Geo 511 – Master Thesis

How will it look like?

A case study with oblique aerial view 3D and 2D representations

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Abstract

When we look at a map it is a natural and familiar process that we image how this area might look like in the real environment. This process, denoted as *visualization* is connected to the field of navigation and wayfinding. It is often acclaimed that 3D representations of the reality provide us with a more familiar and natural view of the earth, and therefore the task of visualization, as well as orientation, within a map, and how it is connected to reality, should be simpler within this form of representation. However, previous research is in disagreement if 2D or 3D representations should be favoured for tasks like this. As the call for realistic 3D representations is especially present in the field of urban planning, this topic was chosen for this study. An interactive web viewer capable to portray 2D as well as 3D representations was built. Those representations were then analyzed in an empirical study. Overall, performance with both representations was high. Small differences were found with a favor for the 3D representation in the scope of the visualization task whilst the 2D representation was more suitable for the orientation task. Several group differences were found in respect to the two representations and tasks. Furthermore, participants preferred in general the 3D representation because of the more natural view and the additional content provided within the scene. Therefore, as it is often the case in cartography, a specific representation is not most suitable for both tasks and every user, but it has to be decided, based on the task and the intended user, which representation type should be used.

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1 Introduction

1.1 Motivation

Maps have been used for centuries to communicate information related to the "real" environment. Among the many different purposes for a map, map reading is a fundamental function. Possible map-reading tasks, which are familiar and used often, are *navigation* and *visualization* (Board, 1978, 6). A subtask of navigation is the self-localization and orientation on a map at a specific location in the physical or virtual environment (Peebles, Davies, & Mora, 2007, 391). As noted by Peebles et al. (2007, 2), this task is not only important during navigation (i.e., during the movement from one location to another location), but also in several other situations. They note, for example, that this task is necessary to match a historic image to a modern map or to make planning decisions based on the real, present environment (or a photograph of it) and a plan of a proposed development. These tasks are linked to the second map-reading task noted, *visualization*. *Visualization* is, in this context, not a physical map, graph, or diagram but rather the ability to derive a mental representation from the map (or another form of representation or communicated information about a locality) in the mind in the form of an *internal visualization* (Hegarty, 2002, 40; MacEachren, Buttenfield, Campbell, DiBiase, & Monmonier, 1992, 101; Lobben, 2004, 276).

The last decades have demonstrated the great popularity of 3D representations (Shepherd, 2008, 200), and the technological possibilities today allow the production of quite realistic 3D representations of the environment. It is often claimed that it is easier to understand and read a complex topic in 3D, especially for non-professionals in a particular field (Hanzl, 2007, 290). However, 3D representations seem to not always be more appropriate than 2D representations (Shepherd, 2008, 200).

Previous research in the field of navigation has also shown that performance of tasks (i.e., walking from one location to another) is worse (in terms of efficiency, e.g., is the goal reached, and effectiveness, e.g., how fast is the goal reached) with 3D than 2D representations (e.g., Coors, Elting, Kray, & Laakso, 2005, 544). On the other hand, personal attitudes toward the use of those 3D representations were often positive (Coors et al., 2005, 544). Smallman and St. John (2005, 1564) called this discrepancy naïve realism. In terms of motivation and encouragement, this preference for 3D representations should not be neglected (Lai, Kwong, & Mak, 2010, 230).

Especially in the field of urban planning, 3D representations are often used to visualize a proposed development of an area or are used within the decision-making process. To understand these representations and how we use them, we must understand whether they are easy to understand and correctly represent the phenomena of interest. Practice with 2D zoning plans reveals that they are often hard to read and understand and are even harder to effectively *internally visualize* the plans in reality. In addition, 3D representation is proposed as a possible solution to making zoning plans more readable.

We believe that it is important to derive an *image* (Lynch, 1960, 120) of a possible environment from a zoning plan or any other representation. This involves, apart from an overview, an egocentric perspective within the scene, and therefore the self-localization and visualization at a given position. As already stated, some research has been done with respect to the match between a 2D representation and the real environment and, in the field of mobile navigation, also the matching of an egocentric 3D representation to a scene. However, to our knowledge, no substantial studies were conducted on the comparison of 2D and 3D representations in terms of a simple representation-to-environment (*visualization*) or environment-to-representation (*self-location* with *orientation*) interaction.

1.2 Research Question

In order to contribute to the vast discussion about 2D and 3D representations and whether one or the other is more valuable self-location and visualization, especially in the context of urban planning, the following research questions were proposed:

RQ 1: Is there a difference between the representation methods (i.e., 2D representation and oblique aerial views of a 3D representation) in participant performance in *representation-to-environment matching* tasks in terms of:

(a) Effectiveness (accuracy of response), confidence, and efficiency (response speed) between the representation to solve the matching task with the real-world scene?

(b) Do the group differences (i.e., familiarity, spatial ability, expertise, or gender) play a role in viewer performance with the tested representations? If yes, is it the same for the two representation types for the following groups:

i. viewers who are familiar with urban planning representations and non-experts?

ii. viewers who have a high or low spatial ability?

RQ 2: Is there a difference between the representation methods (i.e., 2D representation and oblique aerial views of a 3D representation) in viewer performance in *environment-to-representation orientation* tasks in terms of:

(a) Effectiveness (accuracy of response), confidence, and efficiency (response speed) between the representations to solve the orientation task with the real-world scene?

(b) Do the group differences (i.e., familiarity, spatial ability, expertise or gender) play a role in viewer performance with the tested representations? If yes, is it the same for the two representation types for the following groups:

i. viewers who are familiar with urban planning representations and non-experts?

ii. viewers who have a high or low spatial ability?

RQ 3: Is there a difference in participants' preferences between the tested representations?

Based on earlier research in navigation and 3D representations, the working hypothesis for this study split: For RQ 1 (visualizaiton), it is expected that there is a difference between 2D and 3D representations, the 3D is more suitable in this case because the representation is more realistic than the 2D representation, it is simpler to imagine the situation and the cognitive load in the mental transformation is lower.

For RQ 2 (self-location), it is expected that there is also a difference, but in this task the 2D representation will lead to better performance on the ground of the better overview in this representation compared to the 3D representation.

For RQ 1 and RQ 2, between-group differences are expected: It can be hypothesized that participants with a high spatial ability are better in the orientation task than low spatial performers. Based on their professional experience, Urban planners are to be expected to perform better in the 2D representation than lay people. Finally, no gender differences are expected. Finally, for RQ 3 it is expected that there is a difference towards a preference of 3D because of the more realistic and pleasing representation.

To answer those questions, a case study comparing 2D and 3D representation in two different task types (*visualization* and *self-location*) was developed and implemented in an interactive web viewer. Participants solved those tasks to measure the effectiveness and efficiency of the representations used.

1.3 Thesis Structure

Section 2 gives an overview of the research done in the field of 3D representations in general and navigation in particular. Additionally, some fundamental cartographic theories are presented. The case study will be theoretically introduced in Section 3. Further, the results of the study are available in Section 4 and shortly discussed in Section 5. All data used during the study can be found in detail in the Section 6.

2 | State of the Art

This section introduces some fundamental cartographic theories and based on those an overview of the current research in the relevant fields to this study (3D representations of geographical information as well as navigation, mostly wayfinding, with a focus on 3D) is presented.

2.1 A Map

A map, as defined by the International Cartographic Association (ICA), is "a symbolized representation of a geographical reality, representing selected features and characteristics, resulting from the creative effort of its author's execution of choices, that is designed for use when spatial relationships are of primary relevance" (International Cartographic Association, 2003, 17). Maps are used in different forms and for different things and a single map can also be used for several purposes (see DiBiase (1990, n.d.); MacEachren (1994, 2–8) or MacEachren (2011) for more). Maps are, amongst other things, a medium for communication. In its simplest form, a communication process involves a source (e.g., someone speaks), a channel (e.g., a telephone), and a recipient (e.g., the listener) (Singh, 1966, 9). Maps are a form of graphic communication with space in the centre (Leimgruber, 2009, 19). As a component of the *graphicacy* paradigm, maps are important in the communication process based on the visual spatial abilities of human beings (Balchin, 1972, 188f). With a focus on thematic maps, Slocum, McMaster, Kessler, and Howard (2009, 5) define, as shown in Figure 2.1 on the following page, five steps for communicating map information. Several other models of the cartographic process for map communication (see A. H. Robinson and Petchenik (1975) for an early discussion) are available. According to MacEachren (1995, 5f), the focus of those models is mainly on the *design* step by the cartographer (how to symbolize the information) and on the *image formation* (how to read the information) by the viewer. Additional steps, like the decision of what to include in the map and why, as well as the influence of prior knowledge or how a map is viewed and evaluated, are often neglected.

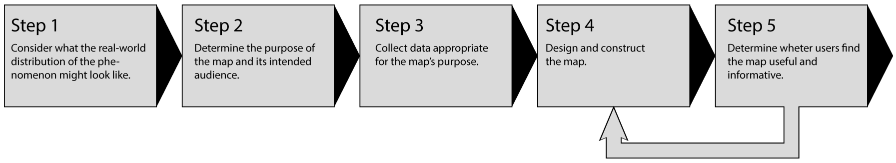


Figure 2.1 Main steps for communicating map information to others (Source: Own illustration after Slocum et al., 2009: 5)

As apparent from the ICA definition, useful maps exhibit only a portion of the *real* world (MacEachren, 1995, 3), and what is shown has to be defined. Woodward (1992, 52) denoted this fairly accurately with the statement, "(...) a map or a picture is not a representation of reality but a representation of ideas, usually highly conventionalized, about that reality". The cartographic paradox (according to Monmonier, 1996, 1) is, that "an accurate map must tell white lies". This can be interpreted as followed: a map is not entirely objective. Therefore, consideration of the other steps in the map communication process is equally important as well.

2.1.1 The History of Map Use for Communication

Utilizing maps as a form of communication is nothing new. Starting from 'mental maps' from a person with distances measured as travel times (Koeman, 2001, 5) to maps of relative positions of islands made out of sticks and reeds (Lyons, 1928, 326; Raisz, 1948, 3; A. H. Robinson, 1953, 2) as well as the first cadastral systems in Mesopotamia and Egypt dating back 7000 years (with the oldest sustained map dating around 4500 BP (Raisz, 1948, 5)), maps have been used as communication tools for centuries. Other examples of early map making in around the world include the Aztec maps (Raisz, 1948, 4) or the Ammassalik wooden maps (Holm, 1888, 144), the latter incidentally continued to be used throughout the 19th century. A climax of map making efforts was seen with the Greeks, Romans and Chinese around 2000 BP (Koeman, 2001, 8–11). During the decline of cartography in the Middle Ages within central Europe (Slocum et al., 2009, 20), the first nautical charts were produced in the Mediterranean (1250 AD). With the 'Great Age of Exploration and Discovery' starting around 1450 AD, additional geographic information was captured and distributed with new tools, starting mainly in the Netherlands (Koeman, 2001, 13; Slocum et al., 2009, 20; Seifert, 2014, 377) and later in France and England (A. H. Robinson, 1953, 5). Beginning in the 18th century, "modern" and accurate maps, mostly topographic, were produced and distributed

(Klöti, 2009, 36). Simultaneously, thematic cartography was initiated (Slocum et al., 2009, 21).

Throughout history, cartography has never been a separate discipline, or 'on its own', but rather connected with several fields, especially art, science and technology (Cartwright, 2009, 9). In the last hundred years, several paths of cartography and maps opened up and more connections to other fields were established. Especially with the introduction of computers (Kraak, 2008, 163), new fields (according to Skarlatidou (2010, 252) or Wood, Kirschenbauer, Döllner, Lopes, and Bodum (2005, 305) often technology-driven and not according to the user's need, for example, Geographic Information System (GIS)-tools) came about that also included knowledge from other fields of research (Jiang & Li, 2005, 3); that ultimately led to geovisualization (Dykes, MacEachren, & Kraak, 2005, 4) or (geo)visual analytics (Thomas & Cook, 2005, 4). Another field led to the use of geographic principles in the representation of non-geographic information (e.g., in Skupin & Fabrikant, 2003, 95).

2.2 2D and 3D Representations of the Environment

2.2.1 Perspectives in the Representation of Space in History

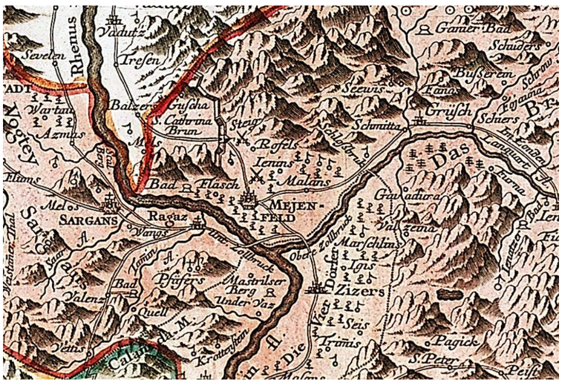


Figure 2.2 Rhætia (ca. 1750) by Matthäus Seutter (Seutter, Silbereisen, & Walser, 1750) (detail) (Source: University of Bern, n.d.)

As shown in Section 2.1.1 on the preceding page, there is a longstanding tradition in 2D mapping (Oulasvirta, Estlander, & Nurminen, 2009, 317). However, it is important to note that, despite the fact that maps have been produced for centuries, they were only available to the broad public once it was possible to mass-produce and -distribute them (Koeman, 2001, 15). Also, abstract projections (Uttal, 2000, 252), and in a way the modern form of symbolization are not as longstanding as they may be currently depicted. Rather, a more scientific approach towards map-making was initiated in the 17th century (Nurminen, 2008, 20). Earlier examples of 2D representations can be found in ancient Egypt, where some elements were drawn as the floor plan and others were elevated in front of the floor plan (Gombrich, 1982, 187), i.e., a multi-perspective view of the environment. Another example already including elevation (mountains) can be found in maps like the one depicted in Figure 2.2, which also includes a multi-perspective view with the mountains drawn in the profile and the other elements in top-down view. Before the 18th century, maps were quite often rendered in realistic paintings, not seldom with an oblique aerial view, also called bird's eye view (i.e., a 3D representation, see Section 2.2.2 on the facing page) and often including an important story (see Figure 2.3). Well known, and on the edge to the scientific approach, are the works, for example, by Pieter Snayers, Jacques Callot and Matthäus Merian from the 17th century (Gehring, 2014). Landscape paintings, as shown in Figure 2.3, also included a multi-perspective view, in this case a degressive perspective where the foreground shows the details from a pedestrian perspective and an overview perspective (i.e., bird's eye view) in the background (Lorenz, Trapp, & Döllner, 2009, 175). After the invention

Figure 2.3 The siege of Breda, 1624–1625 by Jacques Callot (Callot, 1626), see Zurawski (1988) for more
(Source: Stadsarchief Breda, n.d.)

of precise measurements and cadastral survey, oblique aerial views were used (and still are). Good examples can be found in tourism, where it was (and is) common, in the case of skiing areas as a quasi-standard (Patterson, 2000, 39), to draw pseudo-realistic maps. An example is shown in Figure 2.4. The example given in Figure 2.4 includes also a multi-perspective view, in this case a progressive perspective from a bird's eye view in the foreground and a central perspective with the horizon in the background (Lorenz et al., 2009, 177). An elevated viewpoint (i.e., bird's eye view) is often used, according to Gombrich (1982, 188), as it is easy to understand.

Figure 2.4 Yellowstone National Park panorama by Heinrich C. Berann (Berann, 1991), see Patterson (2000) for more
(Source: Patterson, 2000, 64)

2.2.2 What is 3D? – The Cartographer's View

With the previous subsection in mind, it is quite crucial to note that 3D representations are nothing new. Also, 3D computer graphics can be dated back to the 1970s (Johnson, 1963, 347; Sutherland, 1964, 345), albeit in a quite different style to what we are used today. However, what has changed is, that with digital data and modern computer technologies nearly anyone can, also without a training in cartography (Hegarty, Smallman, Stull, & Canham, 2009, 172), generate 3D (as well as 2D) representations. Also, 3D representations are popular in the media (Häberling, Bär, & Hurni, 2008, 176).

To avoid any confusion, it should be noted that, in the scope of this study, 3D representations (as well as 2D representations) are related, in general, to representations based on geographical information[1] and not on other data that also can be represented in a 3D environment (Shepherd, 2008, 200). So, what is the basic difference between 2D and 3D representations (in the field of cartography)? First of all, if we say that the

[1] Geographical Information is defined as "(...) information about the features and phenomena located in the vicinity of the surface of the Earth. What distinguishes this particular type of information from other types is of course the presence of a reference to some geographical location,(...)" (Goodchild, Egenhofer, Kemp, Mark, & Sheppard, 1999, 732)

real world is "real 3D" (or, better, 4D (Çöltekin, 2002, 81)), we cannot perceive this "trueness". The theory of depth perception states, "(...)[that] the third dimension of space is lost in the two-dimensional retinal image" (Gibson, 2015, 140). Hence, it is also not possible to transform "real 3D" into a map, either on paper or on a computer screen. However, as we are aware from everyday life, there are *depth cues* that allow humans to perceive the third dimension: monocular cues (linear perspective, apparent size, superposition, light and shade, relative motion, aerial perspective, and accommodation) as well as binocular cues (binocular disparity and convergence) (Gibson, 2015, 140). Consequently, Kraak (1988, 12) defined "(...) a map, considered as a graphic representation of the milieu, (...) to be three-dimensional when it contains stimuli which make the map user perceive its contents as three-dimensional". To achieve this, depth cues are used. As explained by Kraak (1989, 106), some of those depth cues can, in cartography, be achieved with visual variables (Bertin, 1974, 104) that were originally for 2D graphics; namely, Size, Value, Texture, Color, Orientation, and Shape. Therefore, 3D perception is also achievable in top-down 2D representations. The definition by Kraak (1988) was extended by Kirschenbauer (2005, 364) to discriminate 3D from true 3D. True 3D is achieved when the representation is not perceived on the display (or paper) but rather in front or behind the display plane (Kirschenbauer, 2005, 364). This effect can be achieved, for example, with stereoscopic displays, anaglyphs, or holograms (Kirschenbauer, 2005, 367f). The scope of the present study is limited to the 3D (and not the true 3D) definition. When the 3D effect should be achieved without true 3D (i.e., on a flat display), the third dimension has to be simulated, for example with perspective, motion (MacEachren, 1995, 373), or other cues as described by Kraak (1989, 109). MacEachren (1995, 139–141) distinguished between *physiological approaches* (the true 3D according to Kirschenbauer (2005, 364)), *perspective approaches* (i.e., the map looks "tilted"), and *non-perspective approaches* (plan view relief representation). According to Wanger, Ferwerda, and Greenberg (1992, 49), not all depth cues are suitable for all task types.

To sum up, it has emerged already from this first approach to the topic of "3D" that the field of 3D is diverse, and is used in different contexts and for different things. 3D representations are not simply a 2D representation somewhat "altered", it is more a different view of the same phenomena with another method. The focus of this thesis lies in the 3D representation of an abstracted reality with some thematic information shown with a perspective approach.

