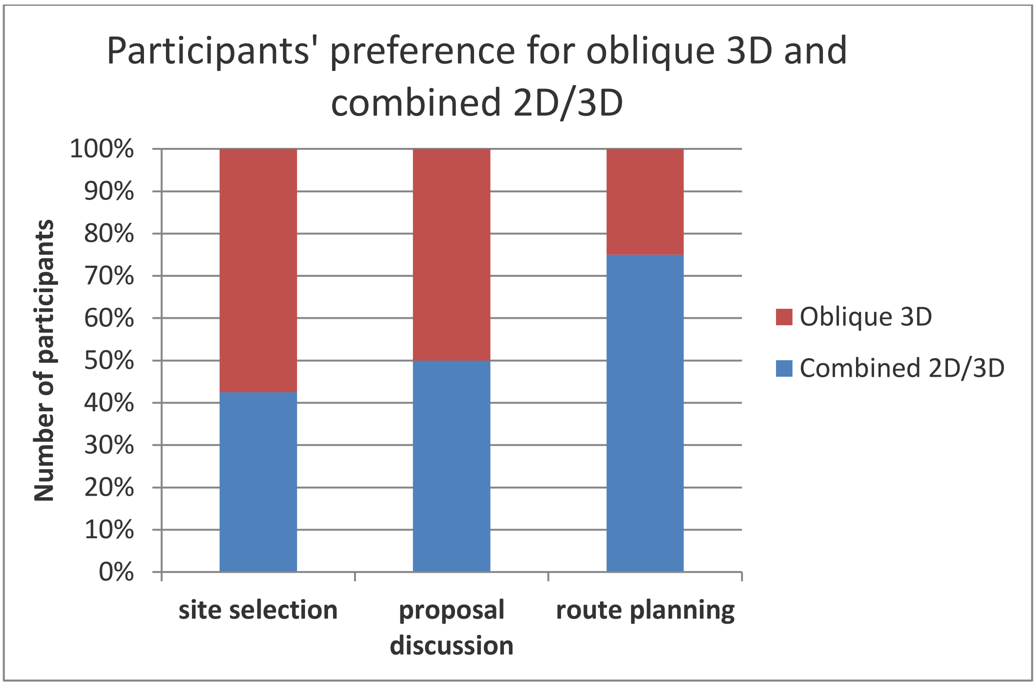


Figure 24: Preferences for oblique 3D and combined 2D/3D for specific tasks before task completion.

4.4.1 Site location

The preference question was asked before and after executing the tasks. Before completing the experiment, *all* participants stated that they would choose an oblique 3D visualisation over a 2D view to make a decision regarding the placement of a new high-rise building (Figure 23). Reasons for that decision were mostly that a 3D view was needed to see the height of the buildings. When asked about their preference between an oblique 3D and combined 2D/3D view, 57.5% of the participants stated they would choose an oblique 3D visualisation (Figure 24). Arguments for the oblique 3D were that it offered a better general overview and was more graphically pleasing. It was also argued that the oblique 3D view allowed participants to better judge the size and shape of shadows. On the other hand, individuals who preferred the combined view said that the first-person 3D view offered a more natural view than the oblique 3D view. One participant also reported that it was easier to compare the height of buildings in a first-person 3D view.

After completing the first site location task, participants were asked again which visualisation type they preferred. This time, 72.5% of the participants found the oblique 3D visualisation more appropriate than the combined 2D/3D view. Explanations were that it offered a better overview of the whole situation, as a larger area could be represented at once and all the locations could be seen side by side within the same visualisation. Other participants also stated that the locations could be identified more easily and the visualisation was more straightforward and quicker to understand:

> "The impact can easily be imagined using the oblique map."

On the contrary, arguments for the combined 2D/3D view were that the 2D view showed the exact locations better and there were no problems with occlusion.

4.4.2 Scenario selection

For the scenario selection task, the preference question was only asked before the completion of the experiment. We asked participants which visualisation they would prefer to discuss the proposal for a new park, which is comparable to our scenario selection task in the experiment. The majority of the participants (65%) would prefer an oblique 3D over a 2D visualisation for this task (Figure 23). Reasons were that the 3D view provided a more "real" representation and was more appealing. Other participants stated that the 2D display was superior as the arrangement could be better judged. In addition, the 3rd dimension was not necessary to make a decision as there was no significant height information in a park. A comparison of the preferences for the oblique 3D and combined 2D/3D display showed that there was an even split between the two displays in terms of which one was favoured (Figure 24).

4.4.3 Distance estimation

Before the completion of the experiment, we asked the participants which visualisation they preferred for a route planning task. We assumed that route planning was important for distance estimation and therefore put this task type under the general term distance estimation. We found that 75% of the participants preferred the 2D or the combined 2D/ first-person 3D over the oblique 3D visualisation (Figure 23 and Figure 24). Several participants commented that the reason behind choosing the 2D was that all roads were visible, whereas in the 3D the roads were occluded by buildings. Thus, the occlusion in the 3D visualisation seemed to be a large disadvantage. Other participants stated that the 2D visualisation offered a better overview. A further argument for the 2D visualisation was its familiarity:

> "Due to conventional maps we are used to 2D visualisations."

In contrast, arguments for the 3D were that it offered a more realistic representation of the buildings and landmarks and that the houses gave a good impression of the scale.

Some participants commented on the usefulness of the two views in the combined visualisation. They noted that this visualisation type was ideal for a route planning task as it offered a 2D map, which was valuable to get an overview, and a 3D map, which helped to see the form and the facades of the buildings.

4.4.4 Usability of visualisations for geographic tasks

At the end of the questionnaire, participants were asked whether they would use a specific visualisation type for a set of geographic tasks. More than one visualisation could be selected for each task. The task categories were adopted from the Master's thesis by Boer (2012), who defined the tasks according to Carter (2005). The seven tasks were self-location, locating objects, route planning, real-time navigation and way-finding, identifying places of interest, communication and virtual tourism. We also added the category urban planning related decisions.

Table 3 presents how many participants would use each visualisation type for the predefined tasks. Participants perceived the 2D display to be useful for self-location, locating objects, route planning and real-time navigation or way-finding. The majority of the participants would use the oblique 3D, rather than the 2D or combined view for tasks that involve communication, urban planning and virtual tourism. For identifying places of interest, the combined representation received more votes than the other visualisation types. It was further rated useful for self-location and locating objects.

	2D	3D	Combined 2D/3D
Self-location	95%	45%	92.5%
Locating objects	95%	37.5%	95%
Route planning	97.5%	15%	77.5%
Real-time navigation and way-finding	85%	37.5%	72.5%
Identifying places of interest	65%	50%	77.5%
Communication	27.5%	87.5%	50%
Virtual tourism	7.5%	92.5%	60%
Urban planning related decisions	30%	87.5%	55%

Table 3: Percentage of participants who would use 2D, oblique 3D and combined 2D/3D visualisations for selected tasks. Multiple answers were possible.

4.4.5 Satisfaction

After the task completion, participants had to rate whether they strongly disagreed (1) or strongly agreed (5) with statements about the visualisations. The satisfaction statements can be found at the end of Appendix B. The Likert responses were aggregated over all variables to give each representation type a total score to reflect its perceived satisfaction. The results are shown in Figure 25. The strict 2D visualisation received the lowest satisfaction rating ($M = 2.9$, $SD = 0.4$), followed by the oblique 3D ($M = 3.1$, $SD = 0.3$) and ultimately the combined 2D/3D visualisation ($M = 3.3$, $SD = 0.5$). A repeated measures ANOVA was performed to compare the means of the satisfaction ratings for all visualisation types. The test revealed that there was a significant difference between the three visualisation types [$F(2, 78) = 16.819$, $p < .01$]. Further, a Bonferroni post hoc test was conducted to analyse the differences in detail. The results showed that there was a significant difference between all three visualisation types ($p < .05$). The difference between the 2D and combined 2D/3D visualisation was even highly significant ($p < .01$).

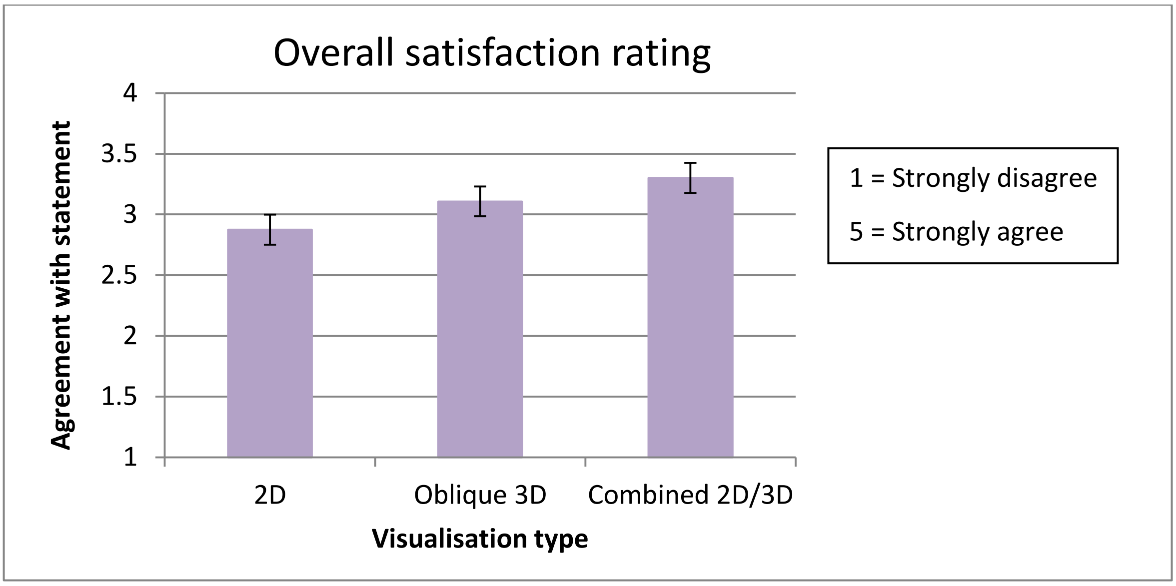


Figure 25: Results of overall satisfaction rating. Error bars: ± SE.

The satisfaction ratings per predefined variables are displayed in Figure 26. The combined visualisation generally received high ratings for most categories. However, it was ranked least in terms of complexity and distraction. The oblique 3D view received the highest satisfaction ratings in the categories helpful, attention-catching, aesthetically pleasing, attractive and usefulness for planning decisions. The only variables where this visualisation type was considered less desirable were its complexity and the usefulness for a distance estimation task. Without the last factor, the oblique 3D would have had the highest satisfaction score. The 2D display was rated the most clear and received the highest satisfaction score for the usefulness in a distance estimation task.