Three-dimensional representations have, according to Shepherd (2008, 202), a third display axis that allows the inclusion of an additional variable; as a basic example, height. This implies, that the perspective (also a depth cue) is altered. Basically, a 2D representation includes an x- and a y- axis, whereas a 3D representation includes an additional z-axis (Kraak, 1989, 107), sometimes referred as an additional degree of freedom (Wood et al., 2005, 300). This additional variable provides the map designer then, for example, the possibility of switching from the application of the visual variable Value (in terms of the depth cue: Shading) to a bird's eye view perspective and use Value as another variable in the map. Another fundamental change is that an additional Volume dimension is added as a form of geographical phenomena when 3D representations are used compared to the 2D representations, where only Point, Line, and Area are present (Dent, 1993, 79). Slocum et al. (2009, 81–84, 390f) expands on the visual variables by Bertin (1974) (and which was already extended by others, e.g., by Morrison (1974, 125), with a focus on generalization, or by McCleary (1983, 52), with complex patterns) then to the 3D space as well as visual variables for animated maps (Duration, Rate of Change, Order by DiBiase, MacEachren, Krygier, & Reeves, 1992, 205 as well as Display Date, Frequency, and Synchronization by MacEachren, 1995, 281), see Appendix 1 for an overview.

2.2.3 3D – The Virtual World

The last decades have recorded a growing interest in the use of 3D representations of the environment (e.g., in Häberling et al., 2008, 176; Niedomysl, Elldér, Larsson, Thelin, & Jansund, 2013, 87; Shepherd, 2008, 200 or Wood et al., 2005, 295). Kraak (1989, 112) concluded that most of the familiar cartographic theory (developed for 2D representations) can also be used within 3D representations. Contrary, others argued that the development of 3D representations was, like many other computer applications with an end user in mind (Nickerson & Landauer, 1997, 16), largely technology-driven (Shepherd, 2008, 200; Skarlatidou, 2010, 252) and there remains a lack of design principles for 3D representations (Häberling et al., 2008, 178f; Fairbairn, Andrienko, Andrienko, Buziek, & Dykes, 2001, 19). Possible graphic variables for 3D (topographic) representations were listed by Häberling (2004)

Generally, there are various advantages inherent in a 3D representation. The perspective view with the tilted surface results in more display space (Shepherd, 2008, 201). This was shown, for example, in the field of information visualization for a desktop organizing system, by Card, Robertson, and Mackinlay (1991, 184); Cockburn & McKenzie, 2002, 203f and Cockburn, 2004, 26f. However, as concluded by Cockburn (2004, 30), the user performance within this 3D environments is not better than within the classic and familiar environment of a computer. The effect of more visible space also holds, partially, as described later, true for the 3D representations of the environment that are withinin the scope of this study.

A clear advantage of 3D representation is, as already stated, the additional variable that can be mapped, something that can not (apart from 2D cartograms) be achieved with 2D representations (Shepherd, 2008, 202). With the tilted view and the additional variable, it is also possible to show stacked symbols at one point (Shepherd, 2008, 203f). This means different entities can be mapped at the same geographical location, something that can hardly be achieved with reasonable symbolization in 2D maps.

One of the most commonly cited advantages of 3D representation is clearly the “natural” or “familiar” view. 2D representations are only a plan view of the world and often have a quite abstract symbolization that has to be learnt (Shepherd, 2008, 202). Consequently, not only the real environment but also non-geographic data can be mapped in a “natural” manner, as it is believed that this view is more familiar and comprehensible, (e.g., in Gee, Pinkney, Pickett, & Grinstein, 1998, 2 or Robertson, 1990, 115). This claim, that 3D representations are nearer to our everyday experience (Häberling et al., 2008, 176) and therefore easier to understand (e.g., in Lai et al., 2010, 221 or Wanarat & Nuanwan, 2013, 679) and that the “detour” from the 2D representation to the mental image of the 3D reality can be omitted (Rase, 2007, 215), is also one of the main interest of this study. It should be mentioned that this view is the complete opposite to the paradigm in cartography (and geovisualization) – abstraction of the reality is fundamental to obtain insight (MacEachren & Kraak, 2001, 9).

2.2.4 Why Urban Planning foster 3D Representations

The trend towards hyper-real virtual environment is pronounced especially in the field of Urban Planning (UP). Wood et al. (2005, 299) mentions, that this fact is hardly surprising based on, simplified, the nature of the topic that is already 3D. It is important to note that this study only focus on the representation-component and not on other aspects of 3D models or 3D GIS used within urban planning like for example analysis of view-shed (e.g., for cellular antenna or the visibility of wind turbines from an particular location) or accessibility (e.g., is it possible to reach a given position), see Batty et al. (2000, 4f) or Shiode (2000, 267) for more.

So far, urban planners use various methods to communicate planning related topics (e.g., in Barsuglia, Sturm, and Schumacher (2014, 78) or Gilgen (2012, 669). The result from an urban planning process, often a proposed design, has to be communicated to professionals as well as to the public, two highly heterogeneous groups (Batty et al., 2000, 1). Various media are used within this process (Delaney, 2000, 16) and it is important to find an effective and visual pleasing form of communication that is understandable by lay-people (as well as experts) Al-Kodmany (1999, 38). Therefore, it is not surprising that also visual forms of communication are used during this process. The legally accepted form is a 2D zoning plan on paper (Aliesch, 2012, 481) as for example given, as a web-version, in Figure 2.5. However, static or interactive representations of 3D

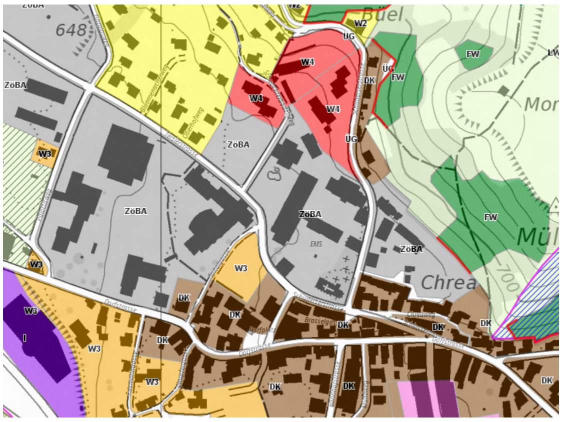


Figure 2.5 2D zoning plan, municipality of Schiers (detail)
(Source: Amtliche Vermessung (AV), Kanton Graubünden, Gemeinde Schiers, 2015)

Figure 2.6 3D Zoning plan as an overlay on Google Earth, municipality of Groningen
(Source: Bos, 2010, 77)

models are also used, for example Figure 2.6 (Hanzl, 2007).

Many studies in the field of UP propose 3D representations, especially when a high photo-realism is used (at the highest stage including a Virtual Environment (VE) with different possible views, from immersive egocentric via 3D bird's eye to a top-down plan view (Verbree, Maren, Germs, Jansen, & Kraak, 1999, 385)) to be an effective medium in the communication process of UP-related topics, particularly in terms of public participation. Examples can be found in Wanarat and Nuanwan (2013, 688) (understanding of a proposed land-use plan seems to be better with 3D representations), Lai et al. (2010, 230) (3D encourage viewers since it includes aspect of entertainment and visual beauty), Delaney (2000, 16) ("When it comes to planning the future of a town, or the entire planet, a 3D model may be priceless"), Neuenschwander, Hayek, and Grêt-Regamey (2014, 246) (reporting positive user feedback towards a platform that allowed to illustrate different scenarios in 3D), Klein, Hayek, Neuenschwander, Melsom, and Grêt-Regamey (2012, 228) (highly realistic 3D representation allows to asses a landscape identity), Bos (2010, 97) (3D zoning plans convey a better estimation of the height of a building compared to 2D plans and interpretation is easier) and finally, for a VE containing audio and visual realism, Drettakis (2007, 330) concludes that this results in a better understanding of the task. This was also shown by Nielsen (2005, 28), who stated that the world view (as defined by Verbree et al., 1999, 385) with a photorealistic 3D representation is suitable for the public while the model view is suitable for professionals.

Apart from the scientific field, 3D is also considered; more than ten years ago, a functional 3D-GIS (GEONOVA DILAS) was available on the market, developed for 3D zoning planing (Geonova AG, 2003, 298). A 3D trend was always around, at the moment reinforced with products like ESRI ArcGIS Pro[2], Autodesk InfraWorks[3] or GeoMedia 3D[4].

2.2.5 3D – The Consequences

With the statements given in the last section, one might think that 3D is, at least in UP where the familiarity has a key role, the solution in every situation and 2D can be abolshed. But there are also many drawbacks when 3D representations are used; some of them can be dealt with, others are inherent in the form of representation.

[2] ESRI Inc., Redlands, US, www.esri.com (accessed: August 29, 2015)
[3] Autodesk Inc., Mill Valley, US, www.autodesk.com (accessed: August 29, 2015)
[4] Hexagon AB, Stockholm, SWE, www.hexagon.com (accessed: August 29, 2015)

If a *perspective approach* is used (and this is often the case, especially when real environments are shown), the scale changes (because of foreshortening) across the map and it is therefore difficult to estimate distances, sizes, or directions in a 3D representation (Harrower & Sheesley, 2005, 12; MacEachren, 1995, 141; Shepherd, 2008, 204). If interactive functions can be implemented, it is possible to provide the user with a simple tool to measure distances within the representation (Germs, Maren, Verbree, & Jansen, 1999, 504; Rase, 2007, 2015). However, this needs an action by the user and the measurement can not be done without the interaction. Another option is to include, similar to a scale bar, a reference frame to convey some meaning of scale (Shepherd, 2008, 204–206). As shown by Eby and Braunstein (1995, 991), this can result in a "flattening" effect and therefore reduce the depth cue perception within a scene. The other options noted by Shepherd (2008, 206) – a reference plane or divided symbol stacks – are especially applicable in the case of 3D data visualization to provide more cues as to how two objects or data points are related to each other. In this case, interactive tools can also be a valid solution. Technically, a 3D representation can also be achieved with an isometric projection (MacEachren, 1995, 370); this 2.5D representation gives the impression of an oblique view (i.e., 3D), with which it is possible to compare sizes across a scene (Shepherd, 2008, 207). As we are used to the perspective projection and this form is used everywhere (in 3D representations) (Wyeld, 2005, 597), and we expect to see a linear perspective and that objects decrease in size when farther away (MacEachren, 1995, 370), the isometric projection does not look "right" to our eyes. If none of those methods can be incorporated, distance estimations are difficult when stereoscopic representations (i.e., "true 3D" as defined by Kirschenbauer, 2005, 364) are utilized, but not in the case of a tilted 2D (denoted as 3D) representation (Seipel, 2013, 857).

Further, Shepherd (2008, 209) mentions symbol occlusion. The perspective projection causes some objects to disappear behind another object in respect to the viewpoint of the user, an effect that we are used to from everyday life. Occluding objects can simply be removed, the visible size reduced, or displaced (Shepherd, 2008, 209f). There is a vast number of techniques for occlusion management available in Elmqvist and Tsigas (2008, 1101). Some options include a distortion of the scene (nonlinear magnification Keahey & Robertson, 1996, 39), or alternatively, multi-perspective views (either progressive or degressive) as described by Lorenz et al. (2009) and Vallance and Calder (2001) (see also Section 2.2.1 on page 7), multiple linked views (Roberts, 2005, 166), giving a detail + context view (Harrower & Sheesley, 2005, 15), shadows (Herbert & Chen, 2015, 31), or reduced opacity (Shepherd, 2008, 210). Possibly most striking, especially as geo-browsers (Riedl, 2008, 343) (can also be named virtual globes (Tuttle, Anderson, & Huff, 2008, 1479) or digital earths (Goodchild, 2000, 352)) are quite common, is the interactivity (zoom, pan or tilt (Schultz, Kerski, & Patterson, 2008, 28)), and therefore also the ability to change the viewpoint and see heretofore hidden symbols or objects and also enhance the depth perception with the movement (MacEachren, 1995, 373; Shepherd, 2008, 210).

Those two aspects, scale variation and symbol occlusion, may be the two main drawbacks in the use of 3D representations; there are others already partially and briefly discussed, for example, the different (or similar) use of map symbolization from the 2D representations (Kraak, 1988, 1989) or practical issues with the technical implementation of 3D representations – 3D representations are, especially if photorealism should be achieved, costly (Plesa & Cartwright, 2008, 83) and hardware-demanding (Rase, 2007, 216; Wood et al., 2005, 302).

Also the term of "familiarity" is not that straightforward and previous studies in the field of 3D representations found contradictory results. Savage, Wiebe, and Devine (2004) tested 2D and 3D representations of topographic maps. According to their results, 3D representations do not lead to better results, even if elevation extraction from the map is required to answer a question (Savage et al., 2004, 1796), a task that seems to be suited to 3D representations with included height information. Their findings were somewhat contrary to the ones by St. John, Cowen, Smallman, and Oonk (2001, 84) who reported a better performance in tasks of shape understanding (i.e., reducing the cognitive load of mental rotation) for the 3D representation (a perspective view) compared to a 2D representation (a top-down view). They reported further that 2D representations are more suitable, as the view is not distorted, to judge relative positions within the map (St. John et al., 2001, 94). This finding was partially confirmed by Seipel (2013, 857) who stated that strong 3D representations (with stereoscopic and kinetic depth cues) result in lower performance in terms of spatial judgement compared to 2D or weak 3D (i.e., a tilted 2D) representations. Two-dimensional representations were in generally also to be found to outperform 3D representations, especially when detailed information should be extracted from a map (Niedomysl et al., 2013, 94).

In the field of Urban Planning (UP), the work by Herbert and Chen (2015) recently contributed to the discussion. They evaluated the preferences of urban planning professionals for 2D or 3D representations in terms of a proposed design. Herbert and Chen (2015, 29) concluded, that the 3D representation can be helpful to imagine the proposed design in the mind. However, the scope of their study is quite limited and they state also that the level of detail was different between the 2D and the 3D representation (Herbert & Chen, 2015, 31), therefore those two representations are not fully comparable.

In respect to VE, Drettakis (2007, 329) mentioned that some participants thought that the representation shows *exactly* how the (possible) design will look after it is build, therefore, a representation can also be too realistic for a given purpose. Plesa and Cartwright (2008, 83) note also in the field of realism, in respect to the abstraction functionality of a traditional map, "[that i]n many situations, presenting an observer with enough information to create the illusion of reality is often more important than simulating reality". A tested prototype of a non-realistic 3D representation was more appreciated by the users than the photorealistic representation.

This finding is quite interesting, since otherwise, following the paradigm of *naïve* realism, users often prefer a (realistic) representation. The term naïve realism, as defined by Smallman and St. John (2005, 1564) as "(...) the misplaced faith in perception's ability to extract information from realistic displays", refers to the fact that users often prefer realistic over abstract representations but have a lower performance with the realistic representation (Smallman & Cook, 2011, 603f). Naïve realism does not only occur in terms of more realism or less realism in 3D, but also in the scope of 2D versus 3D representations (Smallman & St. John, 2005, 1565), suggesting that users may prefer 3D over 2D but do not perform better (or even worser) within the 3D environment, as show in many studies (see: Section 2.2.4 on page 12 and also in Hegarty et al., 2009). An example why this errors happening can be found in Smallman and St. John (2005, 1565) (derived from another study where 3D (realistic) and 2D (abstract) symbolization elements were tested (Smallman, St. John, Oonk, & Cowen, 2001)): If a symbol is drawn similar to the object it stands for and two objects in reality are similar, this results in two alike symbols within the scene and therefore it is difficult to discriminate those two symbols from each other. Another aspect is ambiguity of the symbol and that the perspective view merges the representation plane with the symbol, it is therefore harder to find the symbols in the scene. The dilemma between user preference for realism and effective (abstracted) representations can be solved, according to Smallman and St. John (2005, 1568), with a caricatured reality (i.e., maintain a feeling of familiarity but remove clutter), added elements to guide attention, and uncertainty visualization to represent the error that can happen (i.e., when measuring something within a 3D representation).

A list with several other studies contributing different findings to the 2D or 3D debate can be found in St. John et al. (2001, 95).

With the last subsections in mind, it should be obvious that there are advantages but also disadvantages related to the use of 3D representations. It should also emerged, that there is no clear statement that says if 2D or 3D representations are "better". While those studies and the previous sections give a general overview of research in the topic of 3D (or 2D) representations, more previous research regarding the wayfinding-tasks will be given in Section 2.3.2 on page 23.

2.3 Tasks

As stated in Section 2.1 on page 5, maps are a form of communication. Nearly all types of maps (regardless of whether it is a 2D or a 3D representation), such as the one seen in Figure 2.7, are used for a task. In this case the task was, for the author, to get to know the City of London, and, for the reader, to see another possible view of the city. In a more formal way, maps can be used to *measure* the distance between two locations, to *navigate* from A to B, or they can *visualize* (in a broader view). From this categorization of map reading tasks, being navigation, measurement and visualization (according to Board, 1978, 6), wayfinding (a subset of navigation) and especially visualization are of interest for this study. The former, navigation, as defined by Board (1978, 6), is based on the matching of a map with the environment. The latter, visualization, can be understood as how the map reader perceives the content shown in the map will look (Board, 1978, 8). A basic understanding of how spatial information is acquired will be given in the next subsection, before the *wayfinding* and *visualization* concepts are described in more detail.

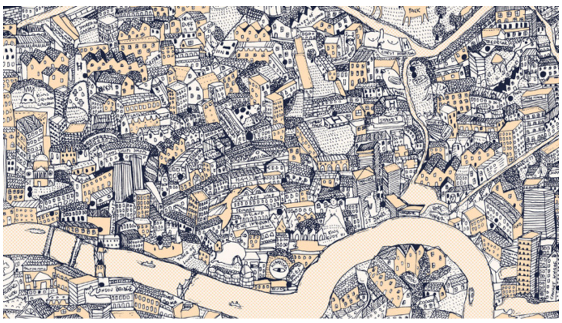


Figure 2.7 Hand drawn map of London (detail)
(Source: D. R. Robinson, 2014, 33)

2.3.1 Knowledge Acquisition

It is widely accepted that spatial information is stored in a form of a so-called *cognitive map* (Tversky, 1993, 14) or, to use a broader term, in *mental models* (Lloyd, Cammack, & Holliday, 1995, 5). As noted by Bryant and Tversky (1992, 76), an *internal* or an *external* perspective can be adopted as spatial points of view. The *external* perspective is achieved when an observer views an object disjoint from the object from a fixed viewpoint, like for example when someone looks at a map (Lloyd et al., 1995, 5). When an environment is learnt that way, survey-knowledge is developed (Lobben, 2004, 274). Therefore, information that is available from maps but not through navigation in the environment is obtained, such as euclidean distances between objects or the location of an object in respect to a fixed reference frame (Thorndyke & Hayes-Roth, 1982, 563). This form of knowledge acquisition (*survey-mapping*) is undertaken from a bird's eye view (Lobben, 2004, 275) and includes the (successful) selection, codification and evaluation of the presented information in the representation (Thorndyke & Stasz, 1980, 171), finally resulting, again, in a bird's eye view of the environment under investigation (Thorndyke & Hayes-Roth, 1982, 585). The other form of knowledge acquisition of space occurs when a person is viewing an object from an *internal* perspective (Lloyd et al., 1995, 5). When a person is navigating the environment, a person is in the same space as the object and the important factor becomes the location of the object relative to the orientation of the person in this space (Lloyd et al., 1995, 5). This environmental and route learning (Stern & Portugali, 1999, 107), or *environmental mapping* (Lobben, 2004, 274) produces route knowledge (Thorndyke & Hayes-Roth, 1982, 561). As noted by Lobben (2004, 275), survey- and route mapping form, independently or together, the cognitive map. Uttal (2000, 250) adds that: "(...) maps bring into view spatial and geographic information that would otherwise remain opaque or inaccessible from direct visual experience, and moreover they facilitate thinking about the represented information". With the repetition of map reading or when the environment is visited several times, the cognitive map gets periodically updated with additional information (Lloyd, 2000, 518). Following Siegel and White (1975, 23), the third notable element of this "dominant" (to use the term by Montello, 1998, 114) framework are landmarks (Montello & Raubal, 2013, 249). This model of spatial knowledge representation is therefore called "LRS" for *Landmark, Route, Survey* (Darken & Peterson, 2002, 497). The model was conceived and described by Siegel and White (1975); Thorndyke (1980, 2) and summarized in Thorndyke and Goldin (1983, 196). As noted by Darken and

Peterson (2002, 498), the model fits quite well with the five elements of Lynch (1960, 46) that comprise the content of a city (-image): Paths, Edges, Districts, Nodes, and Landmarks. It is quite important to note that, despite the fact that a form of 'mental model' seems to be formed around the world, this particular model may not be applicable to non-Western cultures as outside of the West, fundamentally different models are relied on (Uttal, 2000, 252).

Knowledge acquisition will, as stated by Lobben (2004, 274), not lead to a cognitive map with "perfect" accuracy, but to one that is useful to navigate in the environment. It is therefore not a "real" form of a cartographic map (Richardson, 1981, 325) in the mind, but rather an analogy of the environment (Crampton, 1992, 47) that can happen to be quite different from the "real" environment (Golledge, 1999, 7). As stated by Siegel and White (1975, 21), cognitive maps are fragmented, distorted, split in separated parts and do not have to be visual. This is also supported by Tversky (1993, 21) – she notes that the *cognitive map* metaphor can, in some situations, be replaced by the *spatial mental model* or the *cognitive collage* metaphors. The spatial mental model is suitable for well-known areas where (metrically still distorted) spatial relations (and therefore perspective-taking) is possible. The cognitive collage can be referred to in that (spatial) information is not only acquired from the presented exposure to the environment (route mapping or procedural knowledge) or map reading (survey mapping or, partially, imaginative knowledge), but also contributed to through other forms of communication or experience (like linguistic, declarative, or imaginative knowledge (Molitor, Ballstaedt, & Mandl, 1989, 11)) with snippets of information that are relevant (and possibly erroneous) (Tversky, 1993, 21). As noted by Crampton (1992, 61), the mental representation derived from a map can vary for different participants, mainly based on unique interpretations of the map.

2.3.2 Wayfinding

It is necessary to define the two terms that so far have been used to this point: navigation and wayfinding. Those two words are often confused or utilized for different meanings in the literature. Following Darken and Peterson (2002, 494), the term *wayfinding* will refer to the cognitive element of navigation. It includes the parts that guide movement, but not the movement itself. *Motion* would be the motoric element of navigation (not in the scope of this study) whereas *navigation* is the aggregation of wayfinding and motion. Therefore, navigation is not a partial task, but one that is aggregated, including the aggregated components of wayfinding and motion. It should be remarked here that others (e.g., in Golledge, 1999, 6) define wayfinding as the complete process in going from A to B, i.e., what was denoted before (and by Darken & Peterson, 2002, 494) as navigation (wayfinding and motion). Golledge (1999, 6f) divides human movement further into two guiding processes – *navigation*, locating a position or shows a course of, for example, a ship; and wayfinding, the selection of paths from a network configuration.

As Lobben (2004) states, "[t]he task of navigating with a map requires the map reader to interact and relate the map and the environment with and between one another." Two main processes can be identified in this task: visualization and self-location. Those two processes are necessary to navigate in an environment with a map (Blades & Spencer, 1987, 65; Lobben, 2004, 276). The following subsections will introduce the two map environment processes in more detail. Following this, findings from navigation research with respect to visualization and self-location that are central to this study are described.

Visualization Preliminary note: In this context, the term visualization is not denoted as a "(...) method for displaying data (Slocum et al., 2009, 13), but rather, as defined by MacEachren et al. (1992, 101) "(...) foremost an act of cognition, a human ability to develop mental representations that allow geographers to identify patterns and to create or impose order. The mental representations formed and the patterns people see are closely linked to expectations they bring to a given situation". Lobben (2004, 276) notes, with respect to visualization, that "[f]or persons required to navigate in unfamiliar territory, the survey knowledge obtained from a map provides the map reader with an aerial view allowing them to 'see' what lies ahead". This conversion of the top-down view from the map or survey knowledge in a three-dimensional terrain depiction where it is possible to imagine the scene (Crampton, 1992, 59) is graphically explained in Figure 2.8 on the next page and called *mental transformation* by Lobben (2004, 276). With the process of visualization, someone "turns" the view from the map into a real world environment to see, in mind, the view at a given position. This representation-to-environment interaction (Lobben, 2004, 277) means that information from the representation (i.e., a map or something else) is interpreted and the environment (in reality) is imagined. According to Hegarty (2002, 40), an *internal visualization* (i.e., in mind) is derived from an *external visualization* (e.g., a map, in the context of this study a representation). The process of visualization is quite familiar and used, for example, when someone looks at a road map and travels through the environment in his or her mind (Garfield, 2014, 62).

It should also be considered that, as described by Hegarty and Waller (2004, 176), mental transformation consists of two separable but highly correlated and interacting parts: 1) spatial visualization – "(...) the ability to make object-based spatial transformations in which the positions of objects are moved with respect to an environmental frame of reference, but one's egocentric reference frame does not change"; and 2) spatial orientation – "(...) the ability to make egocentric spatial transformations in which one's egocentric reference frame changes with respect to the environment, but the relation between object-based and environmental frames of reference does not change". The former can be denoted as mental rotation, the later as perspective taking (Hegarty & Waller, 2004, 175). Several test procedures are available to test one's ability in terms of these mental processes. However, those processes are highly connected (Hegarty & Waller, 2004, 188); this can be because similar human abilities are used (Hegarty & Waller, 2004, 188; Kosslyn, Digirolamo, Thompson, & Alpert, 1998, 156).

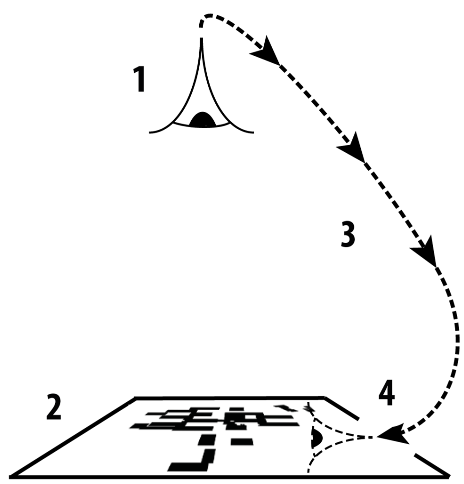


Figure 2.8 Mental transformation – visualization (Source: Own illustration)

1. Position of the map reader
2. The 2D map under investigation by the map reader
3. The mental-transformation
4. The mind's eye seeing the visual image (*visualization*)

Self-Location Self-Location can be discriminated in two, and to some extent, connected parts: the *location* itself (i.e., pointing to a position on a map where one is located) and the *orientation* (Peebles et al., 2007, 391), also called *direction* (Thompson et al., 1990, 707) (i.e., pointing in the direction one is facing). As Lobben (2004, 277) has commented, self-location and visualization both require an interaction between the 2D representation and the 3D environment by the map reader. However, in the case of self-location, it is an environment-to-representation task, and therefore a discrete problem solving process at the beginning of the navigation task (Lobben, 2004, 277f) or in other situations where the *drop-off localisation problem* (as Peebles et al. (2007, 390) or Thompson et al. (1990, 707) call it) arises. According to Thompson et al. (1990, 707) this name "(...) comes from the extreme case in which an observer is "dropped off" into a totally unfamiliar environment", contrary to navigation where a constant updating process takes place when one is moving though an environment. As stated by Peebles et al. (2007, 390), in this case a person has, to match the orientation and maybe the location from the environment to the map. Peruch, Pailhous, and Deutsch (1986, 71) denote this task as the answer to the question 'how can I tell where I am from what I can see?' (Peruch et al., 1986, 73) with the matching process of two spatial frames of reference – the egocentric frame (the environment as seen from a person) with the geocentric frame (the environment as given for example in a map). Therefore, information supplied in the map has to be matched with the environment, like landmarks and relationships between objects (e.g., in Lobben, 2004, 277 or Meilinger, Hölscher, Büchner, & Brösamle, 2007, 384) for example. Figure 2.9 on the following page portrays an overview of this process. At least two elements in the map and the environment must be matched, and then, according to the two-point theorem, the map can be related (and rotated) to the environment (Levine, 1982, 225). As determined Thompson et al. (1990, 706), bottom-up perception is employed to detect the location and type of landmarks, while with top-down perception the map is searched for specific landmarks of this type at specific locations. A third process then tries to match the landmarks (those from the bottom-up process in the map and those from the top-down approach in the environment). This matching always works in both directions, i.e., a feature in the environment can be matched with a feature in the map or vice versa. This search for *cues* within the environment and the map is guided by prior knowledge and heuristics (Thompson et al., 1990, 707).

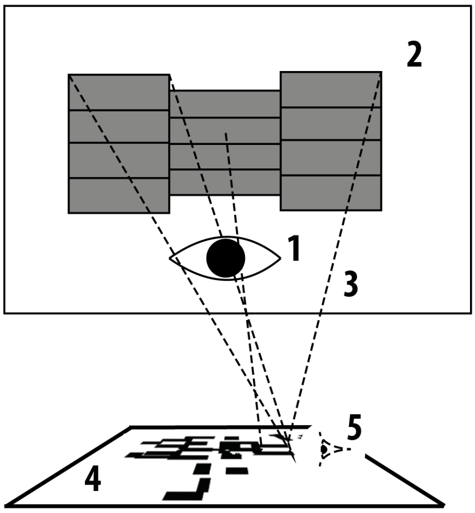


Figure 2.9 Mental transformation – self-location
(Source: Own illustration)

1. Position of the map reader in the environment
2. Buildings in front of the map reader in the environment
3. The environment-to-map task
4. The 2D map under investigation by the map reader
5. The location (and orientation) of the map reader on the map

Previous Work Lobben (2004, 277) has noted that little research has been performed on the topic of self-location. With the technological development and the introduction of mobile maps and Location Based Services (LBS), this has moderately changed (for 2D as well as 3D representations). The topic of *visualization* is often addressed indirectly. Further, Lobben (2004, 277) has stated that *visualization* and *self-location* are, in some aspects, related (and, of course, also connected to *navigation*, in general), thus it is not that easy to investigate those two aspects independently of one another. This also emerges from the statement related to the matching process by Thompson et al. (1990, 706)

It has been widely accepted and confirmed by several studies that map use (for maps with the same information content) works better when the map is *aligned* with the environment, such that the flat map in the hand or on the ground should be parallel to the terrain (Levine, 1982, 230f) and orientated *forward*. If the map can not be aligned horizontally, like for example a map on a wall, the forward-up equivalence takes place and the map is easy to use if the *up* on the map is in the direction of *forward* (Levine, 1982, 231). Levine, Jankovic, and Palij (1982, 173) as well as Levine, Marchon, and Hanley (1984, 156) confirmed this hypothesis in a series of experiments. The underlying task for all experiments was quite similar – the participants had to build a cognitive map of a path from a picture and then walk this path. Therefore, the location was provided but the orientation had to be drawn from environment-to-map matching. In a laboratory experiment, Shepard and Hurwitz (1984, 190) supported those findings. Aretz and Wickens (1992, 326) also observed the same phenomena, as well, and added that mental rotation is the preferred strategy to transform a north-up aligned map to a forward-up aligned map. This is especially the case of so-called ego-centered reference frame (ERF)-based tasks, like the localization of a position from the view seen in the ERF to the WRF (world-centered reference frame, i.e., a map). A north-up view is considered better for WRF-based tasks, such as the development of a cognitive map (Aretz & Wickens, 1992, 326). In a study by Warren, Rossano, and Wear (1986), participants had to view a picture of one single building and identify the location on a 2D floor plan from where the image was taken. Warren et al. (1986) noted that the mental transformation from the top-down viewpoint in a map to the egocentric viewpoint in the environment as well as the difference in detail (richly detailed environment versus limited details in the map) could be problematic and hence the task may be difficult to solve. He also stated that performance was best when the map was aligned with the building because of a perceptual cognitive effect (Warren et al., 1986, 148) (that can be understood as less effort for mental transformation). A similar study was performed again by Warren (1994, 71) – the location of a photograph had to be identified from a 2D (top-down) map or a (static) oblique map representation. A clear alignment effect was found for the top-down map. The results for the oblique map, however, were quite interesting – the overall performance was better than in the 2D top-down representation, yet a strong alignment effect was still apparent (Warren, 1994, 88). Warren noted that the additional information (building height, façade details, etc.) can be helpful in the matching to the environment, but at the same moment, the tilted view occluded information. A problem arose, too, because the oblique map in the static condition can only show one specific viewpoint. The question becomes then, if the map should be aligned with the environment or used upright. Interestingly, participants preferred to use the map in a misaligned but upright orientation and not in the aligned but non-upright orientation; the performance was, as stated, worse in the misaligned orientation than in the aligned condition (Warren, 1994, 95). It should also be commented on that not all results were statistically significant and only a trend could be reported. The task was, with a performance of 13% correct answers, really difficult (Warren, 1994, 94). Following Warren (1994), Iachini and Logie (2003) switched from laboratory to field studies. Participants had to self-localize themselves with respect to a building. Despite the fact that the task was quite similar (participants were supplied with a map with a starting position marked, observed the building, were blindfolded and walked to another position with another perspective of the building, the task being then to mark this position on the map (Iachini & Logie, 2003, 723), the results (response time and accuracy) were far better. They concluded that this is mainly because of the more accurate reality in the field than in the lab and the movement around the building compared to the static view in Warren's setting. This fact was similarly found by Liben, Myers, and Christensen (2010, 128). In a study by Liben et al. (2010), participants had to self-locate and orientate themselves on a map in the field and, in a second task, match photographs to vertical or oblique maps. The alignment effect was verified as well and they observed that the self-location and orientation task was quite hard for some participants in the "real" as well as in the "photograph" setting (Liben et al., 2010, 129). Additionally, spatial ability had a clear influence on the participants ability to self-locate, self-orientate, and point to a building (Liben et al., 2010, 125). In an indoor environment, Hoogenboom (2012, 10) reported (statistically not significant) better performance (time, accuracy, fewer interaction) in a self-localization task with 3D representations. A simple matching between a scene (from photographs or 3D representation with an egocentric viewpoint) and a 2D map to state the orientation with a given location was undertaken by Davies and Peebles (2007, 2010); Peebles et al. (2007). According to them, participants relied on a landmark matching strategy even when a shape-based strategy (abstracted) would be easier to match with the map (Davies & Peebles, 2007, 927). Peebles et al. (2007, 2) also included a list of (non-navigation) task scenarios where it is important to match a scene to a map:

1. trying to identify a specific building or object which is not explicitly labeled on the map, e.g., to visit or study it, or in an emergency scenario;

2. trying to match a historic image (e.g., of an old street scene) to a modern day map, or vice versa;

3. making planning decisions based partly on viewing the current visual landscape (or photographs of it) and partly on a drawn plan or model of a proposed development;

4. trying to judge relative distances and directions to unseen distant locations (whether or not one intends to navigate to them);
5. viewing 'you-are-here' map signage within a space, where location is indicated but orientation is unclear.

Regarding the alignment effect, Pazzaglia and De Beni (2006, 380) reported that a difference in the amount of the effect (and also the existence of the effect itself) is present if one has (based on the MRT) high or low spatial ability; the alignment effect is stronger (i.e., higher differences in the performance) when one belongs to the low spatial ability group. In a number of conditions, no alignment effect was discerned for participants with high spatial ability. They additionally stated that low spatial ability participants focused more on landmarks while high spatial performers preferred survey or route representations (as noted by Nori and Giusberti (2002, 146), no alignment effect was found for participants who had a mental representation in survey style). Therefore, Pazzaglia and De Beni (2006, 380) concluded that spatial abilities are related to spatial representation preferences.

In the context of mobile device-based navigation, Coors et al. (2005); Kray, Laakso, Elting, and Coors (2003); Laakso (2002) asked participants to walk from A to B with different representations of the environment, such as 2D and 3D representations. As no GPS data was available, the current position as well as the orientation had to be evaluated by the participant and not the device (Kray et al., 2003, 121). They concluded that 3D maps were slower to use, especially in the initial orientation to begin the task, compared to 2D maps (paper) (Coors et al., 2005, 544). The users matched the buildings on the screen to the buildings in the environment and followed an arrow on the screen at different possible camera altitudes. According to them, the easiest was the bird's eye view (Coors et al., 2005, 544). The personal attitude towards the use of 3D maps was, however, quite significant (Coors et al., 2005, 545), a fact that should be considered (Kray et al., 2003, 123).

Another group utilized a similar approach. Again, no GPS was used as they stated, first, "(...) [that] most present-day phones do not carry GPS and it is unlikely that the majority will have GPS in the next couple of years" and, second, because of the precision error of GPS data in urban canyons (Oulasvirta et al., 2009, 307). The task, including recognition of objects and egocentric alignment, was also completed faster with the 2D representation compared to the 3D representation (Oulasvirta, Nurminen, & Nivala, 2007, 12; Oulasvirta et al., 2009, 314). This holds also true for bird's eye view in 3D that is quite similar to the familiar 2D representation. They speculated that this could be resultant of the fact that 2D representations use symbols to show objects, whereas 3D includes “real” cues of the environment at the street level, like façades, and only those elements can be matched (Oulasvirta et al., 2009, 318). When textured models are used, a low level of detail can lead to ambiguous cues (Nurminen, 2008, 30). Further, 2D maps are more familiar than newer 3D representations (Oulasvirta et al., 2009, 317). As mentioned by Froehlich, Obernberger, Simon, and Reichl (2008, 366), the oblique aerial perspective (in their case 45°) should be favoured over an egocentric perspective (within mobile navigation). In terms of the alignment effect during mobile navigation, Seager and Fraser (2007, 767) reported that participants solved a navigation task most effective, when they rotated the map physicaly (i.e., the device) and not with an automated rotation or a digital buttons.

An overview of several approaches to self-localization, orientation and partial visualization is available in Peebles et al. (2007) and, in the field of mobile devices, Kiefer, Giannopoulos, and Raubal (2014).

2.4 Summary

After this literature review and the investigation of the two topics, 3D and wayfinding, several findings can be mentioned. First, to visualize a representation and to imagine how it looks like in reality, is a fundamental aspect of map use and map reading. The second, wayfinding, consists in the scope of this study of self-location and orientation, also an important task in everyday life. The studies shown cover most of the aspects, however, the findings are partially weak or even conflicting. This is especially true for the field of 3D representations. Many statements are made, but actually, especially in the case of realistic 3D representations, not much work was done so far that depict how effective and efficient those representations are. Many studies agree in the statement that the alignment of the representation to the environment (i.e., that the area visible is in front of the representation) plays a crucial role. Also, 3D representations seem to lead to higher engagement and motivation with the content provided. To contribute to this discussion, the following section introduces the case study.