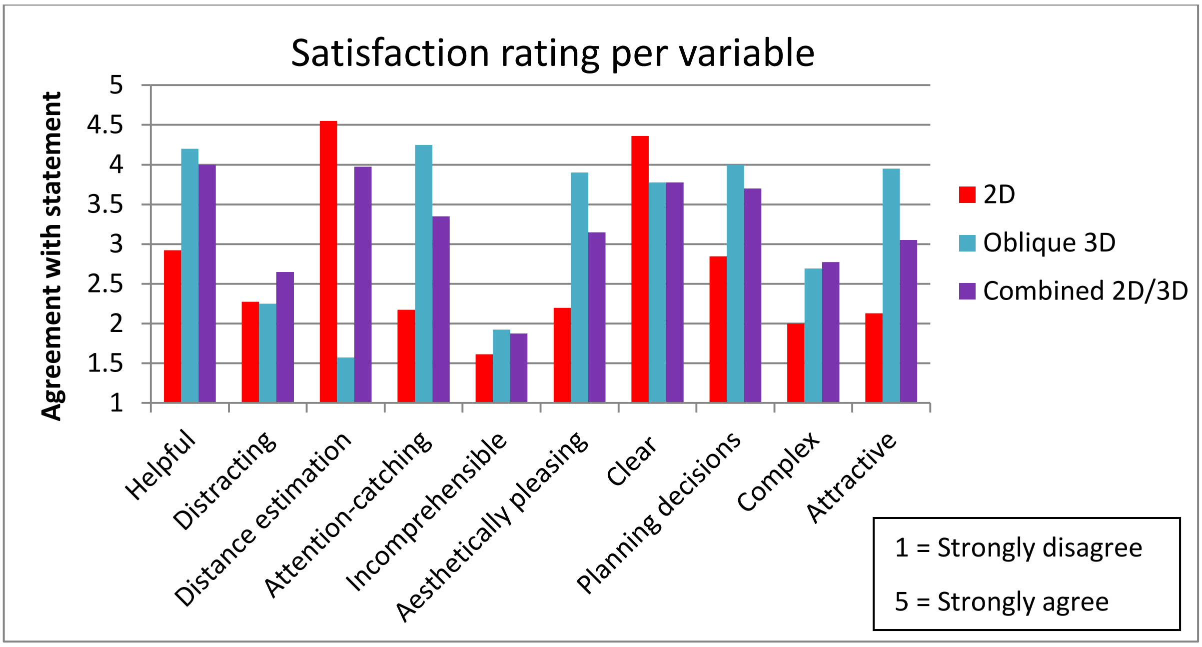


Figure 26: Results of satisfaction rating per selected variables.

Additionally, we asked individuals how they perceived the amount of information in the visualisations for urban planning tasks (1 = too little, 5 = too much). Participants rated the amount of information to be slightly inadequate for the 2D visualisation ($M = 2.1$, $SD = 0.9$), sufficient for the oblique 3D ($M = 2.9$, $SD = 0.8$) and a little too excessive for the combined view ($M = 3.2$, $SD = 0.8$).

4.5 Gaze data

4.5.1 General observations

In the second scene of the site location task, participants did not seem to recognise that there were tall buildings in the combined 2D/3D visualisation, as discussed in Section 4.2.1. However, in the corner of the 3D first-person view of location H, part of the high-rise building was visible as well as a shadow in front of it (See Figure 27). The shadow indicated that there was another high building next to the structure in the corner.

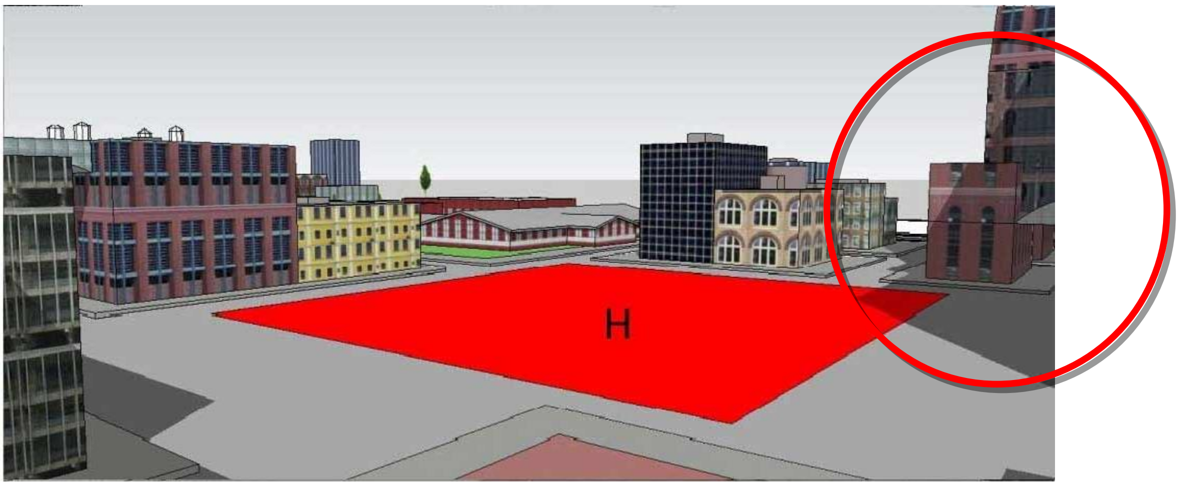


Figure 27: Site location task with high-rise building and shadow.

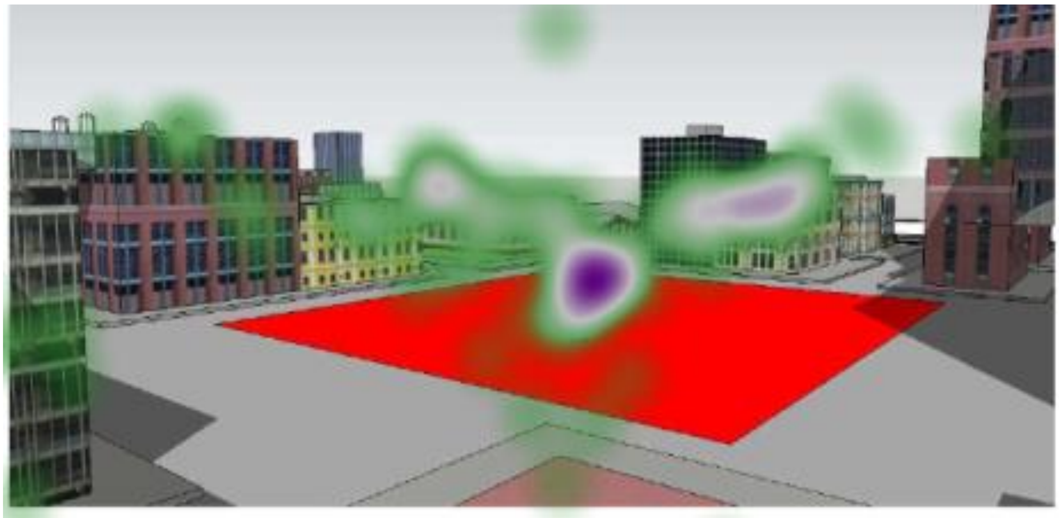


Figure 28: Heat Map of site location task.

Figure 28 illustrates the durations of gaze fixations as a heat map. The minimum fixation duration was 100ms and the fixation filter was set to a radius of 50 pixels. The green colour indicated a low and the purple colour indicated a high degree of visual attention. The eye-tracking analysis showed that participants did not focus much on the high-rise building located in the corner nor the shadow next to it. The attention was mostly on the buildings in the middle of the visualisation behind the red square. Thus, it seemed that they missed the information that there were two high-rise buildings in the surrounding and did not take it into consideration when making the decision.

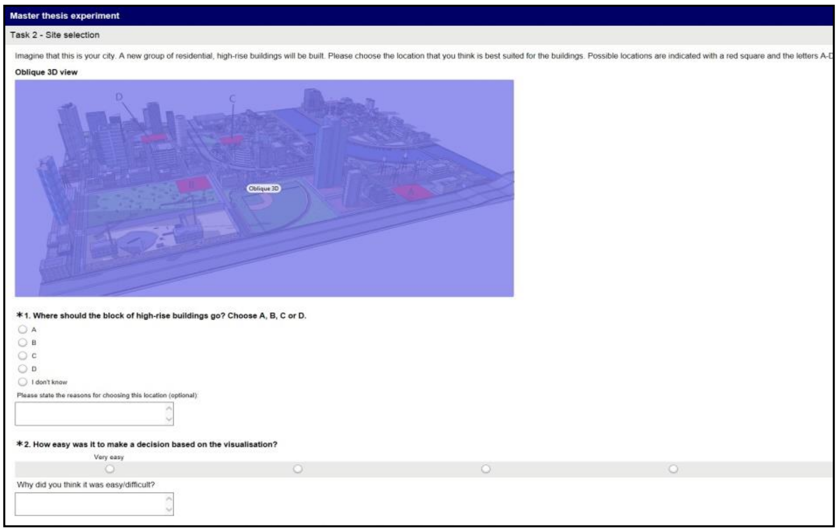
4.5.2 Fixation durations

For the combined 2D/3D visualisation, it was interesting to learn if participants mainly focused on one of the two views or if they considered both views as equally important. To test the relative importance of both views, areas of interest (AOI) were defined. In the site selection task, the four 2D and four 3D first-person views of the combined visualisations were selected, resulting in 8 AOIs per scene. The AOIs can be seen in Figure 29a. The time participants spent fixating the visualisations was extracted and averaged for each of the two visualisation types.

Some of the fixation durations of a few participants were missing or incorrect, resulting in values of 0 seconds. These were removed before the analysis. On average, participants spent 21 seconds looking at the first-person 3D view and 15 seconds analysing the 2D view. These results show that, overall, the fixation durations were longer for the first-person 3D view. This visualisation type therefore received more attention than the 2D view, although some individual differences occurred. Nevertheless, the results imply that both views were regarded as important for making a decision.

An additional AOI was defined for the oblique 3D visualisation to compare it with the combined view (See Figure 29b). We found that on average, participants spent 19 seconds looking at the oblique 3D representation. This value lies between the two fixation times for the 2D (15 seconds) and 3D first-person view (21 seconds). The results indicate that participants spent more time looking at the first-person 3D visualisation than the other two representation types.

a)



b)

Figure 29: AOIs for site location task, a) combined visualisation, b) oblique 3D visualisation.

5 Discussion

This chapter is dedicated to the discussion of the results in relation to the research questions and related literature. In addition, limitations of the experiment are presented.