3 | Methods

3.1 Participants

A total of 43 people with different backgrounds participated voluntarily and without any compensation (apart from a snack and, while stocks lasted, a 5 CHF voucher for the cafeteria) for the study. All participants stated that they were fluent in German. The experiment took place between June 6 and June 24, 2015 at the University of Zurich - Irchel (Institute of Geography University of Zurich (GIUZ)). Based on technical issues with the computer system used that resulted in missing data values, three participants had to be removed from the study.

3.2 Materials

3.2.1 Apparatus

The experiment was conducted in the Eye Movement Recording Lab (EML) at the GIUZ. The EML is a windowless room to ensure that environmental conditions during the experiment are as similar as possible for all participants. As many (external) variables as possible were held constant for all participants during the experiment: the setting of the room, the procedure and the lighting conditions were the same for all participants (Martin, 2008, 27).

The EML is equipped with a Tobii TX300 eye tracker[5] with a sampling rate of 300 Hz and a gaze accuracy (binocular) of .4° (i.e., ≈ .045 mm on the screen at a given distance of 65 cm to the eyes) under ideal conditions (Tobii Technology AB, 2013, 5). The eye tracker is connected to a Dalco[6] workstation with an Intel Core i5 760 processor (2.80 GHz), 16 GB RAM and a Nvidia GeForce GT 430 running Microsoft Windows 7 Enterprise (SP 1). Tobii Studio 3.2[7] was installed on the system. This software is used to guide the experiment with the presentation of the stimuli. Further, all data (expect mouse

[5] Tobii Technology AB, Danderyd, SWE, www.tobii.com (accessed: August 29, 2015)
[6] Dalco AG, Wilen, CH, www.dalco.ch (accessed: August 29, 2015)
[7] Tobii Technology AB, Danderyd, SE www.tobii.com/eye-tracking-research/global/products/software/tobii-studio-analysis-software (accessed: August 29, 2015)

tracking) is recorded with Tobii Studio during the experiment: key logging, screen capturing, eye movements, video and audio (with an external Logitech[8] webcam) of the participants are all stored. The software can in theory also be used for analysis of the data. The content is presented on an Estecom[9] display measuring 23 inches (diagonally) and supporting a resolution of 1920×1080 pixels with a response time of 5 ms. The display features a dithering algorithm (Hi-FRC) that enables full (16.7 M) color representation (Lee & Kim, 2004, 1482).

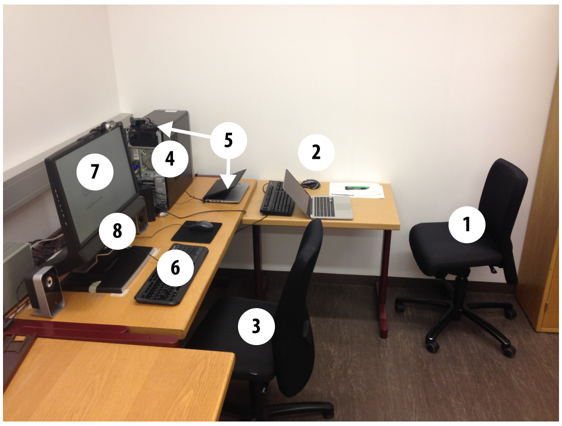


Figure 3.1 Overview of the Eyemovement recording lab (EML): (Source: Own illustration)

1. Seat of the experimenter during the study
2. Input devices to control the Dalco workstation; pen and paper to record the results manually; a MacBook Pro (Retina, 13-inch, Mid 2014) for notes and timer
3. Seat of the participant during the study
4. Dalco Workstation
5. Speedlink Lucent connected to an Asus X201E for additional voice recording
6. Input devices for the participant (keyboard has only the buttons 'A', 'D' and 'F9')
7. Estecom Display
8. Tobii TX300 Eye tracker

3.2.2 Pre-Experiment Questionnaire

Two online questionnaires utilizing SurveyMonkey[10] were used within the experiment. In the pre-questionnaire, participants had to state personal information, like gender, age, visual impairment, education and experience in several fields (none to

[8] Logitech AG, Apples, CH, www.logitech.com (accessed: August 29, 2015)
[9] Estecom Inc., Seoul, KR, www.estecom.net (accessed: August 29, 2015)
[10] SurveyMonkey, Palo Alto, US, www.surveymonkey.com (accessed: August 29, 2015)

professional on a 5-point Likert scale), the commonness in their use of representation[11] and participation in Urban Planning (UP) activities (never to daily on a 5-point Likert scale) and finally their interest in UP and knowledge of the UP-system of Switzerland (low to high on a 5-point Likert scale) in addition to their occupation.

3.2.3 Main Experiment

Following the pre-questionnaire, the system guided the participants to the main experiment. The procedure is described in detail in Section 3.4 on page 41. All participants were given instructions on the two task types and further information related to the two representations types (what is a "floor", information about the background map and the legend). A 3D representation as well as a 2D representation with a labeled cube on the standard mapnik[12]-rendered Open Street Map (OSM) background map[13] were shown to train the participants how to rotate the representations (i.e., what is meant by "left" and "right" and when to press the button).

For the trials in the main experiment (part 1 as well as part 2), 16 representations were created.

Representations The 2D representations (an example is seen in Figure 3.2a on page 33) are mainly "baseline". To ensure minimal difference between the 2D and the 3D representation (and, therefore, reducing the amount of confounding variables according to Martin, 2008, 31), the commonly used zoning plan (Aliesch, 2012, 481) was slightly altered – the parcels were not color coded but only the footprint of the buildings on the parcels. This way, it can be seen as a colored version of a figure-ground plan (a fundamental aspect of the *Gestalt*-law (Arnheim, 2000, 225), where the built-up area can be discriminated from the not built-up areas (Reicher, 2013, 49). The background map consists of the lots according to cadastral surveying. In a formal view, all *visual variables* according to Bertin (1974, 104) are used (size, value, color, orientation, shape) apart from texture. The visible part of the representation was shown in a rectangular window with an aspect ratio of ϕ:1 (golden ratio) as defined as one of the possible map formats by Spiess (1988, 26). The colors of the representation were based on hues defined for a particular zone according to the Institut für Raumentwicklung (2013a,

[11] Please note that we use the term representation for the 2D and the 3D "map" used during the study to avoid any confusion with the term "visualization" also used, but within another context (see Section 2.3.2 on page 20)

[12] www.mapnik.org (accessed: August 29, 2015)

[13] accessed via http://tile.openstreetmap.org

2013b). As additional color differences within the same hue than those given via the guidelines were needed, a color table with more saturations by Stauffer & Studach AG (2012) was employed to derive more colors. As suggested by Habekost (2013, 32), CIE $\Delta E2000$[14] (Luo, Cui, & Rigg, 2000) was used to derive the differences between the colors. A minimum color difference (ΔE) of 15.7 was found. Those two colors should still be easily distinguishable by a participant (Habekost, 2013, 22; Mokrzycki & Tatol, 2011, 398). The legend was designed by following the guideline of Slocum et al. (2009, 194–197). The other map elements are partially given due to the abstraction from a real environment. However, where possible, map design principles as described for example in Dent (1993), A. H. Robinson (1953) or Slocum et al. (2009) were considered.

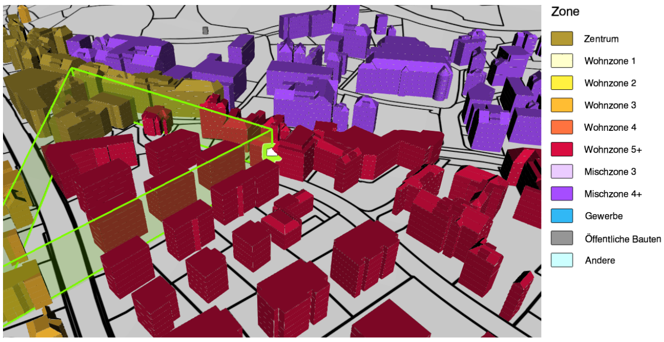
With a (visible) map container of 840 × 520 pixel (ratio 1.62:1 ≈ ϕ:1) and a camera altitude of 500 m, each representation covers an (visible) area of approximately 575 × 355 m = 20 ha at a scale of 1:1200. With the possibility of rotating the representation around the centre, the visible represented-area was extended to an area of approximately 33 ha.

The 3D representation (see Figure 3.2b on the facing page) is just a tilted version of the 2D representation. Therefore, the colors and the map design are the same as in the 2D representation. As a consequence of the tilting of the camera, a 3D map cannot be defined on a fixed map scale (Shepherd, 2008, 204). Rather, the maximal visible area in the 2D representation (33 ha) was converted to a tilting of 55° from nadir (= 35° from the horizon), resulting in a low oblique aerial view (Paine & Kiser, 2003, 28). This angle was also utilized in a study by (Seipel, 2013, 850) whereas Häberling et al. (2008, 185) suggested an angle of about 45°. To cover the same area, a viewing distance of 300 m was iteratively found to be sufficient. Figure 3.3 depicts a visual representation of the interaction between 2D and 3D representations. Additional to the design principles guidelines for the 2D representation, the 3D representation is based on the principles by Häberling et al. (2008). Contrary to many used hyper-real environments in UP they suggested to use a (maybe pseudo-realistic, but not photo-realistic) abstraction for a 3D representation. Smallman and St. John (2005, 1568) points in the same direction whit the argument for an "caricature reality". A similar approach for an abstract 3D zoning plan was for example applied by Bos (2010).

The representations show four different locations in the city of Chur, Switzerland (two around the main train station and two around Masans). According to the suggestion by Brügger (2015, 24) and Griffin and Robinson (2010, 3), the initial state of the

[14] Values calculated with http://colormine.org/delta-e-calculator/cie2000 (accessed: August 29, 2015)

a 2D representation



b 3D representation

Figure 3.2 Example of the two different representation types used (task 1 condition)

four different representations were rotated to avoid possible ordering (i.e., learning) effects within the two main locations (main train station and Masans). To circumvent confounding variables, the initial rotation for the different tasks as well as for the 2D and the 3D representation were constant.

Task Two different task types were included in in the main experiment. The first task, as shown in Figure 3.4a on page 35, is a so-called representation-to-environment (Lobben, 2004, 277) *matching* task, necessary to *visualize* the environment. Participants had to decide which of the five possible images they would see if they were standing at a specific position on the representation with the given field of view (both highlighted with a distinct green color). Photographs were chosen as a suitable trade-off between “reality” in the field and constant lab-conditions as done e.g., by Davies and Peebles (2010). The position in combination with the field of view is basically a *bipart* (Levine, 1982, 235) or *complex* (Klippel, Freska, & Winter, 2006, 120) “you-are-here”-symbol (point and arrow). If the representation is rotated in a way that the arrow, or in this

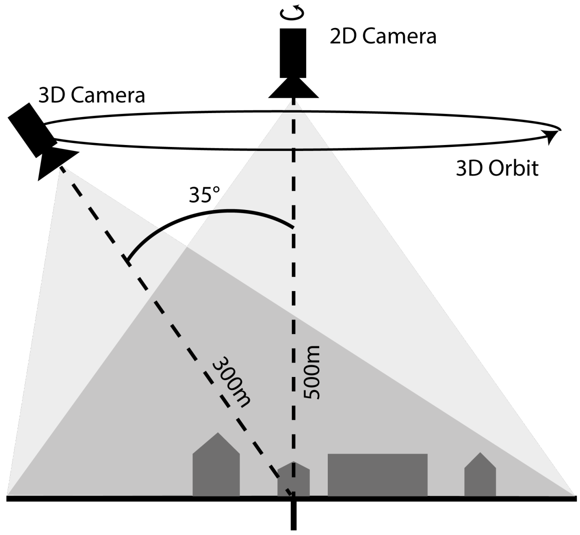
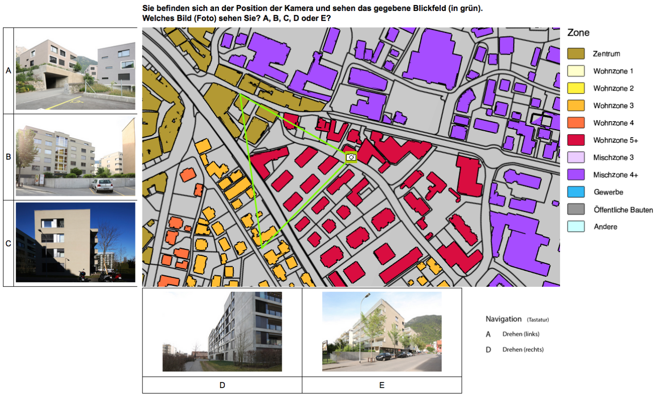


Figure 3.3 Camera settings for the 2D and the 3D representation to cover the same area on the ground
(Source: Own illustration)

case the field of view, are orientated upwards, the representation would be aligned (e.g., Klippel et al., 2006, 120; Levine, 1982, 235; Levine et al., 1984, 19). This reference was incorporated because other studies with similar approaches but without a given "you-are-here" position had (despite homogeneous participant-samples) wide ranges in the result (Liben et al., 2010, 127) or were too difficult (St. John et al., 2001, 88) or (Warren, 1994, 94). The letters A–E were used to select the right image and were always provided in the same order and position. However, the position of the right image changed according to a Latin square method. Therefore, the right solution was not always the same letter. A set of possible images was taken between March 9 and May 11, 2015 at a total of 31 different locations in the city of Zurich (18 locations), Chur (9 locations) and Landquart (4 locations). All locations have comparable, modern architecture and were built after the year 2005. Images with a reasonable quality (263 images in total) were selected and grouped, based on the number of floors, into three categories: 1–2 floors; 3–4 floors; >5 floors. For each of the eight trials, five images had to be selected. This was done according to the following scheme: The real image from this location (1), one image that is the real (right) one in another trial (1), one image from the two different categories (based on the floor levels) grouped together (1) and finally, two images from the same floor-level category (2). The images in each category were numbered and then the required count of numbers was randomly selected with RANDOM.ORG[15]. It was manually ensured that no picture from the three categories was shown twice.



a Task type 1

b Task type 2

Figure 3.4 Example of the two different task types used (shown for the 2D representation)

The second task worked vice versa as an environment-to-representation (Lobben, 2004, 277) *orientation* task, necessary for *self-localization*. Participants had to select one of five possible fields of view (from a particular position) based on a given image (see Figure 3.4b for an example of this task). The letters A–E to select the field of view were always supplied in alphabetical order but assigned based on a Latin square method.

[15] Haahr, Dublin, IRL, www.random.org (accessed: August 29, 2015)

Therefore, the letter for the right answer (i.e., the right field of view) was changed within the eight trials.

In both task settings, the participants had to click on their solution and, as a cross reference, say it aloud. After they clicked on the answer letter (A–E), a pop-up window announced that they would be able to continue with the next task.

In summary, the main part consisted of 16 trials, split into two different representations and two different tasks in four different locations as shown in Figure 3.5.

	2D Visualization	3D Visualization
Task 1	Location 1 Location 2 Location 3 Location 4	Location 1 Location 2 Location 3 Location 4
Task 2	Location 1 Location 2 Location 3 Location 4	Location 1 Location 2 Location 3 Location 4

Figure 3.5 Illustration for the 16 trials
(Source: Own illustration)

After the last trial, they were guided to a concurrent think aloud (Häder, 2015, 403) section with four representations (each task type × each representation) where participants had to speak out loud what they were doing and thinking of as they were solving the task.

3.2.4 Spatial Ability Test

The original 20 item version of the Vandenberg and Kuse MRT, available normally as a paper-and-pencil test, was included in a SurveyMonkey online questionnaire. An example of such an item is seen in Figure 3.6. Each item has a criterion figure on the left and four possible choices in the right part. Two of those choices are correct (rotated positions of the criterion as in the example from Figure 3.6 – the first and the fourth alternative). The other two alternatives are either mirrored versions of the criterion figure (as for example in Figure 3.6 – the second and the third alternatives) or rotated versions of other criterion figures (Vandenberg & Kuse, 1978, 600). Participants had to choose two of the four shown alternatives. As noted by Vandenberg and Kuse (1978, 600), most participants were able to complete the 20 items in 10 minutes. A divided version with two parts each at 3.5 minutes was also conducted by Vandenberg and Kuse (1978, 601). Contrary to this, and following Kuhn (2014, 33), a single session with a time limit of six minutes was made use of in the experiment. Also following Kuhn (2014, 33), a total score system was employed – each correct item was counted as one point. Participants were able to score between 0 (no answer right, low spatial ability) and 40 (all answers correct, high spatial ability) within the time limit.

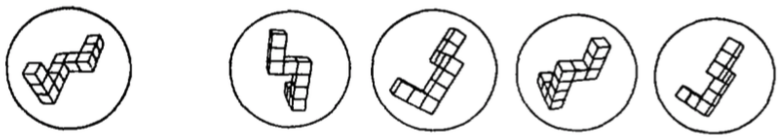


Figure 3.6 Sample item from the Vandenberg and Kuse MRT (Source: Vandenberg & Kuse, 1978, 600)

3.2.5 Post-Experiment Questionnaire

The post-questionnaire was again implemented via SurveyMonkey. Participants answered several questions related to the representations they saw. Split by task, the preference and ease for the 2D, the 3D, both or none representation(s) (in the preference case) to solve the task had to be stated. It was also possible to contribute additional comments and to explain the choice. At that point, the participants had to answer several questions (the representation was helpful to solve the tasks; the representation was understandable; the amount of rotation, counting of the floors, and the consideration of the legend as well as the enjoyment in using the representation) related to the 2D or the 3D representation on a 5-point Likert scale.

Following the written online questionnaire, participants were placed in a semi-structured interview (max. 5 minutes) (Noaks & Wincup, 2004, 80; Silverman, 2014, 226) with two questions asked verbally, being which representation type they favored and why.

3.3 Experiment Design

3.3.1 Within-Subject Design

Mainly following the book of Martin (2008) and the guide by Forsell and Cooper (2014), a 2×2 factorial within-subjects design (also known as repeated-measures design) was created and conducted in a controlled experiment (see also Figure 3.5 on page 36). Therefore, the independent variable was manipulated using the same entities (Field, 2014, 16; Martin, 2008, 148). According to Martin (2008, 152), a within-subjects design has clear advantages compared to a between-subjects design – less participants are required, and, based on the use of the same people for all test conditions and therefore the lack of individual differences between groups, a higher confidence in the statistical tests can be achieved, too. Of course, there are also disadvantages to a within-subjects design – order effects, for example, through learning as participants are familiar with a given type of task after they saw it the first time, have to be expected (Martin, 2008, 155). It could also be that participants performed differently after a while because they became bored or tired (Field, 2014, 18). This can be reduced with breaks after some trials (Forsell & Cooper, 2014, 293). Counterbalancing is a method to ensure that those effects do not lead to a systematic variation between different test conditions (Field, 2014, 18; Martin, 2008, 156). The implemented counterbalancing in Tobii Studio uses a Latin square method to build the number of possible sequences of the presentation depending on the number of elements presented (Tobii Technology AB, 2012, 25). All participants (until participant 16 as there were 16 different stimuli) had to solve the tasks in a different order. With this randomization, bias from order effects can be distributed equally (Martin, 2008, 156).

3.3.2 Independent Variables

Two independent variables were introduced and manipulated. This specifically means that different levels were created that were presented to the participant (Martin, 2008, 25). The most important and main independent variable was the representation type with two individual levels shown in Figure 3.2 on page 33: a (interactive) 2D representation with a traditional top down view and an (interactive) oblique aerial view 3D representation. As a second individual variable, two different task types were implemented as visible in Figure 3.2 on page 33: in the first task, participants had to choose one of the five shown images (the *matching* task) whereas in the second task, they had to choose one of five directions (the *orientation* task). More details regarding the representation and the task types are provided in Section 3.2.3 on page 31.

3.3.3 Dependent Variables

The behavior of a participant depending on the manipulated (independent) variables was measured, the so-called dependent variable (Martin, 2008, 26). Several individual dependent variables were measured during the study:

Effectiveness As one of the three parts of *usability*, effectiveness is defined as how well a user can achieve the goal with the given system (Abran, Khelifi, & Suryn, 2003, 331). Another often used term is accuracy. Every one of the 16 trials presented to the participants during the main experiment has one correct answer. Therefore, with the possibility of right and wrong answers, the effectiveness (or accuracy) is measured as a binary variable (Field, 2014, 8). A total of 16 correct answers could be obtained, meaning 100% correct. From the number of correct answers, the percentage of correct answers for every participant was calculated.

Efficiency Efficiency, the second element of *usability*[16] (based on Dix (2009, 1327) defined as the resources needed to achieve the goal) is represented by the time needed to complete the trials in the main part. Since a loading time of 15 seconds was implemented for every trial, this time was subtracted before further analysis took place. The answer time is therefore the timespan between the moment when the loading screen disappears and the moment a participant clicks on the letter to indicate the answer and the pop-up window appears. As a consequence of the technological inconsistency of the Tobii Studio software, it was not possible to derive this time automatically and it had to be done manually from the screen recording. For the two sessions consisting of eight trials each, a time limit of 24 minutes was enforced, and this includes the loading time for the trials. The loading time was set to be 15 seconds for every trial and not to the effectively necessary loading time that varied between the different trials. This decision was made to ensure that the setting for all trials is as consistent as possible. It also allowed the participants to prepare themselves mentally for the next trial and

[16] The third element, satisfaction (how do the users feel when using the system (Abran et al., 2003, 331)) is not measured as a dependent variable but partially self stated by the participants in the post-questionnaire (Wixon & Wilson, 1997, 684)

have a short rest period between trials (Forsell & Cooper, 2014, 293). The effective time limit to solve the tasks of 20 minutes (a maximum of 75 seconds per trial) was found to be an easily manageable time limit without any pressure in all three pilot studies.

Confidence After every one of the 16 trials, the participants stated their confidence about the decision on a five-point Likert scale (1 = low to 5 = high) (Likert, 1932). According to Lewin (1986, 163), the value 3 can be seen as “neutral” or, following Vogt and Johnson (2011, 208), “undecided”.

Interaction The web viewer (see Section 3.5 on page 42) allowed participant to rotate the view to the left and to the right. For a full rotation the participants had to press the rotation button eight times (obviously always in the same direction). Each individual rotation step rotated the view $\frac{1}{8}$ of a full rotation on the orbit in the 3D representation with a fixed center (Tan, Robertson, & Czerwinski, 2001, 421), respectively, of the full rotation, i.e., 45°, in the 2D representation. The rotation speed was set to 2.5 seconds for every step, a full rotation therefore being possible in 20 seconds. Every rotation was logged and the total number of interactions per trial counted. There was also a distinction made between left and right rotations measured.

3.3.4 Number of Participants

Martin (2008, 230) as well as Forsell and Cooper (2014, 294) did not provide a concrete number of how many participants were necessary for an experiment. Browsing the literature and other studies, a minimum of 20 participants (Field, 2014, 172) could be sufficient. According to Field (2014, 54), large samples are defined as $N > 30$. According to others, the number of participants ranged between 30 and 42 (Brügger, 2015, 21; Fischer, 2013, 21; Heim, 2014, 37; Kleiner, 2013, 45 and Kuhn, 2014, 23). Based on the applied counterbalancing because of the Latin square method with Tobii Studio, at least 16 participants were needed (Tobii Technology AB, 2012, 25). A short *a priori* power analysis with *G*Power 3.1* (Faul, Erdfelder, Lang, & Buchner, 2007, 176) revealed that a N of roughly 20 should be sufficient (based on the experimental design, a significance level of $\alpha = .05$, statistical power of $1\text{-}\beta = .8$ (Cohen, 1977, 56) and a to-be-detected medium effect size of $f = .25$ (Cohen, 1977, 286)).

3.4 Procedure

Potential participants were given a Doodle[17] link where they were able to choose from a list of time slots (1 hour with 30 minutes spacing between two slots). When one agreed to take part in the study, the participant received an email with the confirmation of the time as well as additional information, such as the location and contact information for further questions. Participants were asked to wear contact lenses and not glasses if possible as it was known from previous experience that the eye tracker had issues in capturing eye movement with certain types of glasses. Additionally, the participants received a consent form (see Appendix 2) and were asked to bring this signed to the study.

For the study itself, a written protocol (given in Appendix 3) that: a) guided the experimenter through the study; b) ensured that nothing important got omitted; and c) all participants received the same amount of information, was developed (Forsell & Cooper, 2014, 300f). A complete system reboot was conducted after every third participant, so numbers 1–3 (according to the protocol given in the Appendix) were necessary only after those shutdowns. Numbers 4–13 were conducted before a participant arrived. Number 14–23 followed during the experiment when the participant was present.

After the participant arrived, a copy of the consent form was signed as well and given to the participant. The setup was shortly explained and when they did not have any questions they were asked to take a seat before the screen of the eye tracker system (see also Figure 3.1 on page 30). The eye tracking device had to be calibrated for every candidate. It was ensured that they were seated as comfortable as could be but also in an optimal position for the system itself to capture the eye movement of the participant. After calibration, the process was completely pre-defined in Tobii Studio. The participants were guided by written instructions on the screen and external webpages containing questionnaires and trials were loaded. No interaction between participant and experimenter (apart from the interview at the end) or any device change was necessary during the study. An overview of the procedure is shown in Figure 3.7 with the individual steps described in Section 3.3 on page 38. After a mouse calibration, the participants had to fill in a pre-questionnaire on SurveyMonkey with questions related to their personal background. Afterwards, they saw an introduction to the topic and the web viewer. They also had an opportunity to try the interaction tool and were

[17] Doodle AG, Zürich, CH, www.doodle.com (accessed: August 29, 2015)

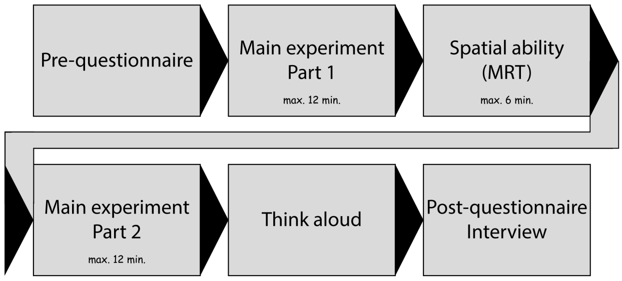


Figure 3.7 Overview of the procedure of the study (Source: Own Illustration)

instructed on how to use the rotation function. They then had 12 minutes (10 minutes + 2 minutes loading time) to solve the first eight of the total of 16 counterbalanced trials. Half-time was verbally announced to the participants. After the first main part, the system led the participants to the MRT with a time limit of six minutes. When this time limit was reached (or the 20 trials were finished), the second main part started, again with eight trials in 12 minutes. After finishing, an additional concurrent think aloud (Häder, 2015, 403) section with four trials started where they expressed what they were doing and thinking while solving the task. Afterwards, the system guided the participants to a post-questionnaire with additional questions related to their preference for the given representations and finally to a short interview. For detailed information about the procedure, refer to Appendix 4 where all details, like written information and individual trials, are presented.

3.5 Technical Implementation of the Web Viewer

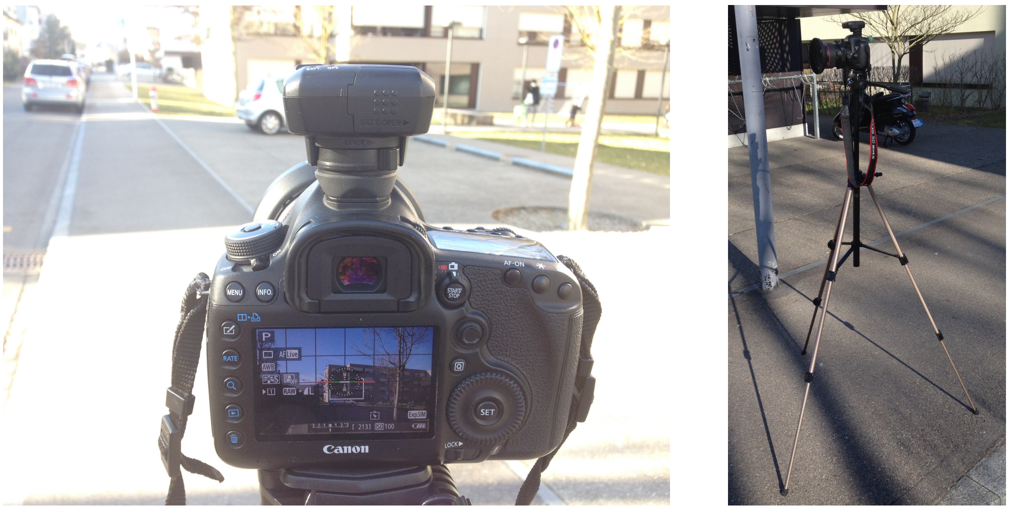
The following subchapter is intended to provide a short overview of the technical process, the data used and the tools as well as the devices applied to create the representations.

3.5.1 Images

All images were taken with a Canon 5D Mark III[18], a full-frame 22.3 MP DSLR camera (Canon Inc., 2012, 378). The lens employed, a Canon TS-E 24 mm f/3.5L II[18], provides a shift function, the optical axis of the lens possibly being moved parallel off the center

[18] Canon Inc., Tokyo, JP, www.canon.com (accessed: August 29, 2015)

of the focal plane. With this method, the converging verticals of an object (in this case, a building) when taking a photograph (when the focal plane is not parallel to the image sensor) can be corrected (Hedgecoe, 2008, 54). A 24 mm lens was selected to be the viewing angle of the lens is at approximately 75° (horizontal). This value is between the "normal" lens (similar to the view of the eye, objects are not reduced or enlarged within the image, the focal length equals the diagonal measure of the image area (around 45 mm for a 24×36 mm sensor) (Miller & Marin, 2015, 31f)), with a narrower viewing angle of approximately 40° (horizontal); and the binocular field by the humans' eyes with a wider angle of 114° (horizontal) according to Howard and Rogers (1995, 32). The value of 114° equals a 12 mm lens with stronger distortion of the image. To collect the position of the image as well as the viewing direction, a Canon GPS Receiver GP-E2[18] was attached to the camera, as shown in Figure 3.8a. The settings were, as long as light conditions allowed for it, kept as constant as possible during the image-taking sessions. The camera was mounted on a tripod as shown in Figure 3.8b to achieve the same height (observer's height of eye $\approx$ 175 cm).



a Camera setup

b Camera setup on tripod

Figure 3.8 The camera setup during image taking sessions (Source: Own illustration)

3.5.2 Data Pre-Processing for the Base Map, the Zoning Plan and 3D Buildings

The base map used in the 2D as well as in the 3D representations showed the lots in the city of Chur. The cadastral survey data[19] for the city of Chur (as per March 5, 2015) and the neighboring town of Haldenstein (as per May, 5 2015) according to the data model DM.01-AV-GR (Amt für Landwirtschaft und Geoinformation, 2005) were obtained as ESRI Shapefiles (ESRI Inc., 1998) from GeoGR[20]. The data was processed in QGIS 2.8 "Vienna"[21]. The data was clipped to a square that covers around 600 ha to ensure that in the 3D representation, the far distance also shows data and no empty areas. A high resolution TIFF (Adobe Developers Association, 1992) image was exported and HiDPI tiles according to the OSGeo TMS 1.0.0 specifications (Masó, Poimakis, & Julià, 2010) were created with Klokan technologies MapTiler Plus 0.6[22].

The raw data for the zoning plan was also derived from GeoGR. The colors were assigned in QGIS 2.8 with the coding list by the Amt für Raumentwicklung Graubünden (2014). The cadastral survey was utilized again to derive the buildings (small buildings were omitted). After several data-processing steps in QGIS 2.8, the zoning plan was clipped with the buildings to derive color-coded buildings according to the zoning plan. This Shapefile was then exported as a GeoJSON (Butler et al., 2008) file. Styles were manually assigned within the GeoJSON file. This file was used within the 2D representation.

The 3D buildings are also based on the footprint derived from the cadastral survey. The zoning plan was used for color coding and height information was derived from swissBUILDINGS^{3D} 1.0 (Bundesamt für Landestopografie swisstopo, 2010). As the newest entries to swissBUILDINGS^{3D} are 10 years old (swissBUILDINGS^{3D} 2.0 was unfortunately not yet available), manual corrections were necessary (based on aerial images and visual inspection on site). With those raw data preprocessed mainly in QGIS 2.8, the models were built in ESRI CityEngine 2014.1.1703[23] and equipped with the Smart Zoning Plus library 1.1 by SmarterBetterCities[24]. The individually built models were exported as individual COLLADA[25] (.dae) files (Barnes & Finch, 2008a, 2008b) and

19 Source: Amtliche Vermessung (AV), Kanton Graubünden, March 5 and May 5, 2015
20 GeoGR AG, Chur, CH, www.geogr.ch (accessed: August 29, 2015)
21 www.qgis.org (accessed: August 29, 2015)
22 Klokan Technologies GmbH, Unterägeri, CH, www.maptiler.com (accessed: August 29, 2015)
23 ESRI Inc., Redlands, US, www.esri.com (accessed: August 29, 2015)
24 SmarterBetterCities AG, Zürich, CH, www.smarterbettercities.ch (accessed: August 29, 2015)
25 www.khronos.org/collada (accessed: August 29, 2015)

converted with COLLADA2GLTF[26] to glTF (.gltf)[27] (Cozzi, Arnaud, Parisi, & Robinet, 2015). The workflow results basically in one individual glTF file per 3D model containing already four necessary files (base64 compressed): the glTF JSON filed itself, vertex and fragment shader as well as the binary buffer. Those glTF files could then be used in Cesium for the 3D representation.

3.5.3 Building the Main Map

Both representation types were created with the Cesium API. Cesium[28] is a JavaScript library for creating 3D globes as well as 2D representations that can be viewed in a web browser without a plugin. The program was started by Analytical Graphics Inc. (AGI)[29] as a cross-platform virtual globe for dynamic-data representations (then named Geoscope) in 2011 (Smith, 2014). In April 2012, Cesium released (beta) their software as open-source (under the Apache 2.0 license[30]), finally reaching Cesium 1.0 in August 2014 (Cozzi, 2014) and since then a new version has been released every month. Cesium uses WebGL 1.0 (Jackson & Gilbert, 2015a) and partly WebGL 2.0 (Jackson & Gilbert, 2015b) for hardware-accelerated graphics. It supports 3D globes, 2D and 2.5D maps and, among other features, terrain data, many industry standard formats for geographical data, 3D models, several geometries and different time and mathematical methods. The documentation[31] is available online. With the deprecation of the Google Earth API[32] by December 12, 2015 (Hoetmer, 2014), Cesium received an increase in interest and can rely on an active and supportive community.

For the maps, Cesium 1.7 (as of March 2, 2015) was used initially and, based on new functionalities, was later updated to Cesium 1.9 (May 1, 2015).

2D representation An example of the implemented code for the 2D representation (in the task 1 condition) can be found in Appendix 5. Comments are provided if a part is not well explained in the Cesium documentation or additional information might be helpful. Technically, the 2D representation is based on the Cesium 3D representation, but as a result of the top down view, the small area covered, and the removed terrain,

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26 https://github.com/KhronosGroup/glTF/tree/master/converter/COLLADA2GLTF (accessed: August 29, 2015)
27 www.gltf.gl (accessed: August 29, 2015)
28 www.cesiumjs.org (accessed: August 29, 2015)
29 Analytical Graphics Inc., Exton, US, www.agi.com (accessed: August 29, 2015)
30 www.apache.org/licenses/LICENSE-2.0 (accessed: August 29, 2015)
31 cesiumjs.org/Cesium/Build/Documentation/index.html (accessed: August 29, 2015)
32 Google Inc., Mountain View, US, www.cesiumjs.org (accessed: August 29, 2015)

lighting and extrusion effects, this can be neglected as at this scale, no distortion from the projection used was to be expected. The main part of the Cesium code is found between code lines 249 and 360.

First, the viewer with all necessary options was declared and all buttons were removed to yield an empty viewer. The camera position was set for a top down view with a range of 500 m and fixed on the center of the representation. All atmospheric effects were removed to achieve the same lightning conditions for all participants. The standard interaction was removed and replaced by a manual rotation to the left (key 'A') and to the right (key 'D') at a given rotation speed (2.5 seconds for 45°, based on the Cesium clock and a fixed frame rate of 20, therefore a continuous motion is perceived by the participants (Hibbard, Levkowitz, Haswell, Rheingans, & Schroeder, 1995, 25)). The background map was called from the built Tile Map Service (TMS) (Masó et al., 2010) and the building footprint map as a GeoJSON layer was added. The field of view (75°, coordinates calculated in QGIS 2.8) and the camera image at the viewpoint was also drawn.

3D representation The 3D representation worked fairly similar to the 2D representation. The main code can be found between lines 225 and line 560 in Appendix 6 with the additional JavaScript (see below) in Appendix 7. For terrain information, the AGI STK World Terrain data[33] was used.

The terrain information for Switzerland originated in the Digital Surface Model (DSM) Digital Elevation Model over Europe (EU-DEM) by the EU's Copernicus[34] program based on Shuttle Radar Topography Mission (SRTM) and the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model (GDEM) data from the year 2000 at a resolution of approximately 30 m.

A list with the positions (latitude and longitude transformed from degrees to radians) of the corners from the different fields of view was next declared. Those coordinates were then sampled on the terrain server to return the altitude at a particular position.

From line 270 to 560, the code is similar to the 2D example described earlier. Only marginal details because of the 3D (like the tilt of the camera) or from bugs in the Cesium JavaScript library had to be considered.

[33] Data attributed by Analytical Graphics Inc., CGIAR-CSI, Produced using Copernicus data and information funded by the European Union – EU-DEM layers, Commonwealth of Australia (Geoscience Australia) 2012

[34] FDC Sarl, Vincennes, FRA, www.copernicus.eu (accessed: August 29, 2015)

Line 560 calls the Javascript file where an array with the positions of every building (model) is stored. The positions were transformed and the height at every position is sampled from the terrain server and stored back in the array. This process needs (for more than 550 individual models) some time. Then, the position was called again (with the altitude), transformed to Cartesian coordinates with a WGS84 ellipsoid as a fixed frame, and the model finally loaded and drawn at a given position at the correct altitude and the right orientation (and scale). The models in the glTF-datatype are rendered according to the COLLADA common profile (see Khronos Group (2010) for an overview).