5.1 Research questions

The first research question was:

1. **Do the decisions change, based on visualisation type? If yes, why?**
   - **For a site selection task**

The results of the first scene for the site location task show that there are minor differences in individuals' choices based on the visualisation type. Location A received more and location C less votes in the oblique 3D visualisation than the combined view. Participants stated that the closeness to other high buildings and the river made location A more favourable. However, location D was the most popular location for both visualisation types, which could mean that in most cases, the two representation types led to the same decisions. This could indicate that there is no significant influence of the visualisations type on the decision-making process. This assumption is contradicting to literature that says the way information is presented drives the decision processes, as for example discussed by Dennis & Carte (1998). Yet, the second scene for the site location task reveals that participants changed their decision to a large extent, depending on which visualisation type they saw. These results allow us to interpret that even though both visualisation types showed the same area, participants extracted different information and details from them, which led to changes in decisions. This is in line with literature about the influence of information representation on the decision process (Dennis & Carte 1998). Participants' comments for the second scene of the site selection task can help analyse what the cause of their change in decision was. A few participants expressed that the heights of the surrounding buildings were not as clear in the combined view as in the oblique 3D view. Their comments on the combined view were:

> "In this view I can't see the high buildings near (location) H."

> "The buildings in (location) H don't seem high from this point of view."

After seeing the oblique 3D view, another participant commented:

> "Spot "H" would have been applicable as well. This was not clearly visible in the combined 2D/3D example."

Bill Jepson, founder of the Urban Simulation Laboratory, stated that the public wants a new project to blend in with the surrounding neighbourhood (Delaney 2000). As a result, if a building or other project fits in well with its surrounding area, the neighbourhood environment will be improved. This implies that participants prefer to position the new high-rise building in a neighbourhood with other tall buildings. For the second scene in our experiment, participants only perceived the neighbourhood with skyscrapers in the oblique 3D visualisation. For the combined 2D/3D visualisation, participants seemed to find it difficult to assess the height of the neighbouring buildings and imagine how the building would fit into the neighbourhood. Reasons could be that the viewing angle hampered the understanding of the shown content or that the visualisation was too complex to comprehend. Thus, this complicated extraction of the height of the surrounding buildings in the combined view seemed to have influenced their decision.

A further important finding is that the number of participants who changed their decision was considerably different between scene 1 and scene 2, demonstrating the importance of the scene content when evaluating visualisations. For the first scene, only 10% of the participants made a decision change, whereas it was 42.5% for the second scene. Because we used the same participants and same tasks, the difference between the two scenes can be attributed to the scene content. The variances may have come from the distinct difficulty to vote for a location in one of the two scenes. The area with high buildings could be identified more easily in the first scene and for this reason, it may have been easier to decide for a location. According to Simon (1987), logical decision-making consists of comparing and evaluating alternatives. One can argue that this comparison of different alternatives was easier for the first scene, as the different locations differed in regard to height of the neighbouring buildings to a larger extent than in the second scene and thus a decision could be reached faster or more easily. For the second scene, participants seemed to have trouble recognising the high buildings already present in the area. The analysis of the gaze data supported this. The heat map of participants' fixations showed that they did not look at the tall building in the corner nor the shadow next to it.

We can conclude that the decision changes with the presentation of different visualisation types. This effect seems to be especially large for scenes with a large variation of buildings' heights. As a result, it may be useful for urban planners to show the scene with an oblique 3D view, if there is a larger variation of high-rise buildings or other height information.

The second part of the first research question was:

1. **Do the decisions change, based on visualisation type? If yes, why?**
    - **For a scenario selection task**

For the scenario selection tasks, 27.5% of the participants shifted their decision in the first scene (park). In the 2D visualisation, participants seemed to struggle to decide between the two scenarios, resulting in both scenarios receiving the same amount of votes. Participants reported that it was difficult to imagine the scenarios based on the 2D visualisation. Zeleny (1982) reasons that to go from the pre-decision to the post-decision stage, all alternatives are evaluated and the most unsuitable ones are removed. However, he states that when different alternatives are equally attractive, a sense of conflict arises. For our experiment, this could mean that participants had difficulties to move past the pre-decision stage, as the alternatives were equally preferable. This problem seemed to be less extreme in the oblique 3D. For this visualisation type, one scenario was preferred, which could indicate that the decision-making process was facilitated and thus resulted in a different decision outcome. The different choices in the oblique 3D visualisation appeared to be caused mostly by the distinct representation of the trees. One participant stated that the 3D visualisation had more information about the trees than the 2D visualisation. Another participant explained the change in decision as follows:

> "Now I changed my opinion because the right option has more trees."

Even though both visualisation types displayed the same scenarios and had the exact same amount of trees, it seemed that the oblique 3D view provided a different and better impression of them. Either participants were not able to interpret the symbols for the trees in the 2D image easily, or when they saw the realistic representation of the trees, their imagination of the park was affected. If trees or other objects are important for the task and the scene, we therefore recommend using 3D visualisations to avoid confusion with unclear symbols and allow better imagination of the scene. However, sometimes trees are put into the scene to make it look more attractive, but they are not actually part of the plan or will not be arranged in that specific way. In this case, the visualisation of such objects in 3D might influence the decision to a large extent which may not be justifiable, as they are not the focus of the proposal. Thus, it may be more reasonable to present the plan in a 2D visualisation.

For the second scene (playground), 22.5% of the participants shifted their decision. For this scene, one finding is related to the *sense of place*. In general, the comments about the reasoning for individual's decisions were very similar for both visualisation types. But, for the oblique 3D visualisation, the individuals also made remarks about the aesthetics, ambience and layout of the scene. According to some participants one scenario looked "friendlier", "more spacious", "less packed" and "more open". Thus, adding the third dimension may have enabled the participants to better understand the arrangement of the objects in the scene. St. John et al. (2001) revealed that 3D visualisations can help to understand shapes as well as the layout of scenes. This was confirmed, at least to some degree, with our study. We can accordingly suggest that if the layout of the scene is important, a 3D visualisation may be more helpful.

The first part of the second research question was:

2. **Which visualisation type is rated the easiest and why?**
    - **For a site selection task**
    - **For a scenario selection task**

The results showed that for a site selection and scenario selection task, the oblique 3D visualisation was rated easier than the 2D and combined 2D/3D visualisation. These discoveries indicate that for a direct urban planning decision-task, an oblique 3D visualisation may be more helpful to make a decision. This is in agreement with the findings of Wu et al. (2010) who stated that designers started using 3D technologies to provide the public with a more intuitive visualisation. Herbert & Chen (2014) formulate that a 3D view may be useful for developing a sense of the context that a building is situated in. This aspect also seemed to be important in our study. Participants valued the oblique 3D view because it provided a better overview of the whole area and all locations were shown on the same map, which seemed to facilitate decision-making. Additionally, individuals valued the more natural representation the 3D provided compared to the 2D view. This finding is supported by Lai et al. (2010), who argued that the natural depiction of the world can make it easier for users to interpret the visualisation.

On average, the combined 2D/3D visualisation was considered helpful to make a choice. This is also supported by literature (for example Bleisch & Nebiker (2008)). Participants explained that the two views supported each other and made the decision-making easier. The 2D view helped to get an overview of the scene and the first-person 3D view provided information about the height of the buildings and the atmosphere of the location. That being said, the switching between the two displays was considered as irritating and time-consuming. Furthermore, two out of 40 participants stated that in the first-person 3D visualisation, the viewing angle was too small and the perspective too close to the ground, which made it difficult to interpret the scene. Hence, we can assume that participants could not get a satisfactory impression of the neighbouring buildings and therefore perceived the oblique 3D view as more useful.

The second part of the second research question was:

2. **Which visualisation type is rated the easiest and why?**
   - **For a distance estimation task**

For the distance estimation task, the results were reversed to the other tasks. The 2D visualisation was rated easiest, followed by the oblique 3D and then first-person 3D view. Not surprisingly, these findings are comparable to previous studies which examined the usability of 2D and 3D displays for metric tasks. For example, Herbert & Chen (2014) found that 2D visualisations were perceived more useful for measurement-based tasks than 3D representations. In our experiment, individuals stated they used 2D maps more frequently than 3D models. This may indicate that they are more accustomed to that visualisation type which may explain the high usefulness score. A significant disadvantage of 3D visualisations that may have affected their usefulness was their inherit distortions. St. John et al. (2001) and Lind et al. (2003) discuss how the judgment of distances in 3D models is hampered as distances and angles are not represented truthfully. Distortions aside, the findings by Tory et al. (2007) provide another possible explanation for the high difficulty rating of 3D displays. They argue that the occlusion in 3D images complicates data interpretation and impairs performance. We can support this with our study. Several participants explained that the hindered visibility of all roads was a reason why they perceived the 3D as undesirable. Ratings for the two 3D visualisations showed that participants rated the oblique view easier than the first-person view. This may be due to the larger occlusion in the first-person 3D view compared to the oblique view.

The third and last research question was:

3. **How do the preference ratings before task execution compare to the satisfaction ratings after the task completion?**

Before completion of the tasks, participants preferred the 2D and combined 2D/3D visualisation for distance estimation tasks. Participants especially valued that there was no occlusion of the roads in the 2D view. The preference ratings after the task completion revealed similar findings. The 2D map was perceived most useful for self-location, identifying locations, route planning and real-time navigation or way-finding. These discoveries are similar to those from Boer (2012). Additionally, the satisfaction ratings showed that the 2D visualisation was ranked the most useful for distance estimation tasks and was perceived as the easiest to understand. On the other hand, it was considered less helpful for urban planning tasks, as information about the third dimension was missing. In conclusion, the preference and satisfaction ratings for the 2D visualisations are comparable.

Boer (2012) used a 3D street model, which can be compared to our first-person 3D view in the combined visualisation. Similar to our results, she also found that this view was rated useful for identifying places of interest. Yet, in her study, the street view received only a few votes for the tasks self-location and locating objects. This could indicate that the high votes for these tasks for the combined 2D/3D visualisation in our experiment were influenced by the 2D view.

The preference ratings further showed that the oblique 3D representation was preferred over the 2D for site selection and scenario selection tasks. The 3D oblique and combined representations were almost equally preferable. The oblique 3D view was favoured for its ability to simultaneously provide an overview and detailed view of the scenario. After the task completion, 87.5% of the participants stated that they would use the oblique 3D visualisation for an urban planning task, whereas only 55% would use the combined view and 30% the 2D view. In addition, the satisfaction ratings for making urban planning decisions revealed that the oblique 3D visualisation was rated slightly more useful than the combined 2D/3D visualisation and significantly more useful than the 2D visualisation. Besides being perceived as the most useful for urban planning tasks, the oblique 3D view also received the highest satisfaction ratings in the categories helpful, attention-catching, aesthetically pleasing and attractive. Furthermore, unlike Cockburn & McKenzie (2002) who stated that 3D visualisations can be too cluttered and thus less effective, participants in our experiment considered the oblique 3D visualisation to have an adequate amount of information for an urban planning task. In general, before as well as after the task completion (with the exception of usefulness for metric tasks), this visualisation type appears to be the most favoured in our experiment. These findings are supported by previous research that discussed the value of 3D models in urban planning, especially for non-experts. For example, Hanzl (2007) reports that 3D models are easy to understand and may be beneficial for empowering citizens. Coors & Ewald (2005) report that 3D models are more intuitive than other visualisation types and can consequently help citizens interpret the map. Wanarat & Nuanwan (2013) mention that 3D representations appear to be an essential planning tool and may lead to a faster decision-making.

On the other hand, the combined 2D/3D visualisation yielded different results. In regard to urban planning, the combined display's preference ratings were higher than its satisfaction ratings. The satisfaction ratings also showed that the combined 2D/3D was rated the most distracting and most complex. It seems that after the task completion, the appeal of this visualisation type for urban planning tasks was reduced at the expense of the oblique 3D representation. A possible explanation for this could be that shifting the attention between the two views was confusing or tedious. Additionally, participants formulated that the combined visualisation had slightly too much information for an urban planning task. Delaney (2000) discusses the disadvantage of too much information in a visualisation. A highly detailed representation can be distracting and can force the user to put more time into the task-solving. Due to the mixed design, the combined view includes information contents from 2D and 3D, which might have had a negative impact on the task performance. The analysis of the fixation durations revealed that participants spent on average 21 seconds looking at the first-person 3D view and 15 seconds looking at the 2D view. This suggests that individuals use both views to make a decision and hence have to process the information of both. Consequently, these results, along with the satisfaction ratings, indicate that the combined 2D/3D visualisation type may lead to an information overload and may complicate the information processing and evaluation. Thus, it should not be used if only one of the views is important for the task, as providing two views may enforce additional problems for the user in regard to complexity.

5.2 Further findings

As stated before, St. John et al. (2001) argue that the distortions of angles and distances inherent in 3D visualisations make the judgement of distance problematic. This explanation corresponds to our results. As expected, for the distance estimation task, the differences between real and estimated distances were clearly larger in the two 3D visualisations compared to the 2D representations. Similarly, Bleisch & Dykes (2006) found through an experiment that participants could not estimate the lengths of routes satisfactory when using 3D views. In another user study, Piryankova et al. (2013) used large screen immersive displays (LSIDs) with different shapes and specifications to investigate egocentric distance perception. They concluded that for all 3D displays, distances were significantly underestimated compared to the actual distances. Grechkin et al. (2010) supported those findings. They compared distance estimation for real and virtual environments and found that distances were clearly underestimated in the virtual 3D environments. These results are consistent with our findings. In our experiment, 3D visualisations mostly led to underestimation of the perceived distances. Some of the estimated values deviated from the actual distances to a large extent. It is thus important to keep this notion in mind when using 3D views for urban planning tasks. If metric estimations are a part of the task, we recommend using 2D visualisations instead.

For the distance estimation task, we also discovered that the accuracy of individuals' answers only partly matched their preference or difficulty rating for a specific visualisation type. For a distance estimation task, the 2D was clearly preferred over the realistic 3D visualisation. Participants' ability to estimate the correct distance was also best for this visualisation type. Hence, the preferences conformed to the effectiveness of the visualisations. These conclusions contribute to the *naïve realism* debate. Hegarty et al. (2009) found that individuals often prefer realistic displays, even though they did not perform well with them. Our comparison of 2D and 3D displays for a distance estimation task did not support this assumption of *naïve realism*. The individuals performed worse with the 3D display and this appeared to have influenced their preference and difficulty rating. Opposed to this, the difficulty ratings and performances for the two 3D displays did not correspond. The difficulty ratings revealed that participants perceived the oblique 3D visualisation as easier for decision-making. However, the accuracy of participants' answer for this visualisation type was worse than for the first-person 3D visualisation. Accordingly, there seemed to be some discrepancy between the perceived usability and actual performance of individuals regarding the oblique and first-person 3D visualisation. A possible explanation for the low accuracy of the oblique view might be that the effect of the distortions is unequal for the two displays. Jobst & Döllner (2008) describe how expanding the field of view leads to a higher degree of perspective distortions. In our experiment, the field of view in the oblique 3D was larger than in the first-person view. Thus, this means that the distortions had a larger impact in the oblique 3D view compared to the 3D first-person view, which could have affected their accuracy. Another possible explanation for the better accuracy of first-person 3D views may be that participants are more trained in this visualisation type, as it represents our perception of the world closer to the real world. We draw from this that participants cannot always assess the efficiency of a visualisation type correctly. For the urban planning community this may signify that the visualisation types which should be used are those most beneficial for the task, even if they are not in line with citizens' preferred representations.

5.3 Limitations of the study

In this section, perceived problems and limitations of the study are discussed.

One weakness of the study was that only the oblique 3D view was shown in all tasks. The 2D image was shown twice and the first-person 3D and combination 2D/3D each once, which may have impaired the comparison of the visualisations.

The reason for this experiment design was that for some tasks, the presentation of a specific visualisation type would not have made sense. For instance, the site location task would have been complicated to solve with a strict 2D representation, due to the missing height information. A strict first-person 3D view would have also been problematic for this task, as it does not provide a sufficient overview of the surroundings of each location. Therefore, both views were necessary to compare it to the oblique 3D view. Furthermore, the combined 2D/3D visualisation could not be compared directly with the strict 2D or first-person 3D display, as a repetition of the same view would have led to biases. A possible solution for this would be to use a between-subject design, where each group sees either the strict 2D, first-person 3D or combined 2D/3D view and compares it to the oblique 3D visualisation.

Additionally, the visualisation types may have had a different amount of information. While we tried to keep the visible content of each image as similar as possible, there were still some minor differences, i.e. uncontrolled variations. For example, the field of view was bigger in the oblique 3D than the first-person 3D view. Further, the objects in the 3D view were more discernible than in the 2D view, like for instance the different playground items. This made the comparison of visualisations even more complicated.

Furthermore, even though we found that decisions can change with the presentation of different visualisation types, it is hard to say which decision is better. The desirability of an outcome depends on various factors, such as the planning goal and the role of the decision maker. For instance, citizens have different perceptions and concerns than experts. Therefore, a good proposal for experts may be perceived as unsatisfactory for citizens. Similarly, while some focus on the costs of different proposals, others focus more on the appeal of different alternatives. This means that there is no universal “best” planning outcome and it is consequently difficult to state which visualisation type is more suited, as they lead to different but not necessarily better outcomes.

A further limitation concerns the preference ratings. We asked participants about their preference for route planning but not for a distance estimation task. We assumed that these tasks are comparable, as route planning most likely plays an important role in distance estimation. However, it may be that the results would have been different if we had asked them explicitly about their preference for distance estimation.

Lastly, we used a limited sample of participants for our study. Mostly young individuals with a high education were chosen for the experiment. Hence, it is not guaranteed that the results are applicable to the whole population.

6 Conclusion

This thesis investigated the influence of different visualisation types on the decision-making process. We wanted to explore which illustrations were most suited for urban planning and what influence they have on decision-making. In order to evaluate these questions, a user study was conducted. We compared 2D, 3D and combined 2D/3D representations through an experiment with the three urban planning related tasks site selection, scenario selection and distance estimation. The results suggested that individuals change their decision, depending on the visualisation type they work with. Participants found it easier to assess the height of the surrounding buildings in the oblique 3D than the combined 2D/3D visualisation. This may be due to the limited visible content the viewing angle in the first-person 3D visualisation provided. Further, the combined visualisation was perceived as being more difficult to understand and more complex than the oblique 3D visualisation. This may explain why participants did not seem to apprehend the height of the surrounding buildings in the combined visualisation and made a different choice than with the oblique 3D view. We found that this effect was especially crucial when there were large variations in the third dimension, e.g. the height of buildings. It may therefore be more adequate to use the oblique 3D visualisation for those scenes. Additionally, we found that the oblique 3D appeared to enable participants to better judge the impact of trees and the layout of a scene, which seemed to have a large influence on their decision. Possible reasons may have been the more realistic visualisation of trees and the additional third dimension in the oblique 3D. Our results imply that the different visualisation types provided the participants with distinct information, which may have influenced their decision-making.

We further found that oblique 3D visualisations are preferred for urban planning activities, followed by combined 2D/3D visualisations and finally 2D visualisations. The oblique 3D model was mostly valued for its ability to provide a good overview of the whole situation while simultaneously giving information about the height of objects. This visualisation type also received high satisfaction ratings. The combined 2D/3D visualisation was generally perceived as useful for urban planning decisions. That being said, the matching between the two views seemed to be a disadvantage of that visualisation type and decreased its efficiency. Participants' fixation durations for the 2D and first-person 3D views showed that both views are regarded and taken into account when making a choice. This may lead to an enhanced complexity of that visualisation type. The perceived large amount of information in the combined 2D/3D visualisation is a further indicator for its complexity. On the other hand, 2D views were favoured for route planning and distance estimation. Additionally, participants' performance to estimate distances was more accurate for 2D displays than 3D views.

We conclude that oblique 3D visualisations appear to be the best choice for urban planning activities. However, neither of the visualisation types is superior for general decision-making. Each of them has different properties and advantages for specific purposes. Consequently, the efficiency of the visualisation type is relative to the task for which it is used. In addition, the context for every planning process is unique. Thus, the demands for each particular task or planning proposal should be taken into account when deciding which visualisation type to use. We can therefore support the literature that says the usefulness of a visualisation type is dependent on the task.

Implications for future research

We studied the influence of visualisation types on decision-making for people with little knowledge about urban planning. It is yet unclear how experts would perform in our experiment. This could be studied in future research.

Collaborative approaches play an increasing role in urban planning. Therefore, further studies should be performed to investigate how the visualisations affect group decision-making.

Finally, this study only explored static visualisations. However, many 3D models have interactive features, such as zoom, pan or fly-through. What effect those visualisation types with interactive tools have on users' decisional performance deserves more explorations.

Literature

Barndt, M. (1998) Public Participation GIS—Barriers to Implementation. *Cartography and Geographic Information Systems*, *25*(2), 105-112.

Barton, J. (2007). *A spatial decision support system for the management of public housing*. Faculty of the Built Environment, University of New South Wales, Australia.

Batty, M., Dodge, M., Jiang, B., & Smith, A. (1998). *GIS and Urban Design*. Working Paper 3, UCL Centre for Advanced Spatial Analysis (CASA), London.

Batty, M. (2000). The new urban geography of the third dimension. *Environment and Planning B: Planning and Design*, *27*(4), 483-484.

Batty, M., Chapman, D., Evans, S., Haklay, M., Kueppers, S., Shiode, N., Smith, A., & Torrens, P. M. (2000). *Visualizing the City: Communicating Urban Design to Planners and Decision-Makers*, Centre for Advanced Spatial Analysis (CASA), University College London, UK.

Bertin, J. (1983). *Semiology of Graphics: Diagrams, Networks, Maps*. University of Wisconsin Press, Madison, Wisconsin, USA.