Legend The problem of different colors for the same element (i.e., should have the same color) was familiar in map reproduction (when different devices are used) before computers were introduced (Palm & van der Steen, 2001, 189f). As noted by Slocum et al. (2009, 240), this issue is still present with computers, for example, between two different software applications. To reduce this difference to a minimum, the legend was displayed in a second Cesium viewer with exactly the same setting as the main viewer. A GeoJSON file shows the rectangles of the legend, the annotations are drawn in Cesium and, and as a geographic location is needed, the elements were located in the Bordeaux wine area (see, for example, code lines 30 to 196 in Appendix 6).

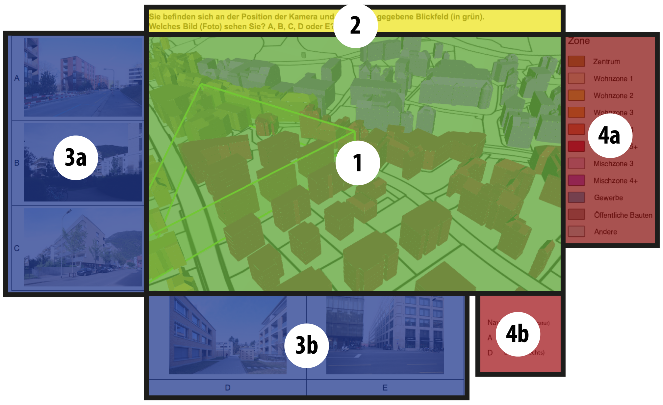


Figure 3.9 Example of the web viewer

1. Map area
2. Question
3. Image selection for task 1 (shown in area 3a and 3b). For task 2 only the area 3b is shown with one image
4. Legend for the map (4a) and for the interaction (4b)

3.5.4 Web Viewer

The different elements of the web viewer are portrayed in Figure 3.9 on the preceding page were already described. The web viewer is based on Hypertext Markup Language (HTML) in combination with a Cascading Style Sheet (CSS) file (refer to Appendix 8). Apart from the structure of the web viewer, a loading screen was included that disappears automatically after 15 seconds. The content was loaded in the background. Another function displays an alert when a participant pressed on the solution to give clear feedback that the solution was submitted (as suggested by Silver, 2005, 36).

3.6 Statistics

The raw data from the various measuring tools (SurveyMonkey, Tobii Studio and manual coding during and after the experiment) was preprocessed in Microsoft Excel for Mac (Version 15.13.1)[35] and Stanford Vis Group's DataWrangler^{alpha} [36] (Kandel, Paepcke, Hellerstein, & Heer, 2011). Further statistical analysis was conducted in IBM Statistical Package for the Social Sciences (SPSS) Version 22.0.0.0 [37]. Statistics were first computed with the aggregated independent variables (representation or task) and in a second step treated as two independent variables in the interaction. Details on the applied statistical methods can be found in Section 4 and particularly in Section 4.2 on page 54. If nothing specific was stated, the suggestions and terminology from Field (2014) are used. All statistical tests are conducted with a .05 probability (α) and r is reported as the effect size (i.e., the importance of an effect (Field, 2014, 79). According to Field (2014, 82), r can be favored over other possible effect sizes. Cohen (1977, 79f) defined an r of .10 as a small effect, .30 as a medium effect and .50 as a large effect size. For the effectiveness data, percentage values were calculated within a range from 0 to 1 but are presented in Tables and Graphs from 0 to 100 for the sake of convenience. All Graphs were created in Tableau Desktop 9.0.3[38].

[35] Microsoft Corporation, Redmond, US, https://products.office.com/en/mac/microsoft-office-for-mac (accessed: August 29, 2015)
[36] Stanford Visualization Group, Stanford, US, http://vis.stanford.edu/wrangler/app (accessed: August 29, 2015)
[37] IBM Coorporation, Armonk, US, www-01.ibm.com/software/analytics/spss/products/statistics/ (accessed: August 29, 2015)
[38] Tableau Software, Seattle, US, www.tableau.com (accessed: August 29, 2015)

4 | Results

4.1 Participants

As stated previously in Section 3.1 on page 29, three participants had to be removed from the study. Of the remaining 40 participants, 17 were women ($M_{age} = 28.24$, $IQR_{age} = 4$), and 23 were men ($M_{age} = 27.39$, $IQR_{age} = 3$). Their ages ranged from 20 to 57 ($M = 27.75$, $IQR = 3$). As shown in Figure 4.1, most participants (90%) were between 20 and 32 years old. Eight participants stated that they considered to be as Urban Planning (UP) professionals.

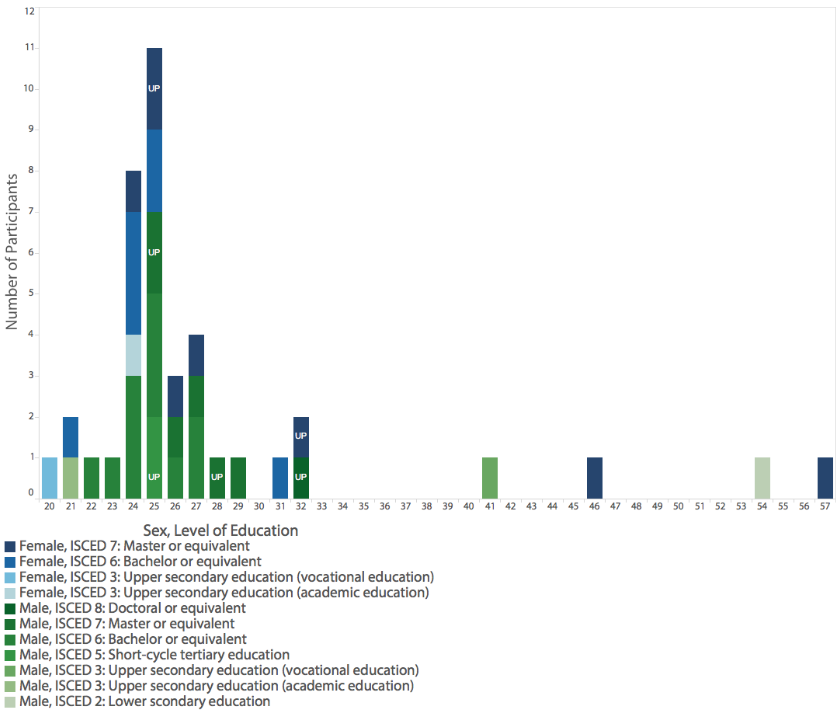
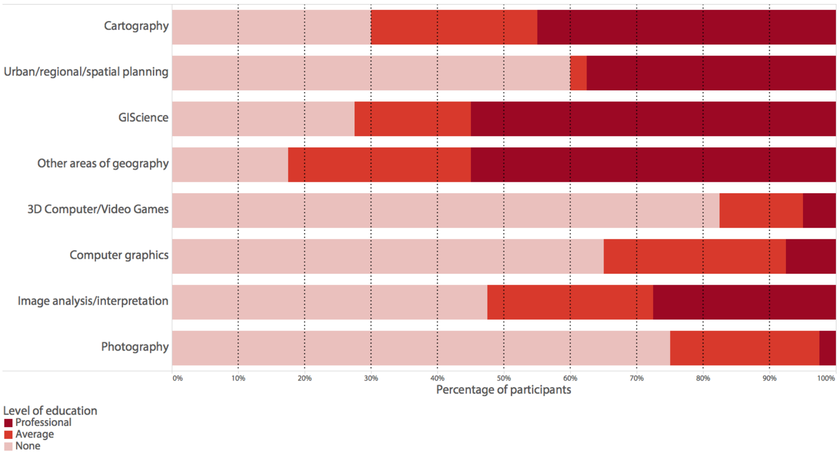


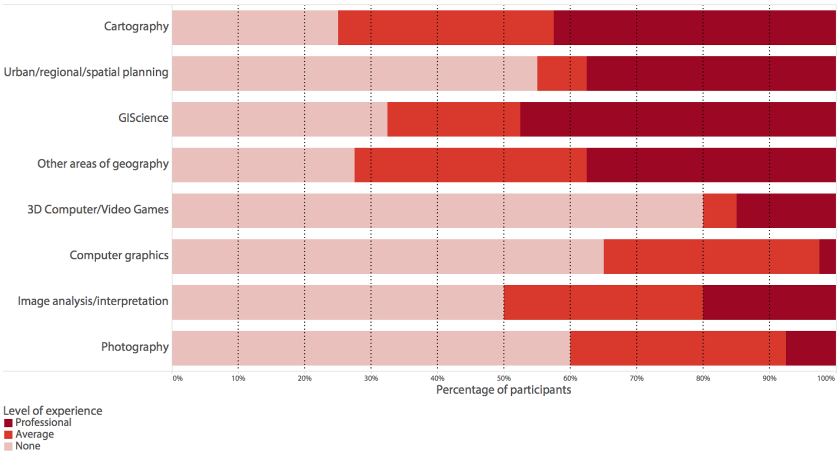
Figure 4.1 Background of all participants (age, gender, UP, education according to UNESCO Institute for Statistics, 2012)

Education and Experience

The participants stated their theoretical knowledge, as well as their experience in several fields (Figure 4.2 on page 51). As shown in Figure 4.2a, most of the participants that participated in the experiment had a good educational background in geography, GIScience and cartography. On the other hand, only a few participants had been trained in photography, image analysis, 3D games, computer graphics, and UP. Figure 4.2b on the next page reveals a similar pattern in terms of knowledge and experience. According to a Spearman's correlation analysis (see Appendix 9), a significant positive relationship with a large effect (Field, 2014, 267) between the stated level of education and the stated level of experience is present (r_s always higher than .529, $p < .01$). This means that participants who stated that they had a good educational background in one particular field also stated that they had considerable experience in this field. The table shows further large effects ($r_s > .5$) for the relationship between education and experience in several other fields. Positive relationships can also be found among several fields of education (Appendix 10) and fields of experience (Appendix 11). With regard to the topic of education, cartography has a strong relationship with all fields expect photography; GIScience has a strong relationship with all fields except UP and photography. Computer graphics shows a relationship with 3D games and image analysis. For the topic of experience, only relationships between cartography and UP as well between cartography and GIScience and between computer graphics and 3D games as well as between computer graphics and image analysis are observable.



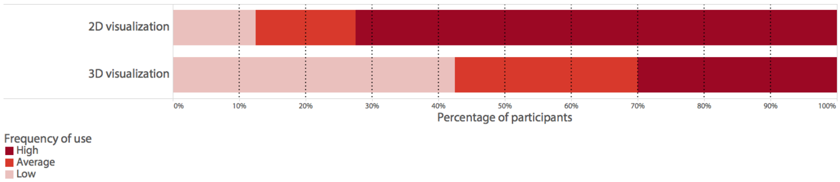
a Level of education



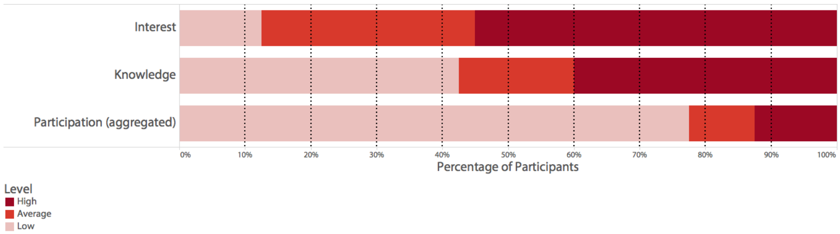
b Level of experience

Figure 4.2 Level of experience and education stated by the participants. Percentage of participants with none, average and professional education (a) or experience (b).
Data aggregated: Never (1–2), Average (3), Professional (4–5)

Familiarity



a Familiarity with representations



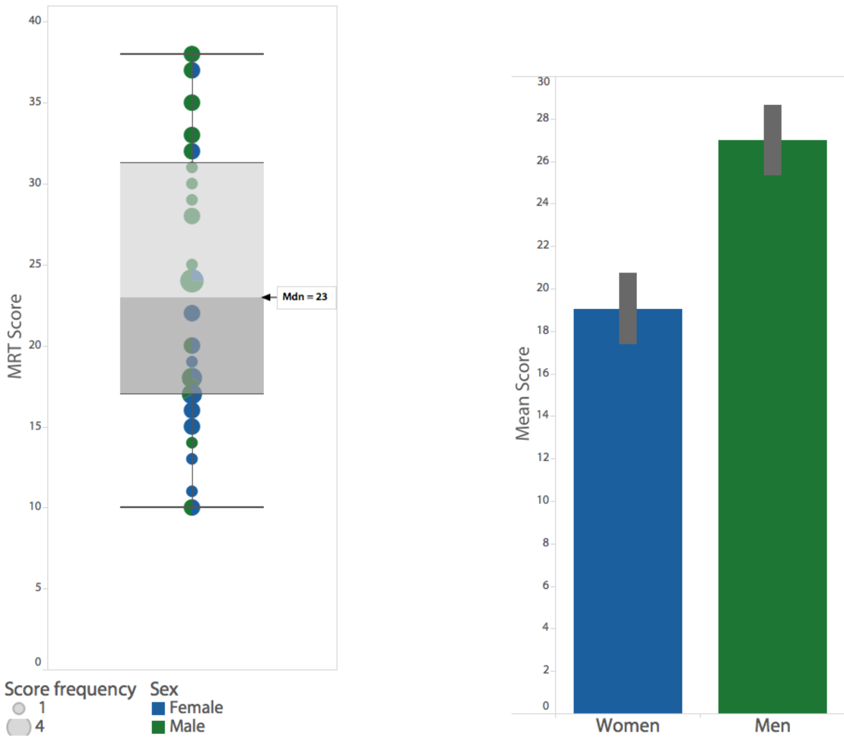
b Familiarity with UP

Figure 4.3 Familiarity with representations and UP as stated by the participants. Percentage of participants with a low, average and high frequency of the use of representations (a) and with a low, average and high interest, knowledge and participation in UP (b). Data aggregated: Low (1–2), Average (3), High (4–5)

As shown in Figure 4.3a, most participants had previously used 2D representations frequently, and more than half of all participants stated that they sometimes use 3D representations. Figure 4.3b shows that most participants were generally interested in Urban Planning (UP). A smaller percentage of the participants stated that they were familiar with Switzerland's UP system, and only 22% of the participants were involved in UP-related participation and decision-making processes. A Spearman's correlation analysis (see Appendix 12) revealed a positive relationship between the frequency of the use of 2D and 3D representations ($r_s = .487$, $p < .01$). A positive relationship with a large effect is observable in all three fields related to UP and between 2D representations and a general interest in UP.

Spatial Ability

Based on the scores (*range* = 10–38, *Mdn* = 23, *IQR* = 14.75) achieved in the Vandenberg and Kuse Mental Rotation Test (MRT) (see Figure 4.4a on the facing page), a median split (identical to e.g., Brügger, 2015, 35; Francelet, 2014, 30 or Wilkening & Fabrikant, 2011, 4) was applied, resulting in a high spatial group ($n = 20$, $M = 30.85$, $SE = 1.108$) and a low spatial group ($n = 20$, $M = 16.40$, $SE = 0.789$). In a second approach, *extreme groups*



a MRT scores of all participants
Error bar: 1 *SE*

b MRT scores of women and men
Error bar: 1 *SE*

Figure 4.4 MRT scores

(e.g., Feldt, 1961, 307; DeCoster, Iselin, & Gallucci, 2009, 353; Preacher, MacCallum, Rucker, & Nicewander, 2005, 178) were created using an approach which was applied for example by Sholl and Liben (1995, 1626) as well as Wilkening and Fabrikant (2011, 4). With a tercile split based on the MRT score, three spatial ability groups were created: high ($n = 15$, $M = 15.00$, $SE = 0.730$), medium ($n = 12$, $M = 23.33$, $SE = 0.838$) and low ($n = 13$, $M = 33.85$, $SE = 0.846$).

With reference to Figure 4.4a and Figure 4.4b, a clear difference between the MRT scores of women and men is visible. A z-score conversion (Field, 2014, 31f, 179f) shows no extreme outliers (z-score > 3.29) in the groups of females and males. Based on the small sample sizes ($n_{women} = 17$, $n_{men} = 23$), a Shapiro-Wilk test (Shapiro & Wilk, 1965, 608) was used to test the samples for normal distribution ($W_{women} = .886$, $p = .040$; $W_{men} = .954$, $p = .351$). Base on the non-normal distribution of the women's sample, and since the sample sizes are less than 25 per group, a Kolmogorov-Smirnov Z-test was applied to test for differences between men and women in the MRT scores (Field, 2014, 223). According to the Kolmogorov-Smirnov Z test, a significant difference in the MRT scores of women and men ($KS\text{-}Z$ = 1.759, p = .004, r = .278) can be reported. As suggested by Field (2014, 214), this finding was confirmed via an independent-samples t-test (BCa, equal variances assumed[39]): ($t(38)$ = 3.282, p = .003, r = .452).

Table 1 shows the unequal distribution of women and men in the high and low MRT groups, respectively, and in the high, medium and low MRT groups; for a visual explanation, see Figure 4.4b. No differences in the spatial ability scores were found if

Table 1 Distribution of women and men in the MRT groups

	Median split		Tercile split	
Group	n_{women}	n_{men}	n_{women}	n_{men}
high	3	17	2	11
medium	–	–	5	7
low	14	6	10	5

someone stated to be an UP-expert or not. As the data is normal distributed within the groups (according to the Shapiro-Wilk test: W_{UP} = .897, p = .059; $W_{non\text{-}UP}$ = .936, p = .059), an independent-samples t-test (equal variances assumed[40]) was used that showed no significant differences between the groups: $t(38)$ = -.370, p = .714, r = .060.

4.2 Effectiveness

Overall Result

Table 2 Descriptives of the overall effectiveness (percentage) of all participants

	N	*M*	*SE*	*Mdn*	*IQR*	*Min*	*Max*
Score	40	91.719	.025	100.000	.125	18.750	100.000
Score w	40	92.234	2.160	100.000	12.500	39.370	100.000

The effectiveness, or accuracy, is measured as the number of correctly solved tasks. Twenty-three of the 40 participants solved all 16 tasks correctly; thus, the mean of all

39 Hartley's F_{max} = 1.308, critical value = 2.46; Levene's: F = 1.267, p = .267
40 Hartley's F_{max} = 1.519, critical value = 2.07; Levene's: F = .620, p = .436 and (because of the unequal group sizes): Brown-Forsythe's: F = .137, p = .714

participants is at 92% for tasks that were solved correctly, or 14.68 correctly solved tasks. Please see the *score* in Table 2 on the facing page for details.