Bleisch, S., & Dykes, J. (2006). Planning Hikes Virtually–How Useful are Web-based 3D Visualizations?. *Proceedings GIS Research UK 14th Annual Conference. Nottingham, UK*, 313-318.

Bleisch, S., & Nebiker, S. (2008). Connected 2D and 3D visualizations for the interactive exploration of spatial information. *Proceedings of 21th ISPRS Congress, Beijing, China.*

Boer, A. (2012). *Abstracting the Reality: Usability Evaluation of Levels of Abstraction and Realism in Geographic Visualizations*. Department of Geography, University of Zurich, Switzerland.

Bojórquez-Tapia, L. A., de la Cueva, H., Díaz, S., Melgarejo, D., Alcantar, G., José Solares, M., Grobet G. & Cruz-Bello, G. (2004). Environmental conflicts and nature reserves: redesigning Sierra San Pedro Mártir National Park, Mexico. *Biological Conservation*, *117*(2), 111-126.

Borkin, M., Gajos, K., Peters, A., Mitsouras, D., Melchionna, S., Rybicki, F., Feldman, C., & Pfister, H. (2011). Evaluation of artery visualizations for heart disease diagnosis. *IEEE Transactions on Visualization and Computer Graphics*, *17*(12), 2479-2488.

Bulkeley, H., & Mol, A. P. (2003). Participation and environmental governance: consensus, ambivalence and debate. *Environmental Values*, *12*(2), 143-154.

Bulmer, D. (2001). How can computer simulated visualizations of the built environment facilitate better public participation in the planning process. *Online Planning Journal*, *11*, 1-43.

Carsjens, G. J., & Ligtenberg, A. (2007). A GIS-based support tool for sustainable spatial planning in metropolitan areas. *Landscape and urban planning*, *80*(1), 72-83.

Carter, J. R. (2005). The many dimensions of map use. *Proceedings, International Cartographic Conference*.

Carver, S. (2001). Participation and Geographical Information: a position paper. *ESF-NSF Workshop, Spoleto, Italy*.

Chen, C. (2006). *Information visualization: Beyond the horizon*. 2nd edition, Springer, London.

Cockburn, A., & McKenzie, B. (2002). Evaluating the Effectiveness of Spatial Memory in 2D and 3D Physical and Virtual Environments. *Proceedings of CHI Conference on Human Factors in Computing Systems,* Minneapolis, Minnesota, 203-210.

Çöltekin, A. (2002). An Analysis of VRML-based 3D Interfaces for Online GISs: Current Limitations and Solutions. *Finnish Journal of the Surveying Sciences, 20*(1/2), 80-91.

Coors, V., & Ewald, K. (2005). Compressed 3D urban models for internet-based e-planning. *Paper on NextGeneration3DCityModels, Bonn*.

Delaney, B. (2000). Visualization in urban planning: they didn't build LA in a day. *Computer Graphics and Applications, IEEE*, *20*(3), 10-16.

Dennis, A. R., & Carte, T. A. (1998). Using geographical information systems for decision making: Extending cognitive fit theory to map-based presentations. *Information Systems Research*, *9*(2), 194-203.

Dillon, S. M. (1998). *Descriptive decision making: Comparing theory with practice.* Unpublished manuscript, Department of Management Systems, University of Waikato, New Zealand.

Drettakis, G., Roussou, M., Reche, A., & Tsingos, N. (2007). Design and evaluation of a real-world virtual environment for architecture and urban planning. *Presence: Teleoperators and Virtual Environments*, *16*(3), 318-332.

Elmqvist, N., & Tsigas, P. (2007). A taxonomy of 3D occlusion management techniques. *Virtual Reality Conference, 2007. VR'07. IEEE*, 51-58.

Elwood, S., & Leitner, H. (1998). GIS and community-based planning: Exploring the diversity of neighborhood perspectives and needs. *Cartography and Geographic Information Systems*, *25*(2), 77-88.

Field, A. (2009). *Discovering statistics using SPSS: (and sex and drugs and rock 'n' roll).* 3rd edition, SAGE Publications, London.

Geertman, S. (2002). Participatory planning and GIS: a PSS to bridge the gap. *Environment and Planning B*, *29*(1), 21-36.

Goodchild, M. F. (2010). Towards Geodesign: Repurposing Cartography and GIS?. *Cartographic Perspectives*, *66*, 7-22.

Grechkin, T. Y., Nguyen, T. D., Plumert, J. M., Cremer, J. F., & Kearney, J. K. (2010). How does presentation method and measurement protocol affect distance estimation in real and virtual environments?. *ACM Transactions on Applied Perception (TAP)*, *7*(4), 26.

Gröger, G., & Plümer, L. (2012). CityGML–Interoperable semantic 3D city models. *ISPRS Journal of Photogrammetry and Remote Sensing*, *71*, 12-33.

Harris, T., & Weiner, D. (1998). Empowerment, Marginalization, and "Community-integrated" GIS. *Cartography and Geographic Information Systems*, *25*(2), 67-76.

Harris, T., & Weiner, D. (2003). Linking community participation to geospatial technologies. *Aridlands newsletter*, *53,* Arizona.

Hastie, R., & Pennington, N. (1995). Cognitive approaches to judgment and decision making. *Psychology of Learning and Motivation*, *32*, 1-32.

Hegarty, M., Smallman, H. S., Stull, A. T., & Canham, M. S. (2009). Naïve Cartography: How Intuitions about Display Configuration Can Hurt Performance. *Cartographica: The International Journal for Geographic Information and Geovisualization*, *44*(3), 171–186.

Herbert, G., & Chen, X. (2014). A comparison of usefulness of 2D and 3D representations of urban planning. *Cartography and Geographic Information* Science, *42*(1), 22-32.

Hanzl, M. (2007). Information technology as a tool for public participation in urban planning: a review of experiments and potentials. *Design Studies*, *28*(3), 289-307.

Innes, J. E., & Booher, D. E. (2004). Reframing Public Participation: Strategies for the 21st Century. *Planning Theory & Practice*, *5*(4), 419-436.

Jobst, M., & Döllner, J. (2008). 3D City Model Visualization with Cartography-Oriented Design. *REAL CORP 008 Proceedings / Tagungsband*, Vienna, 507–515.

Köninger, A., & Bartel, S. (1998). 3D-GIS for urban purposes. *Geoinformatica*, *2*(1), 79-103.

Krek, A. (2005). Rational Ignorance of the Citizens in Public Participatory Planning. *10th symposium on Information-and communication technologies (ICT) in urban planning and spatial development and impacts of ICT on physical space, CORP.*

Lai, P. C., Kwong, K. H., & Mak, A. S. (2010). Assessing the applicability and effectiveness of 3D visualisation in environmental impact assessment. *Environment and Planning B: Planning and Design*, *37*, 221-233.

Lind, M., Bingham, G. P., & Forsell, C. (2003). Metric 3D structure in visualizations. *Information Visualization*, *2*(1), 51-57.

Martin, D. W. (2008). *Doing Psychology Experiments*. 7th edition, Belmont, CA, USA: Wadsworth/ Thomson Learning.

Obermeyer, N. J. (1998). The Evolution of Public Participation GIS. *Cartography and Geographic Information Systems*, *25*(2), 65-66.

Payne, J. W., Bettman, J. R., Johnson, E. J., & Luce, M. F. (1995). An information processing perspective on choice. *Psychology of Learning and Motivation*, *32*, 137-175.

Piryankova, I. V., de la Rosa, S., Kloos, U., Bülthoff, H. H., & Mohler, B. J. (2013). Egocentric distance perception in large screen immersive displays. *Displays*, *34*(2), 153-164.

Pleizier, I., Van Lammeren, R., Scholten, H. J., & Van de Velde, R. (2004). Using virtual reality as information tool in spatial planning. *Proceedings EuroConference on methods to support interaction in geovisualisation environments.*

Ranzinger, M., & Gleixner, G. (1997). GIS datasets for 3D urban planning. *Computers, environment and urban systems*, *21*(2), 159-173.

Rase, W. D. (2003). Von 2D nach 3D – perspektivische Zeichnungen, Stereogramme, reale Modelle. In Deutsche Gesellschaft für Kartographie (ed.) *Visualisierung und Erschließung von Geodaten. Kartographische Schriften, 7,* Bonn: Kirschbaum, 13-24.

Reed, M. S. (2008). Stakeholder participation for environmental management: a literature review. *Biological conservation, 141*(10), 2417-2431.

Resnik, M. D. (2000). *Choices: An Introduction to Decision Theory*. Fifth printing, University of Minnesota Press, Minneapolis, USA.

Richards, C., Blackstock, K., Carter, C. (2004). *Practical Approaches to Participation.* SERG Policy Brief No. 1, Macauley Land Use Research Institute, Aberdeen.

Rohrmann, B., & Bishop, I. (2002). Subjective responses to computer simulations of urban environments. *Journal of Environmental Psychology*, *22*(4), 319-331.

Sayce, K., Shuman, C., Connor, D., Reisewitz, A., Pope, E., Miller-Henson, M., Poncelet, E., Monié, D. & Owens, B. (2013). Beyond traditional stakeholder engagement: public participation roles in California's statewide marine protected area planning process. *Ocean & Coastal Management*, *74*, 57-66.

Shepherd, I. D. H. (2008). Travails in the third dimension: a critical evaluation of three-dimensional geographical visualization. In M. Dodge, M. McDerby & M. Turner (Eds.), *Geographic Visualization: Concepts, Tools and Applications,* John Wiley & Sons, 199-210.

Shiode, N. (2000). 3D urban models: recent developments in the digital modelling of urban environments in three-dimensions. *GeoJournal*, *52*(3), 263-269.

Simon, H. A. (1987). Making management decisions: The role of intuition and emotion. *The Academy of Management Executive (1987-1989)*, 57-64.

Smallman, H. S., & John, M. S. (2005). Naïve Realism: Misplaced Faith in Realistic Displays. *Ergonomics in Design: The Quarterly of Human Factors Applications*, *13*(3), 6-13.

Stadtentwicklung Zürich (2006). *Mitwirkungs- und Beteiligungsprozesse. Checkliste*. Zürich: Stadt Zürich.

Stadtentwicklung Zürich (2013). *ePartizipation in der Stadtentwicklung. Begriff – Möglichkeiten – Empfehlungen.* Zürich: Stadt Zürich.

Steinmann, R., Krek, A., & Blaschke, T. (2005). Can online map-based applications improve citizen participation? *E-Government: Towards Electronic Democracy,* Springer Berlin Heidelberg, 25-35.

St John, M., Cowen, M. B., Smallman, H. S., & Oonk, M. H. (2001). The use of 2D and 3D displays for shape-understanding versus relative-position tasks. *Human Factors: The Journal of the Human Factors and Ergonomics Society*,*43*(1), 79-98.

Tory, M., Moller, T., Atkins, M. S., & Kirkpatrick, A. E. (2004). Combining 2D and 3D views for orientation and relative position tasks. *Proceedings of the CHI conference on Human factors in computing systems*, 73-80.

Tory, M., Kirkpatrick, A. E., Atkins, M. S., & Moller, T. (2006). Visualization task performance with 2D, 3D, and combination displays. *IEEE Transactions on Visualization and Computer Graphics, 12*(1), 2-13.

Tory, M., Sprague, D. W., Wu, F., So, W. Y., & Munzner, T. (2007). Spatialization design: Comparing points and landscapes. *IEEE Transactions on Visualization and Computer Graphics, 13*(6), 1262-1269.

Tsoukiàs, A. (2008). From decision theory to decision aiding methodology. *European Journal of Operational Research*, *187*(1), 138-161.

Wanarat, K., & Nuanwan, T. (2013). Using 3D visualisation to improve public participation in sustainable planning process: experiences through the creation of Koh Mudsum Plan, Thailand. *Procedia - Social and Behavioral Sciences*, *91*, 679-690.

Wiedemann, P. M., & Femers, S. (1993). Public participation in waste management decision making: Analysis and management of conflicts. *Journal of Hazardous Materials*, *33*(3), 355-368.

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*, *34*(4), 291-298.

Zeleny, M. (1982). *Multiple Criteria Decision Making.* McGraw-Hill, New Yor

Appendix A: Consent form

University of Zurich October 2014

Participant Information Statement and Consent Form

Participant No:_____

Purpose of study
You are invited to participate in a study regarding the evaluation of 2D and 3D visualisations. The purpose of the study is to learn more about the effect of different dimensionalities (2D and 3D or combined) on the decision-making process in the context of urban planning.

Description of study and risks
The whole experiment will be conducted at the computer. If you decide to participate we will first ask you to give us some background information, followed by a series of tasks and a few questions regarding your opinions about 2D and 3D visualisations. During this process we will record your interactions with the computer using a webcam, audio recorder and eye tracker. The eye tracking device is non-contact, uses near infrared light and should not cause any discomfort. The whole procedure should take maximum 45 minutes and there are no particular risks or benefits to you from participating in this experiment.

Confidentiality and disclosure of information
Any information that can be identified with you in connection with this study will remain confidential and will be disclosed only with your permission. If you give us permission by signing this document, we plan to publish the results of this research in scientific publications. In any publication, information will be provided in such a way that you cannot be identified.

Compensation
We do not provide any compensation for your participation in this experiment, nor are there any costs for you for your participation.

Feedback to participants
If you would like to be kept informed about the results of this research, please leave your name and contact details with the experiment leader. A copy of publications resulting from this research will be sent to you when available.

Your consent
Your decision whether or not to participate will not affect your future relations with the University of Zurich. If you decide to participate, you are free to withdraw your consent and to discontinue participation at any time without prejudice. We are happy to answer any questions you may have. For any questions or comments after the experiment please contact Bettina Kalt (076 478 82 33, bettina.kalt@uzh.ch) or Dr. Arzu Coltekin (044 635 54 40, arzu@geo.uzh.ch).
You will be given a copy of this form to keep.

1

University of Zurich October 2014

Your signature indicates that you have read and understood the information provided on the previous page and that you agree to take part in the experiment.

....
Participant signature Experimenter signature

....
Please PRINT name Please PRINT name

....
Date and Place

REVOCATION OF CONSENT
If you wish to WITHDRAW your consent to participate in the research proposal described above and understand that such withdrawal WILL NOT jeopardize any treatment or my relationship with the University of Zurich, please send an electronic request to arzu@geo.uzh.ch acc bettina.kalt@uzh.ch within the next 60 days.

2

Appendix B: Questionnaire

Start

University of Zurich

Welcome!
In this experiment, you will see some visualisations with different dimensionality (2D and 3D). You will be asked to make decisions or state your opinions about the visualisations. If anything is unclear about the tasks, do not hesitate to ask.
Click "Next" once you have answered the question to go to the next page.

Personal information

***1. Participant No: (to be filled by the experimenter)**

***2. Age:**

- ◯ Under 18
- ◯ 18 - 24
- ◯ 25 - 31
- ◯ 32 - 38
- ◯ 39 - 45
- ◯ 46 - 52
- ◯ 52+

***3. Gender:**

- ◯ Male
- ◯ Female

***4. Please rate your training in following categories:**

	1 No training	2	3	4	5 Professional
Cartography	◯	◯	◯	◯	◯
Urban planning	◯	◯	◯	◯	◯
GIScience	◯	◯	◯	◯	◯
Other geography related disciplines	◯	◯	◯	◯	◯
Computer Graphics	◯	◯	◯	◯	◯

***5. How frequently do you use the following visualisation types?**

	1 Never	2	3	4	5 Daily
2D visualisations (maps, plots, other graphics...)	○	○	○	○	○
3D visualisaions (city models, terrain models, software such as Google Earth...)	○	○	○	○	○

***6. How often have you been involved in the following urban planning related activities?**

	1 Never	2	3	4	5 That's my job
Online discussion (e.g., stating your opinion about a proposed plan)	○	○	○	○	○
Workshop participation (e.g., discussing a proposed plan with others)	○	○	○	○	○
Decision making (e.g., voting for or against a proposed plan)	○	○	○	○	○

Please specify your involvement if you wish to, or if your involvement does not fit into the categories above:

***7. How interested are you in urban planning issues?**

1 Not at all	2	3	4	5 Very interested
○	○	○	○	○

Please specify (optional):

***8. How often do you play 3D computer/video games?**

1 Never	2	3	4	5 Daily
◯	◯	◯	◯	◯

***9. Please rate your level of proficiency in English:**

1 Minimal understanding	2	3	4	5 Native
◯	◯	◯	◯	◯

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

◯ Yes

◯ No

Comments (if any)

***11. If you need prescription glasses or contact lenses, are you wearing them now?**

◯ Yes

◯ No

◯ Not applicable

Comments (if any)

Preference 2D vs. 3D

You will now see two different visualisation types of the same area.

2D view

Oblique 3D view

***12. Which visualisation would you prefer for planning a route (before the journey) to go from one point to another?**

◯ top (2D)

◯ bottom (Oblique 3D)

Please state your reasons for choosing this visualisation (optional):

***13. Imagine that you live in the neighbourhood that is shown in the visualisations above. A new high-rise residential building (skyscraper) is being proposed in your neighbourhood. This building can be placed in several alternative locations from the planner's perspective, however, citizens will decide through a vote where the new building should be placed. Which of the two visualisations above would you prefer to make such a decision?**

- ◯ top (2D)
- ◯ bottom (Oblique 3D)

Please state your reasons for choosing this visualisation (optional):

***14. Imagine that the two visualisations were interactive, you can zoom in or out, pan and rotate in 2D; and you can view the 3D from all angles, zoom, pan, rotate, tilt and simulate walking. Which one would you prefer for an urban development decision-making task, such as the one in question 13?**

- ◯ top (2D interactive)
- ◯ bottom (3D interactive)

Please state your reasons for choosing this visualisation (optional):

***15. If you had all of the previously mentioned visualisation types to solve the urban planning task, which one would you prefer?**

- ◯ 2D static
- ◯ Oblique 3D static
- ◯ 2D interactive
- ◯ 3D interactive

Please state your reasons for choosing this visualisation (optional):

***16. Which visualisation would you prefer to discuss a proposal for a new park in your neighbourhood with other stakeholders (citizens, planners, all involved parties)?**

- ◯ top (2D)
- ◯ bottom (Oblique 3D)

Please state your reasons for choosing this visualisation (optional):

Preference 2D/3D vs. 3D

You will now see a combined 2D/3D view and a 3D oblique view of the same area.

Combined 2D/3D view

Oblique 3D view

***17. Which visualisation would you prefer for planning a route (before the journey) to go from one point to another?**

- ◯ top (Combined 2D/3D)
- ◯ bottom (Oblique 3D)

Please state your reasons for choosing this visualisation (optional):

***18. Imagine that you live in the neighbourhood that is shown in the visualisations above. A new high-rise residential building (skyscraper) is being proposed in your neighbourhood. This building can be placed in several alternative locations from the planner's perspective, however, citizens will decide through a vote where the new building should be placed. Which of the two visualisations above would you prefer to make such a decision?**

◯ top (Combined 2D/3D)

◯ bottom (Oblique 3D)

Please state your reasons for choosing this visualisation (optional):

***19. Imagine that the two visualisations were interactive, that is, you can zoom in or out, pan and rotate in 2D; and you can view the 3D from all angles, zoom, pan, rotate, tilt and simulate walking. Which one would you prefer for an urban development decision-making task, such as the one in question 18?**

◯ top (Combined 2D/3D interactive)

◯ bottom (3D interactive)

Please state your reasons for choosing this visualisation (optional):

***20. Which visualisation would you prefer to discuss a proposal for a new park in your neighbourhood with other stakeholders (citizens, planners, all involved parties)?**

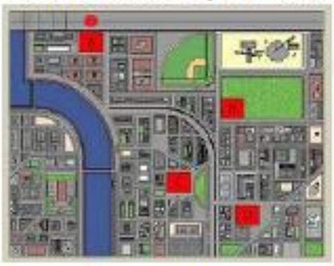
◯ top (Combined 2D/3D)

◯ bottom (Oblique 3D)

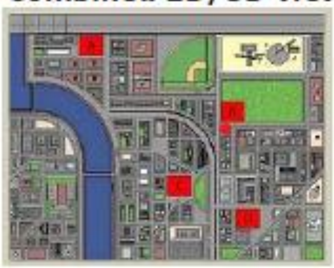
Task 1

Imagine that this is your neighbourhood. A new residential, high-rise building (skyscraper) will be built. Four alternative locations are proposed. Please choose the location that you think is best suited for the building. Possible locations are indicated with a red square and the letters A-D. On the left side you see an overview of the city in 2D and on the right side you see a close up of the individual locations in 3D. Your location in the 2D visualisation is marked with a red circle.