Outliers

The value of the extreme outliers (see Table 3) was Winsorized, as described by Field (2014, 198): The value was replaced with the last non-extreme value. A z-score of 3.29 was used and, from this, with the initial M and s, the new score was calculated according to Equation 1. The corrected data are given in Table 2 on the preceding page (*score w*).

$$Score\ w = (z * s) + M \qquad \textbf{Equation 1}$$

Table 3 Outliers effectiveness in relation to the individual representation- and task types

	2D T1	2D T2	3D T1	3D T2	2D	3D	T1	T2	All
Extreme	1	1	1	1	1	1	1	1	1
Probable	1	0	0	0	0	0	1	0	0
Potential	0	0	2	0	1	0	1	0	1
Normal	38	39	37	39	38	39	37	39	38

Extreme: z-score > 3.29; Probable: z-score 2.58–3.29; Potential: z-score 1.96–2.57; Normal: z-score < 1.96 according to Field (2014, 179)
$N = 40$

Main Differences

$$z_{skewness} = \frac{skewness - 0}{SE_{skewness}} \qquad \textbf{Equation 2}$$

$$z_{kurtosis} = \frac{kurtosis - 0}{SE_{kurtosis}} \qquad \textbf{Equation 3}$$

The mean of correct answers from the participants for the two representation types (2D and 3D) and the two task types (task 1: *matching* and task 2: *orientation*) are shown in Figure 4.5 on the following page and Appendix 13. As demonstrated, there is nearly no difference between the score reached with the two representation types and only a small difference with the two task types.

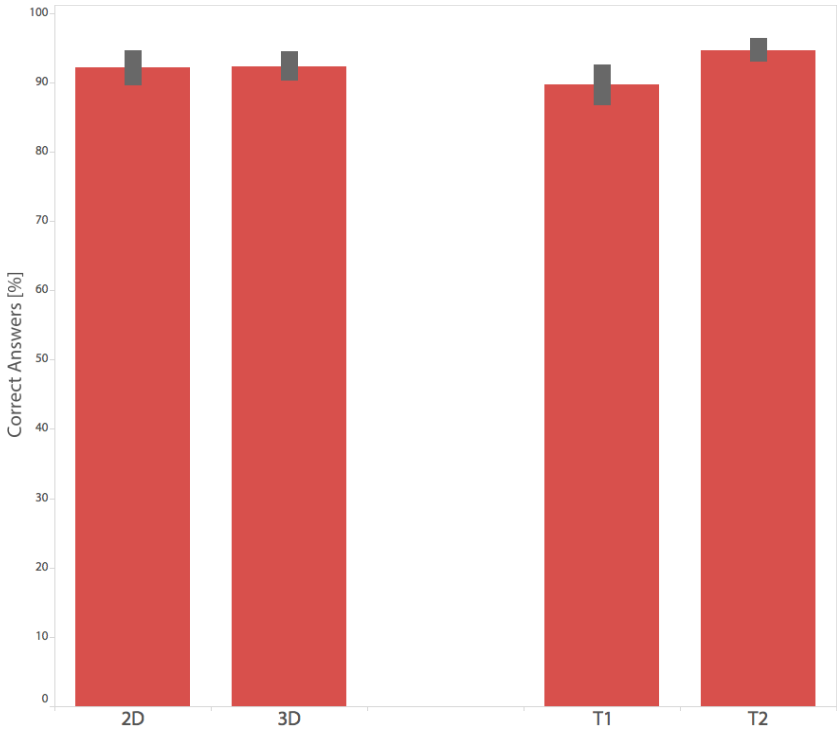


Figure 4.5 Score on representation (left) and task (right) level
Error bar: 1 *SE*

Testing for normal distribution The $z_{skewness}$ and $z_{kurtosis}$ values calculated with Equation 2 and Equation 3 on the previous page (see Appendix 14), for the Winsorized data (see Section 4.2 on the preceding page) are all < -3.29 ($z_{skeweness}$) respectively and > 3.29 ($z_{kurtosis}$) and hence strongly negatively skewed and leptokurtic with a significance of $p = < .001$ (see Field, 2014, 184). Therefore, significance problems with the data related to skew, kurtosis or both have to be expected. A visual interpretation of the graphs as well as a Kolmogorov-Smirnov test ($D(40)$ = [41], $p = .000$) shows that the distribution of the scores differed significantly from a normal distribution.

A normal distribution (at least of the data to be analyzed and not, first, the residuals of the population when estimating model parameters or, second, the individual levels of the predictor variable (Field, 2014, 168f)) is not necessary in every situation (or for every test) (see Glass, Peckham, and Sanders (1972) and Lumley, Diehr, Emerson, and Chen (2002, 151) for a broader discussion). If N is large enough, according to the Central Limit Theorem (CLT) (see Field, 2014, 54 and Wilcox, 2010, 37), a plot of the

[41] The test statistics is different for the individual groups, the details as well as the results from the Shapiro-Wilk test used for confirmation of the Kolmogorov-Smirnov test are available in Appendix 15

means will be nearly normal with a value of M equal to the $M_{Population}$ and a value of s of:

$$\sigma_{\mathrm{M}} = \frac{s}{\sqrt{N}} \qquad \textbf{Equation 4}$$

A sample size, N, of 30 (Field, 2014, 54), 25 (Wilcox, 2010, 29) or even 20 (Field, 2014, 172) can be assumed as sizeable enough (see also Section 3.3.4 on page 40). However, as Wilcox (2010) has shown, this assumption has limitations with a) heavy-tailed (i.e. leptokurtic) distributions (Wilcox, 2010, 40) as well as b) skewed distributions (Wilcox, 2010, 73). In these cases, Wilcox (2010, 73) notes that an N of 200 observations or more is necessary to properly adapt for the purposes of the CLT. The stated case, a), is not a relevant issue for the effectiveness data (see Table 3 on page 55); b) is, however, with the strongly negative skewed distribution, important. For cases such as this, Field (2014, 202) suggests transforming data. However, there are many reservations when considering the use of transformations (see Games and Lucas (1966, 326), Grayson (2004, 110–113) or Wilcox (2012, 5f) for more) and the interpretation can be difficult (Munro, 2005, 79). A number of authors (e.g., in Osborne, 2002, n.d.) have noted that the level of measurement (as defined by Stevens, 1951, 25) changes and parametric tests can not be used afterwards. Contrary to this, others (e.g., in Gaito, 1980, 566, Norman, 2010, 629 or Zumbo & Zimmerman, 1993, 390) state that, in general, this conclusion is too strict and parametric tests can also be employed on ordinal data. In conclusion and according to suggestions by Field (2014, 202), Sheskin (2004, 406), Tabachnick and Fidell (2013, 86) and also partially Games and Lucas (1966, 324), a transformation can be applicable in the given case for the effectiveness data with strong negative skew and positive kurtosis. Possible λ (Box-Cox parameter) values, according to Box and Cox (1964, 241), and calculated with a tool by Wessa (2015) range from 2.16 to 7.21 (therefore, a stretch would be applied (Osborne, 2010, 4)). A tested "optimal" λ value of 4.07 was still not sufficient enough for the effectiveness data. Several standard transformations were investigated as well and, following Tabachnick and Fidell (2013, 87), a reverse score reciprocal transformation ($\widehat{=}\lambda$: -1.00 (Osborne, 2010, 4)) with an added constant of 1 (and a constant to ensure that the lowest value is 1), similar to the procedure described in Field (2014, 208), was utilized. The descriptives of the used reciprocal transformation are available in Appendix 16.

On the transformed data, a Kolmogorov-Smirnov test ($D(40) =$ [42], $p = .000$) indicates that the distribution of the scores after the transformation still differs significantly from

[42] See footnote [41] for the description and Appendix 17 for the data

a normal distribution. In contrast, the Q-Q plots reveal that the data now better fits a normal distribution line and the values for $z_{skewness}$ and $z_{kurtosis}$ (available in Appendix 18) are also nearer to 0 and therefore less negatively skewed and less leptokurtic.

Based on these results, a Wilcoxon signed-rank test was used (on the reciprocal transformed data) and revealed no significant difference between the scores for the two representation types (2D and 3D) with both tasks (task 1 and task 2) grouped together (T = 40, p = .697, r = -.044). A significant difference can be discerned between the two task types when the representation types are grouped together (T = 85.5, p = .037, r = .234). As Field (2014, 214) believes in employing robust methods wherever possible, a paired-samples t-test bootstrapped with bias correction and an accelerated confidence interval (BCa) (Efron & Tibshirani, 1993, 178) was used for verification. No significant differences were seen for the representations ($t(39)$ = .127, p = .904, r = .020) but significant differences were found for the tasks ($t(39)$ = -2.398, p = .037, r = .359). The percentage of correct answers scored by the participants in the two different representations are therefore similar but the values reached in task 2 are significantly higher than the scores for task 1.

Testing for homogeneity of variance For between-group differences (spatial ability gender and UP), the values for $z_{skewness}$ and $z_{kurtosis}$ (given in Appendix 19) indicate issues with skew, kurtosis or both. Apart from normality-testing, the data was also analyzed for homogeneity of variance (see Appendix 20, Appendix 21, Appendix 22 and Appendix 23). Recommended by Sheskin (2004, 382), Hartley's F_{max} test (Hartley, 1940) with critical values from Hartley (1950, 310) was utilized to test for heteroscedasticity. As noted by Kutner, Nachtsheim, Neter, and Li (2004, 782), the Hartley test is (as well as the Levene test (Sheskin, 2004, 706) or the Bartlett-Box F test (Maxwell & Delaney, 2004, 116)) affected by non-normal distributions and small sample- or unequal group sizes (Zimmerman, 2004, 180). However, the suggested Brown-Forsythe test (Kutner et al., 2004, 116) was not applicable because of the small range of the dataset as the test is based on Mdn. For the unequal sample sizes (different values of n), the larger n was used (according to Kirk, 2013, 101) to determine df and thus the critical value for the test.

The found test values for F_{max} indicated issues with heteroscedasticity in the gender group (as well as in one sub-group of the UP groups) differences. Therefore, and based on the non-normal distribution also present in the other groups, a Kolmogorov-Smirnov Z test was employed to test for group effects on scores. For the overall achieved scores, no significant effect of spatial ability (with the median split: *KS-Z* = .791, *p* = .560, *r* = .125, and with the extreme groups approach: *KS-Z* = .595, *p* = .870. *r* = .112), gender (*KS-Z* = .744, *p* = .638, *r* = .118) or UP (*KS-Z* = .237, *p* = 1.000, *r* = .038) can be reported. There was also no significant difference for the scores obtained by the participants if they were in one of the four groups with respect to the individual representation or task types (see Appendix 24 for the results of the Kolmogorov-Smirnov Z test and Appendix 25 for the confirming independent samples t-test (BCa)). This also suggests that there is also no significant difference between the different representation- or task types in regards to the different groups (in gender as well as spatial ability and UP). This will be verified later.

Individual Differences and Interactions

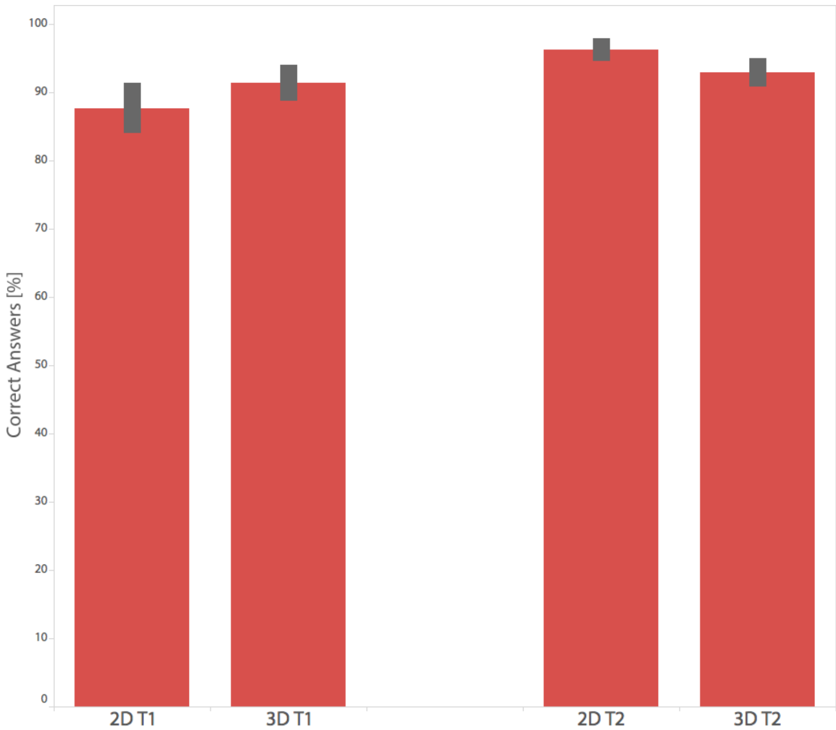


Figure 4.6 Score on individual interaction representation and task level
Error bar: 1 *SE*

Figure 4.6 reveals small differences between the 2D representation for task 1 compared with the 3D representation for task 1 as well as small differences between the 2D representation for task 2 and the 3D representation for task 2. Various differences between the 2D representation for task 1 and the 2D representation for task 2 are also apparent. The differences in the sub-categories (as well as the interactions with other variables) can be investigated with factorial repeated-measures designs (Field, 2014, 568), also known as within-subjects factorial analysis of variance (Sheskin, 2004, 932). However, no non-parametric equivalent for factorial repeated-measures designs exists and bootstrapping is not possible (i.e. no robust method is available) (Field, 2014, 565). Several alternative approaches beyond the scope of the suggested methods by Field (2014) were investigated and tested (always with the Winsorized as well as with the reciprocal dataset). Theoretically, the most promising approach would be to use an Aligned Rank Transform (ART) approach. This procedure overcomes the problem (and thus also the lack of non-parametric tests) of the normally used Rank Transform (RT) methods and applied tests for interaction effects (Higgins, Blair, & Tashtoush, 1990, 185; Higgins & Tashtoush, 1994, 202; Salter & Fawcett, 1993, 141). The response variable of each main effect and interaction is "aligned", meaning it exposes the effect of interest in the results. After alignment, the response variable gets ranked and a factorial Analysis of Variance (ANOVA) can be applied (Wobbrock, Findlater, Gergle, & Higgins, 2011, 2). The *ARTool*[43] by Wobbrock et al. (2011) was used to obtain the ranked data. However, the conducted factorial repeated-measures ANOVA in SPSS as well as an alternative approach with restricted maximum likelihood (REML) (a mixed model approach) (Corbeil & Searle, 1976, 31f) in SAS JMP 11[44] led to results with a warning (according to the guideline for the *ARTool*[43]). Therefore, the ART method is not suitable for the available effectiveness data. It can be hypothesized that the main reason for this is because of the many tied ranks in the data (Wobbrock et al., 2011, 4).

As a result of this, a two-step approach was carried out to investigate possible score differences at the representation-task level and on representation-task interactions.

Standard parametric approach In the first approach a repeated-measures factorial ANOVA was used (despite the lack of normality and the discussion about level of measurement; but, as already stated, it is controversially discussed in literature if this really matters; see above and also Norman (2010, 631) for more). With only two levels, Mauchly's test on sphericity can be neglected (Field, 2014, 561). Confirming the findings from Section 4.2 on page 55, no significant main effect of representation used on the scores of the participants can be established ($F(1, 39) = .110$, $p = .742$, $r = .054$) but a

[43] Available here: http://depts.washington.edu/aimgroup/proj/art/ (accessed: August 29, 2015)
[44] www.jmp.com (accessed: August 29, 2015)

significant main effect of task type ($F(1, 39) = 6.000$, $p = .019$, $r = .369$) was seen. There was also a significant interaction effect between the type of representation and the type of task ($F(1, 39) = 4.641$, $p = .037$, $r_{\text{representation vs. task}} = .330$). As such, the representation has different effects on a participant's score depending on the task type. Simple contrasts revealed that the 2D representation led to significantly higher scores in task 2 (compared to task 1) than the 3D representation. Therefore, the scores reached with the two task types were similar in the 3D representation but not for the 2D representation.

For between-group differences, the divided data was analyzed for homogeneity of variance as well as normality as described earlier (to view the results see, Appendixes 19 to 23). Again, normality and, in the gender group and one of the UP sub-groups, homogeneity of variance, is not supplied.

A mixed-design ANOVA confirmed the non-significant main effect of gender ($F(1, 38) = 3.233$, $p = .080$, $r = .280$). No significant interaction between the representation type and gender ($F(1, 38) = .670$, $p = .418$, $r_{\text{gender vs. representation}} = .132$) could be found. Gender interacted significantly with the task type ($F(1, 38) = 5.182$, $p = .029$, $r_{\text{gender vs. task}} = .346$) but not with representation × task ($F(1, 38) = .538$, $p = .468$, $r_{\text{gender vs. task vs. representation}} = .123$). Therefore, the scores achieved overall are similar for women and men. As a consequence of the non-significant interaction with representation, the scores of women and men are not different for those two groups when considering the representation. Task indeed shows a significant interaction with gender. According to the estimated marginal means, the increase in scores in the task 1 condition to the task 2 condition is greater for women than for men, men having nearly the same score in both task conditions while women had higher scores in task 2 versus task 1. Finally, the combined effect of representation and task is the same for women and men. Both groups had significantly higher scores for task 2 (respectively lower scores for task 1) in the 2D representation than in the 3D representation.

For spatial ability (median split), no significant main effect ($F(1, 38) = 1.042$, $p = .314$, $r = .163$) as well as no interaction effect (representation ($F(1, 38) = .011$, $p = .916$, $r_{\text{sa-m vs. representation}} = .017$, task ($F(1, 38) = 2.141$, $p = .152$, $r_{\text{sa-m vs. task}} = .231$) or both ($F(1, 38) = 2.704$, $p = .108$, $r_{\text{sa-m vs. task vs. representation}} = .258$) was found. The same results may be reported for spatial ability (extreme groups) – no significant main effect ($F(1, 26) = .069$, $p = .795$, $r = .052$) as well as no interaction effect (representation: ($F(1, 26) = .067$, $p = .797$, $r_{\text{sa-e vs. representation}} = .051$), task: ($F(1, 26) = .471$, $p = .499$, $r_{\text{sa-e vs. task}} = .133$) or both: ($F(1, 26) = 1.552$, $p = .224$, $r_{\text{sa-e vs. task vs. representation}} = .237$)) is present. Therefore, no differences between the tasks or representations as well as no differences overall are reported if a participant belongs to one particular spatial ability group.

The same findings as for spatial ability can be reported for UP: No significant main effect ($F(1, 38) = .078$, $p = .782$, $r = .055$) as well as no interaction effect (representation ($F(1, 38) = .002$, $p = .963$, $r_{\text{UP vs. representation}} = .007$), task ($F(1, 38) = 1.993$, $p = .166$, $r_{\text{UP vs. task}} = .066$) or both ($F(1, 38) = 1.234$, $p = .274$, $r_{\text{UP vs. task vs. representation}} = .177$).

Non-parametric approach and sub-level pairwise comparison As the assumptions (see previous discussion) for the repeated-measures factorial and the mixed design ANOVA were not entirely met and apparently no common non-parametric procedure is available for this case (Field, 2014, 555) with the available kind of data (ART), a second approach was carried out.

According to the list by Wobbrock et al. (2011, 1) and as also suggested by (among others) Ma, Mazumdar, and Memtsoudis (2012, 6), a Generalized Estimating Equation (GEE) (Liang & Zeger, 1986) (an extension to the Generalized Linear Model (GLM) (Hardin & Hilbe, 2013, 3)) may be used (and is more robust) to analyze data with non-normal distributions, heteroscedasticity and correlated residues. Further, the GEE procedure allows derivation of pairwise comparisons with pairwise contrast (instead of simple contrast) of all independent variables in combination, similar to the Friedman ANOVA.