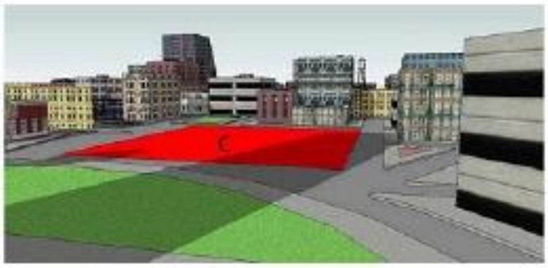
Combined 2D/3D view



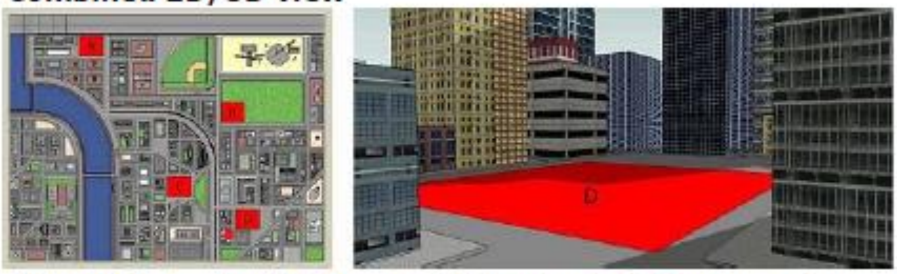

Combined 2D/3D view




Combined 2D/3D view

Combined 2D/3D view



***21. Where should the new high-rise building go? Choose A, B, C or D.**

- ◯ A
- ◯ B
- ◯ C
- ◯ D
- ◯ I don't know

Please state the reasons for your response (optional):

***22. How easy was it to make a decision based on the visualisations?**

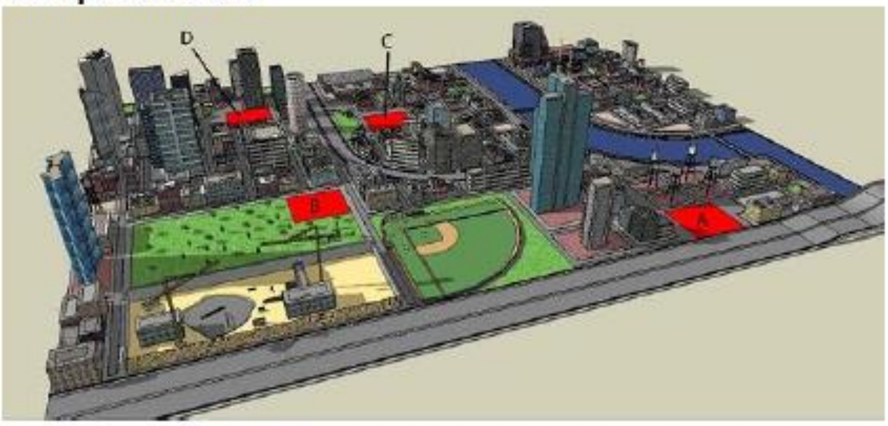
1 Very easy	2	3	4	5 Very difficult
◯	◯	◯	◯	◯

Please specify why you think it was easy/difficult (optional):

Task 1

Imagine that this is your city. A new residential, high-rise building will be built. Please choose the location that you think is best suited for the building. Possible locations are indicated with a red square and the letters A-D.

Oblique 3D view



***23. Where should the block of high-rise buildings go? Choose A, B, C or D.**

- ◯ A
- ◯ B
- ◯ C
- ◯ D
- ◯ I don't know

Please state the reasons for your response (optional):

***24. How easy was it to make a decision based on the visualisations?**

1 Very easy	2	3	4	5 Very difficult
◯	◯	◯	◯	◯

Please specify why you think it was easy/difficult (optional):

***25. Out of the two options you just saw (combined 2D/3D or oblique 3D), which do you think is more appropriate for this task?**

- ○ Combined 2D/3D
- ○ Oblique 3D

Please state the reasons for your response (optional):

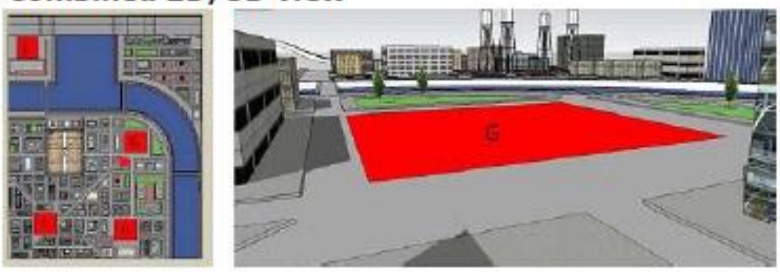
Task 1

Imagine that this is your city. A new residential, high-rise building will be built. Please choose the location that you think is best suited for the building. Possible locations are indicated with a red square and the lettes E-H. On the left side you see an overview of the city in 2D and on the right side you see a close up of the individual locations in 3D. Your location in the 2D visualisation is marked with a red circle.

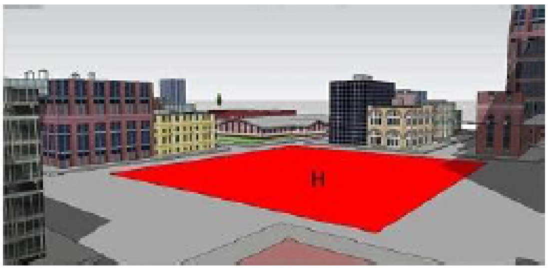
Combined 2D/3D view

Combined 2D/3D view

Combined 2D/3D view



Combined 2D/3D view



***26. Where should the new high-rise building go? Choose E, F, G or H.**

- ◯ E
- ◯ F
- ◯ G
- ◯ H
- ◯ I don't know

Please state the reasons for your response (optional):

***27. How easy was it to make a decision based on the visualisations?**

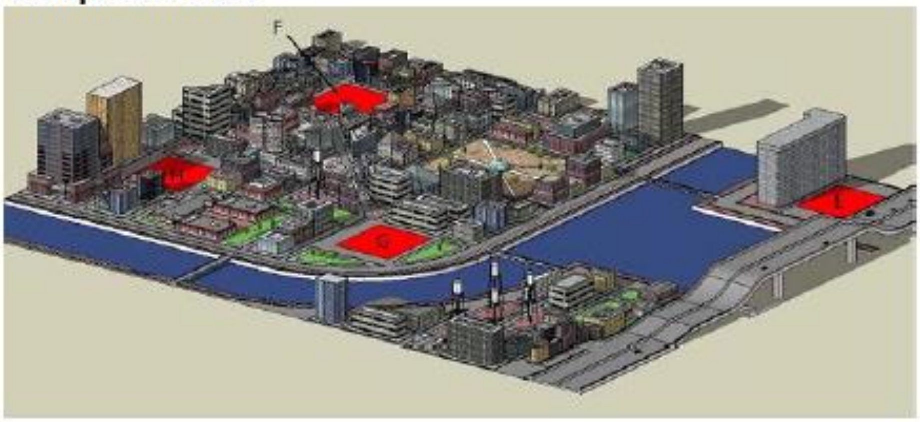
1 Very easy	2	3	4	5 Very difficult
◯	◯	◯	◯	◯

Why did you think it was easy/difficult?

Task 1

Imagine that this is your city. A new residential, high-rise building will be built. Please choose the location that you think is best suited for the building. Possible locations are indicated with a red square and the letters E-H.

Oblique 3D view



***28. Where should the new high-rise building go? Choose E, F, G or H.**

- ◯ E
- ◯ F
- ◯ G
- ◯ H
- ◯ I don't know

Please state the reasons for your response (optional):

***29. How easy was it to make a decision based on the visualisation?**

1 Very easy	2	3	4	5 Very difficult
◯	◯	◯	◯	◯

Why did you think it was easy/difficult?

Task 2

Your neighbourhood park is being redesigned. You will now see two alternative proposals for your new park design. You, as a citizen, can decide which of the two alternatives should be realised through a vote.

***30. You visit this park often to play sports with your friends. Which proposal would you choose for the new park?**

- ◯ left
- ◯ right
- ◯ I don't know

Please state the reasons for your response (optional):

***31. How easy was it to make a decision based on the visualisation?**

1 Very easy	2	3	4	5 Very difficult
◯	◯	◯	◯	◯

Task 2

Your neighbourhood park is being redesigned. You will now see two alternative proposals for your new park design. You, as a citizen, can decide which of the two alternatives should be realised through a vote.

Proposal 1

Proposal 2

***32. You visit this park often to play sports with your friends. Which proposal would you choose for the new park?**

- ◯ left
- ◯ right
- ◯ I don't know

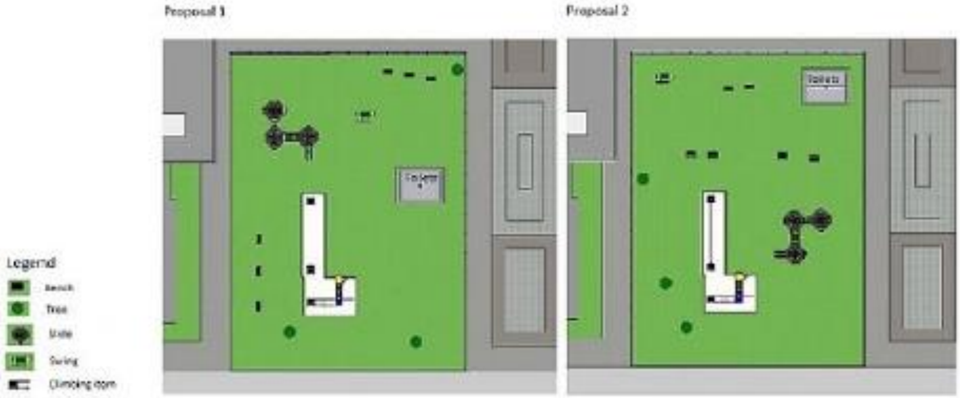
Please state the reasons for your response (optional):

***33. How easy was it to make a decision based on the visualisation?**

1 Very easy	2	3	4	5 Very difficult
◯	◯	◯	◯	◯

Task 2

Your neighbourhood park, which is famous for its playground, is being redesigned. You will now see two alternative proposals for your new park design. You, as a citizen, can decide which of the two alternatives should be realised through a vote.



✱34. You visit this park often with a toddler. Which proposal would you choose for the new park?

◯ left

◯ right

◯ I don't know

Please state the reasons for your response (optional):

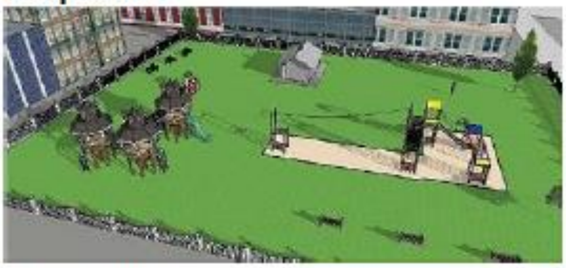
✱35. How easy was it to make a decision based on the visualisation?

1 Very easy	2	3	4	5 Very difficult
◯	◯	◯	◯	◯

Task 2

Your neighbourhood park, which is famous for its playground, is being redesigned. You will now see two alternative proposals for your new park design. You, as a citizen, can decide which of the two alternatives should be realised through a vote.

Proposal 1



Proposal 2

***36. You visit this park often with a toddler. Which proposal would you choose for the new park?**

- ◯ left
- ◯ right
- ◯ I don't know

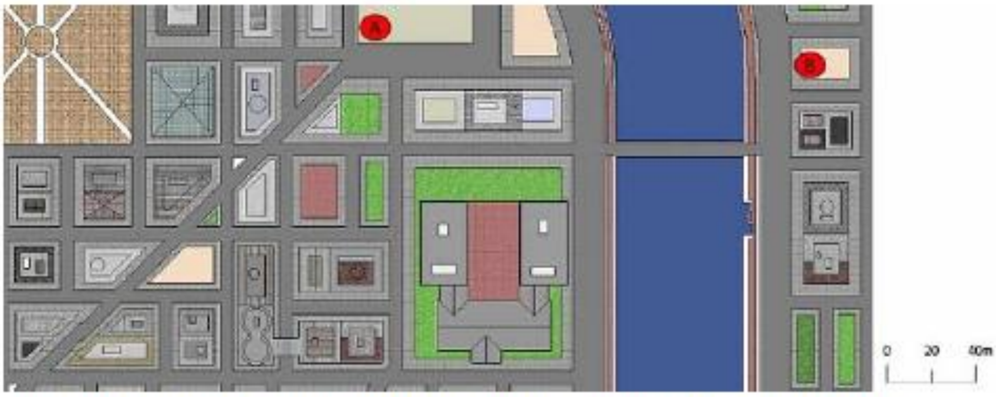
Please state the reasons for choosing this proposal (optional):

***37. How easy was it to make a decision based on the visualisation?**

1 Very easy	2	3	4	5 Very difficult
◯	◯	◯	◯	◯

Task 3

Below you can see a section of a city shown as a 2D visualisation.



***38. What is the walking distance from point A to point B?**

Distance in metres

***39. How easy was it to make a decision based on the visualisation?**

1 Very easy	2	3	4	5 Very difficult
○	○	○	○	○

Task 3

Below you can see a section of a city shown as a 2D visualisation.

***40. What is the walking distance from point A to point B?**

Distance in metres ______________________

***41. How easy was it to make a decision based on the visualisation?**

1 Very easy	2	3	4	5 Very difficult
○	○	○	○	○

Task 3

Below you can see a section of a city shown as a 3D visualisation.

***42. What is the walking distance from point A to point B?**

Distance in metres

***43. How easy was it to make a decision based on the visualisation?**

1 Very easy	2	3	4	5 Very difficult
○	○	○	○	○

Task 3

Below you can see a section of a city shown as a 3D visualisation.

***44. What is the walking distance from point A to point B?**

Distance in metres ________________

***45. How easy was it to make a decision based on the visualisation?**

1 Very easy	2	3	4	5 Very difficult
○	○	○	○	○

Task 3

Below you can see a section of a city shown as a 3D visualisation.

***46. What is the walking distance from point A to point B?**

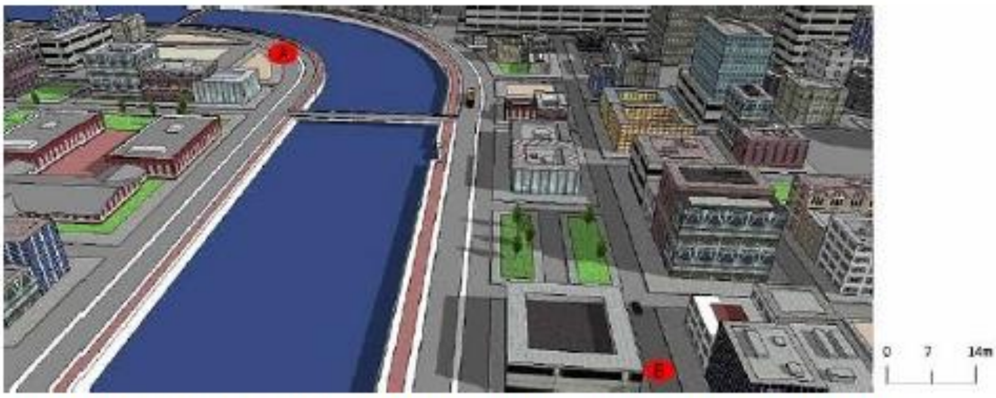
Distance in metres ____________________

***47. How easy was it to make a decision based on the visualisation?**

1 Very easy	2	3	4	5 Very difficult
○	○	○	○	○

Task 3

Below you can see a section of a city shown as a 3D visualisation.



***48. What is the walking distance from point A to point B?**

Distance in metres ____________________

***49. How easy was it to make a decision based on the visualisation?**

1 Very easy	2	3	4	5 Very difficult
○	○	○	○	○

Satisfaction (2D)

Below you can see a section of a city shown as a 2D visualisation.

2D view

***50. For which tasks would you use the visualisation above? You can select multiple tasks and/or add additional tasks.**

- ☐ Self-location (where am I)
- ☐ Identifying locations (where is a building/address)
- ☐ Route planning (which route to take when going from A to B, planning before the journey, estimating distances)
- ☐ Real-time navigation and way-finding (which route to take when going from A to B, planning real-time)
- ☐ Identifying places of interest (where to do what, e.g. restaurants, tourism destinations)
- ☐ Communication (presenting ideas, support ideas, education)
- ☐ Urban planning related decisions (approving or declining a proposal)
- ☐ Virtual tourism (exploring a place from afar)

Other tasks (please specify)

***51. Please rate the following statements in relation to the urban planning tasks you have solved:**

	1 Strongly disagree	2	3 Neither agree nor disagree	4	5 Strongly agree
This visualisation helps me to make a decision about the approval of a plan.	○	○	○	○	○
The details in the visualisation are distracting.	○	○	○	○	○
This visualization is ideal for distance estimation.	○	○	○	○	○
This visualisation would catch my attention if I saw it in a newspaper.	○	○	○	○	○
This visualisation is complex, I have trouble understanding what is shown.	○	○	○	○	○
This visualisation is aesthetically pleasing.	○	○	○	○	○

Other (please specify)

***52. For urban planning tasks, the amount of inormation in the visualisation is**

1 Too little	2	3	4	5 Too much
○	○	○	○	○

***53. Tick the box that best describes the visualisation above**

	1 Not at all	2	3	4	5 Very much
Clear (easy to understand)	◯	◯	◯	◯	◯
Useful for planning decisions	◯	◯	◯	◯	◯
Useful for distance estimation	◯	◯	◯	◯	◯
Complex	◯	◯	◯	◯	◯
Attractive	◯	◯	◯	◯	◯

Satisfaction (3D)

Below you can see a section of a city shown as a 3D visualisation.

Oblique 3D view

***54. For which tasks would you use the visualisation above? You can select multiple tasks and/or add additional tasks.**

- [ ] Self-location (where am I)
- [ ] Identifying locations (where is a building/address)
- [ ] Route planning (which route to take when going from A to B, planning before the journey, estimating distances)
- [ ] Real-time navigation and way-finding (which route to take when going from A to B, planning real-time)
- [ ] Identifying places of interest (where to do what, e.g. restaurants, tourism destinations)
- [ ] Communication (presenting ideas, support ideas, education)
- [ ] Urban planning related decisions (approving or declining a proposal)
- [ ] Virtual tourism (exploring a place from afar)

Other tasks (please specify)

***55. Please rate the following statements in relation to the urban planning tasks you have solved:**

	1 Strongly disagree	2	3 Neither agree nor disagree	4	5 Strongly agree
This visualisation helps me to make a decision about the approval of a plan.	◯	◯	◯	◯	◯
The details in the visualisation are distracting.	◯	◯	◯	◯	◯
This visualization is ideal for distance estimation.	◯	◯	◯	◯	◯
This visualisation would catch my attention if I saw it in a newspaper.	◯	◯	◯	◯	◯
This visualisation is complex, I have trouble understanding what is shown.	◯	◯	◯	◯	◯
This visualisation is aesthetically pleasing.	◯	◯	◯	◯	◯

Other (please specify)

***56. For urban planning tasks, the amount of inormation in the visualisation is**

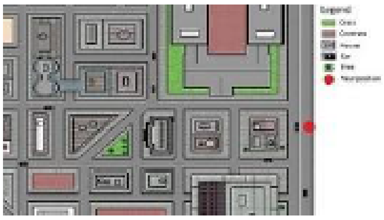
1 Too little	2	3	4	5 Too much
◯	◯	◯	◯	◯

***57. Tick the box that best describes the visualisation above**

	1 Not at all	2	3	4	5 Very much
Clear (easy to understand)	◯	◯	◯	◯	◯
Useful for planning decisions	◯	◯	◯	◯	◯
Useful for distance estimation	◯	◯	◯	◯	◯
Complex	◯	◯	◯	◯	◯
Attractive	◯	◯	◯	◯	◯

Satisfaction (2D/3D)

Below you can see a section of a city shown as a 2D visualisation (left) and 3D visualisation (right).



***58. For which tasks would you use the visualisation above? You can select multiple tasks and/or add additional tasks.**

- ☐ Self-location (where am I)
- ☐ Identifying locations (where is a building/address)
- ☐ Route planning (which route to take when going from A to B, planning before the journey, estimating distances)
- ☐ Real-time navigation and way-finding (which route to take when going from A to B, planning real-time)
- ☐ Identifying places of interest (where to do what, e.g. restaurants, tourism destinations)
- ☐ Communication (presenting ideas, support ideas, education)
- ☐ Urban planning related decisions (approving or declining a proposal)
- ☐ Virtual tourism (exploring a place from afar)

Other tasks (please specify)

***59. Please rate the following statements in relation to the urban planning tasks you have solved:**

	1 Strongly disagree	2	3 Neither agree nor disagree	4	5 Strongly agree
This visualisation helps me to make a decision about the approval of a plan.	○	○	○	○	○
The details in the visualisation are distracting.	○	○	○	○	○
This visualization is ideal for distance estimation.	○	○	○	○	○
This visualisation would catch my attention if I saw it in a newspaper.	○	○	○	○	○
This visualisation is complex, I have trouble understanding what is shown.	○	○	○	○	○
This visualisation is aesthetically pleasing.	○	○	○	○	○

Other (please specify)

***60. For urban planning tasks, the amount of inormation in the visualisation is**

1 Too little	2	3	4	5 Too much
○	○	○	○	○

***61. Tick the box that best describes the visualisation above**

	1 Not at all	2	3	4	5 Very much
Clear (easy to understand)	◯	◯	◯	◯	◯
Useful for planning decisions	◯	◯	◯	◯	◯
Useful for distance estimation	◯	◯	◯	◯	◯
Complex	◯	◯	◯	◯	◯
Attractive	◯	◯	◯	◯	◯

Additional comments

62. Please add any additional comments you may have in the box below. Also, if you are interested in the results of the study, please leave us your email address in the comment box.

Personal declaration:

I hereby declare that the submitted thesis is the result of my own, independent, work. All external sources are explicitly acknowledged in the thesis.

Zurich, 31 January 2015

Bettina Kalt