The utilized GEE model makes use of a robust estimator, an exchangeable working correlation matrix (Dobson, 2001, 221) and Bonferroni-adjusted pairwise comparisons. Confirming the findings from the Wilcoxon signed-rank test and the paired-samples t-test (BCa), no significant effect of representation types on the scores could be demonstrated ($Wald\ \chi^2(1) = .113$, $p = .737$). Again, significant effects are revealed for the task types ($Wald\ \chi^2(1) = 6.154$, $p = .013$). The scores achieved in task 2 are significantly higher than the scores from task 1. With $Wald\ \chi^2(1) = 4.760$, $p = .029$, a significant interaction between task and representation can be reported. Pairwise comparison (Bonferroni adjusted) revealed a significant mean difference between the 2D task 1 type and the 2D task 2 type (i.e. at the task type sub-level) with a $M_{\text{2DT1-2DT2}}(1) = -.053$, $p = .011$ as well as between 2D task 2 and 3D task 1 ($M_{\text{2DT2-3DT1}}(1) = .033$, $p = .015$).

Gender has no significant effect overall ($Wald\ \chi^2(1) = 2.846$, $p = .092$) on representation ($Wald\ \chi^2(1) = .729$, $p = .393$) or on the interaction with representation and task ($Wald\ \chi^2(1) = .549$, $p = .459$). A significant effect is uncovered again on task (*Wald*

$\chi^2(1) = 4.563$, $p = .033$). Pairwise comparisons also show that women had a significantly higher increase from the task 1 to the task 2 condition, $M_{♀T1-♀T2}(1) = -.061$, $p = .049$.

For the median split spatial ability groups, no significant effect overall (*Wald* $\chi^2(1) = 1.097$, $p = .295$) on representation (*Wald* $\chi^2(1) = .012$, $p = .914$) or task (*Wald* $\chi^2(1) = 2.254$, $p = .133$) or in interactions with both (*Wald* $\chi^2(1) = 2.846$, $p = .092$) was exhibited. The same findings can be reported for the spatial ability (extreme split) groups – no significant effect overall (*Wald* $\chi^2(1) = .070$, $p = .792$) on representation (*Wald* $\chi^2(1) = .073$, $p = .787$) or task (*Wald* $\chi^2(1) = .535$, $p = .464$) or in interactions with both (*Wald* $\chi^2(1) = 1.826$, $p = .177$) was seen.

Finally, the results from the mixed ANOVA are also confirmed for the UP-groups (because of the small sample size of one group a model-based estimator was used): No significant effect overall (*Wald* $\chi^2(1) = .079$, $p = .779$), on representation (*Wald* $\chi^2(1) = .002$, $p = .966$) or task (*Wald* $\chi^2(1) = 2.415$, $p = .120$) or in interaction with both (*Wald* $\chi^2(1) = 1.110$, $p = .292$) can be found.

Therefore, the scores obtained by participants if they belonged to one particular spatial ability or UP group are similar and, as well, the changes between task or representation conditions are similar for the groups.

4.3 Efficiency

Table 4 Descriptives of the overall efficiency of all participants

	N	*M*	*SE*	*Mdn*	*IQR*	*Min*	*Max*
Time [sec]	40	33.452	1.729	32.688	14.531	11.50	59.94

Efficiency was measured based on the time it took the participants to solve the task. The overall descriptives are provided in *Time* in Table 4. On average, a participant had around 30 seconds to solve a task.

Outliers

The value of the extreme outlier (see Table 5 on the following page) was Winsorized and replaced with the last non-extreme value.

Table 5 Outliers efficiency in relation to the individual representation- and task types

	2D T1	2D T2	3D T1	3D T2	2D	3D	T1	T2	All
Extreme	0	0	1	0	0	0	0	0	0
Probable	0	1	0	1	0	1	0	1	0
Potential	1	1	1	1	2	1	1	0	3
Normal	39	38	38	38	38	38	39	39	37

Extreme: z-score > 3.29; Probable: z-score 2.58–3.29; Potential: z-score 1.96–2.57; Normal: z-score < 1.96 according to Field (2014, 179)
$N = 40$

Main Differences

The mean time to solve the tasks by the participants for the two representation types (2D and 3D) and the two task types (task 1 and task 2) are seen in Figure 4.7 on the next page and Appendix 26. $z_{skewness}$ and $z_{kurtosis}$ values (available in Appendix 27) for the Winsorized data are all < 3.29 ($z_{skeweness}$) respectively < 3.29 or > -3.29 ($z_{kurtosis}$). Two groups are positively skewed with a significance of $p < .01$ and are platykurtic or leptokurtic. For a number of the groups, there were issues with skew, kurtosis or both. A visual interpretation of the graphs and a Kolmogorov-Smirnov test ($D(40)$ = [45], p = [45]) revealed a significant difference for the time data from a normal distribution in three cases.

Based on the derived λ (Box-Cox parameter) between .04 and .87 and following the suggestion by Tabachnick and Fidell (2013, 87) and Sheskin (2004, 405), a square root transformation as described in Field (2014, 207) was used. As stated by Field (2014, 201), the transformation has to be applied to all groups and all values, not simply for the non-normal or significantly skewed data. The descriptives of the utilized square root transformation can be viewed in Appendix 29.

Regarding the transformed data, a Kolmogorov-Smirnov test ($D(40)$ = [46], p = [46]) showed that the time data became normally distributed. This can be confirmed with a visual inspection of the Q-Q plots and with the values for $z_{skewness}$ and $z_{kurtosis}$ (avail-

[45] The test statistics and the p-value are different for the individual groups, the details as well as the results from the Shapiro-Wilk test used for confirmation (or in case of the lower-bound p-value as a replacement) of the Kolmogorov-Smirnov test are available in Appendix 28

[46] See footnote [45] for the description and Appendix 30 for the data

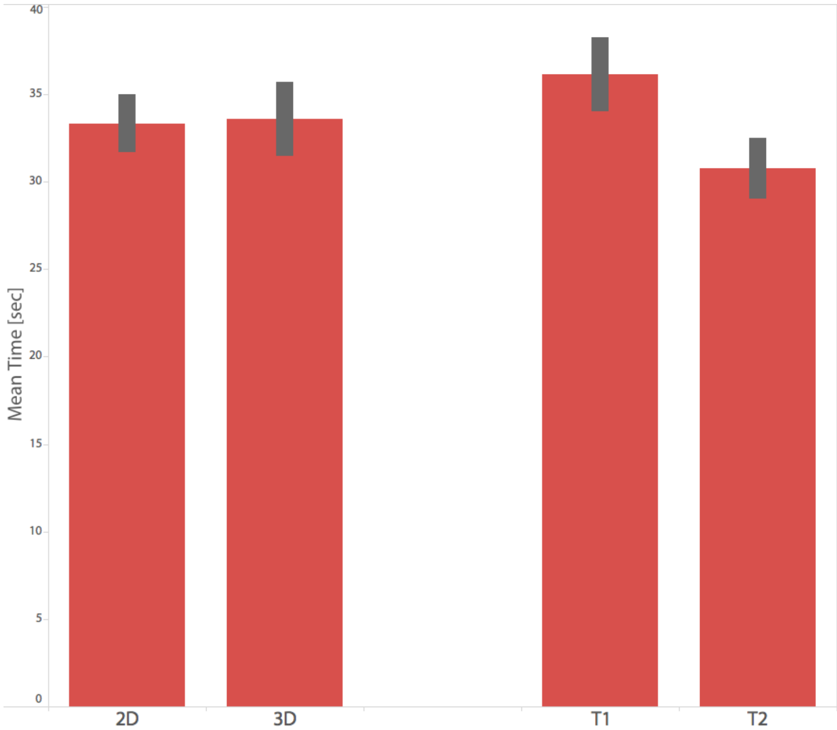


Figure 4.7 Task time on representation (left) and task (right) level
Error bar: 1 *SE*

able in Appendix 31) where all values are < 1.96 or > -1.96. This means that, after the transformation, no issues with non-normality, skew or kurtosis were expected.

A paired-samples t-test demonstrated no significant difference between the time it took the participants to solve the tasks with respect to the two representation types ($t(39) = .112$, $p = .912$, $r = .018$) but a significant difference between the two task types ($t(39) = 3.099$, $p = .004$, $r = .445$). This difference is easily visible in Figure 4.7, participants having had longer to solve task 1 than task 2.

For between-group differences, the data was analyzed for homogeneity of variance and normality (Appendix 32, Appendix 33, Appendix 34, Appendix 35 and Appendix 36) as described in Section 4.2 on page 56. The square root transformed data is significantly normally distributed (apart from one sample in the UP-group, but this subgroup is not of interest in the main analysis). There are two groups (in UP and the spatial ability (extreme groups) that showed signs of heteroscedasticity. Those groups are not of interest for the primary analysis. Therefore, an independent samples t-test was made us of that revealed no significant difference in the overall time it took the participants if they belonged to a particular spatial ability group (median split) – $t(38) = 2.027$, $p = .050$, $r = .313$ as well as for the extreme groups: $t(26) = 1.693$, $p = .102$. $r = .265$). Also no difference can be found in respect to UP: $t(38) = 1.364$, $p = .181$, $r = .216$. For gender, ($t(38) = -3.193$, $p = .003$, $r = .460$), a strong difference in the time can be reported and women had significantly longer to solve the tasks. There were also significant differences in the time it took participants to solve the tasks regarding individual representation or task types related to gender (women needed more time in all cases), but not to spatial ability (see Appendix 37 for the results of the independent-samples t-test). For UP, a difference can be reported in the task 2 case: Urban planners were significantly faster to solve this task than non-urban planners.

Individual Differences

Figure 4.8 Task time on individual interaction representation and task level
Error bar: 1 *SE*

Figure 4.8 shows some differences between the two representation types (2D and 3D) split at the the task level. A repeated-measures factorial ANOVA was conducted, exhibiting no significant main effect of representation ($F(1,39) = .001$, $p = .971$, $r = .000$)

or interactions ($F(1, 39) = 3.225$, $p = .080$, $r_{\text{representation vs. task}} = .459$). This means that no significant difference could be found in the time it took participants to solve the task when representation type 1 changed to representation type 2 (when task 1 or task 2 is used). A significant main effect of the task type on the time it took the participants to solve the task can be gleaned again ($F(1, 39) = 10.731$, $p = .002$, $r = .862$).

For between-group differences, the split data was analyzed for homogeneity of variance as well as normality as described earlier (results see Appendixes 32 to 36). As already stated, normality is given in all but but one case. Homogeneity of variance was not met for two relevant cases.

A mixed design ANOVA confirmed a significant main effect of gender ($F(1, 38) = 10.323$, $p = .003$, $r = .859$). Overall, women took more time to solve the tasks versus men. No significant interaction between the representation type and gender ($F(1, 38) = 1.474$, $p = .232$, $r_{\text{gender vs. representation}} = .233$), task and gender ($F(1, 38) = 1.492$, $p = .229$, $r_{\text{gender vs. task}} = .235$) or in interactions ($F(1, 38) = 1.980$, $p = .167$, $r_{\text{gender vs. representation vs. task}} = .306$) could be found. Based on the non-significant interaction with representation, the time it took women and men is not different for those two groups when dependent on the representation, task or in combination, but different overall.

For spatial ability (median split), the independent-samples t-test stated a p-value of exactly .05. According to the mixed design ANOVA, this value is actually indicative of a significant main effect ($F(1, 38) = 4.279$, $p = .045$, $r = .318$). Participants in the low spatial ability group were therefore significantly slower in solving the task than participants in the high spatial ability group. No significant interaction effect for the spatial ability (median split) group could be seen for representation ($F(1, 38) = .301$, $p = .587$, $r_{\text{sa-m vs. representation}} = .049$ and task ($F(1, 38) = .068$, $p = .795$, $r_{\text{sa-m vs. task}} = .011$). The representation $\times$ task interaction, however, is different for the low and the high spatial ability (median split) groups ($F(1, 38) = 7.821$, $p = .008$, $r_{\text{sa-m vs. task vs. representation}} = .785$).

Spatial ability (with the extreme group approach) had no significant overall effect on the time it took to solve the tasks ($F(1, 38) = 2.858$, $p = .103$, $r = .421$). Additionally, again, no significant interaction effect for the spatial ability (extreme split) group was exhibited for representation ($F(1, 38) = .032$, $p = .860$, $r_{\text{sa-e vs. representation}} = .005$) and task ($F(1, 38) = .000$, $p = .993$, $r_{\text{sa-e vs. task}} = .000$). Yet, the representation $\times$ task interaction is different for the low and the high spatial ability (extreme split) groups ($F(1, 38) = 4.889$, $p = .036$, $r_{\text{sa-e vs. task vs. representation}} = .337$).

According to simple contrasts, participants in the low spatial ability group (median split and extreme split) solved both tasks in the 3D representation at nearly the same speed, but in the 2D representation, they were faster in solving task 2 versus task 1. On the contrary, participants in the high spatial ability group (median and extreme split) solved task 1 less speedily than task 2 in both representations, with task 1 taking them nearly the same amount of time in both representations, while task 2 was solved faster in the 3D representation than in the 2D representation.

UP shows no effect overall ($F(1, 38) = 2.062$, $p = .159$, $r = .227$) or for representation ($F(1, 38) = .050$, $p = .824$, $r_{\text{sa-e vs. representation}} = .114$), task ($F(1, 38) = 3.057$, $p = .088$, $r_{\text{sa-e vs. task}} = .273$) and in interaction with both ($F(1, 38) = .086$, $p = .771$, $r_{\text{sa-e vs. task vs. representation}} = .048$).

In the case of the efficiency data, the GEE approach was only used for pairwise comparison of the individual sub-levels and the between-group differences in the (extreme split) spatial ability group (with a robust-estimator) as well as the UP groups (with a model-based estimator) as one group had unequal variances.

At the individual representation and task level, pairwise comparison (Bonferroni adjusted) revealed a significant mean difference between the 2D task 1 and 2D task 2 ($M_{\text{2DT1-2DT2}}(1) = .675$, $p = .002$).

The findings from the mixed design ANOVA for spatial ability (extreme groups) confirmed there was no significant effect overall (*Wald* $\chi^2(1) = 2.935$, $p = .087$) on representation (*Wald* $\chi^2(1) = .037$, $p = .848$) or task (*Wald* $\chi^2(1) = .000$, $p = .996$). A significant effect, though, can be seen in the interaction of the representation × task (*Wald* $\chi^2(1) = 5.641$, $p = .018$). Pairwise comparison showed that participants in the high spatial ability group were significantly faster in solving task 2 in the 2D representation (compared to task 1 in the 2D representation) than participants in the low spatial ability group $M_{\text{2DT2-high–2DT2-low}}(1) = -1.536$, $p = .000$).

The same holds true for the UP groups: No significant effect overall (*Wald* $\chi^2(1) = 2.075$, $p = .150$), on representation (*Wald* $\chi^2(1) = .048$, $p = .826$) or task (*Wald* $\chi^2(1) = 3.421$, $p = .064$) as well as in interaction representation × task (*Wald* $\chi^2(1) = .078$, $p = .780$).

4.4 Confidence

Confidence is self stated by the participants on a Likert scale with five stages (1 = low to 5 = high). Based on the nature of Likert scale data as determined by Norman (2010, 629), the overall descriptives are given as *Value* in Table 6 on the next page.

Table 6 Descriptives of overall confidence of all participants

	N	*M*	*SE*	*Mdn*	*IQR*	*Min*	*Max*
Value	40	4.255	.105	4.406	1.05	2.69	5.00

Outliers

According to the z-score values, no extreme outliers could be found in the data (see Table 7) and, therefore, there is no reason to correct the data.

Table 7 Outliers confidence in relation to the individual representation- and task types

	2D T1	2D T2	3D T1	3D T2	2D	3D	T1	T2	All
Extreme	0	0	0	0	0	0	0	0	0
Probable	0	0	1	1	0	0	0	0	0
Potential	0	3	1	0	3	2	3	1	3
Normal	40	37	38	39	37	38	37	39	37

Extreme: z-score > 3.29; Probable: z-score 2.58–3.29; Potential: z-score 1.96–2.57; Normal: z-score < 1.96 according to Field (2014, 179)
$N = 40$

Main Differences

The mean confidence ratings are provided in Figure 4.9 on the next page and Appendix 38. According to the $z_{skewness}$ and $z_{kurtosis}$ values (available in Appendix 39), most groups are negatively skewed with a significance of $p < .05$ and slightly leptokurtic. A visual interpretation of the graphs as well as a Kolmogorov-Smirnov test ($D(40) =$ [47], $p =$ [47]) revealed a significant difference for the confidence data from a normal distribution in all cases (see also Section 4.2 on page 56).

Based on the heterogeneous pattern in the data, none of the familiar transformations were efficient. Possible λ (Box-Cox parameter) ranged from 2.47 to 3.96. A tested "optimal" λ value of 3.47 was still not sufficient for the confidence data. In fact, positive as well as negative effects on the data were observable. Thus, no transformation was applied to the confidence data.

[47] The test statistics and the p-value are different for the individual groups, the details as well as the results from the Shapiro-Wilk test used for confirmation of the Kolmogorov-Smirnov test are available in Appendix 40

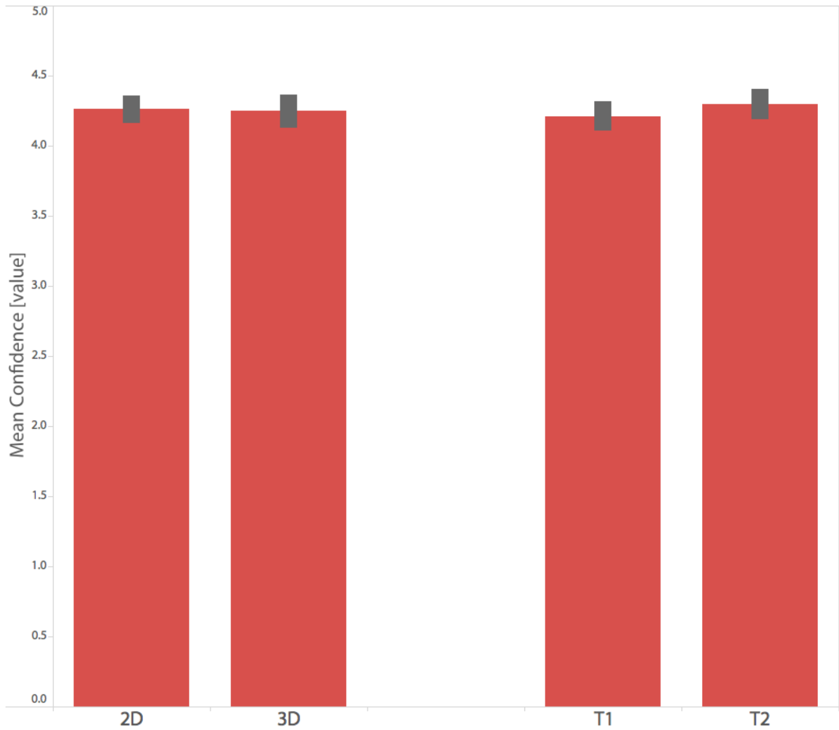


Figure 4.9 Confidence ratings on representation (left) and task (right) level
Error bar: 1 *SE*

From Figure 4.9, it was expected that no difference in confidence for the representation types as well as between the task types is present. This can be confirmed with a Wilcoxon signed-rank test, which uncovered no significant difference between the confidence ratings for the two representation types (2D and 3D) with both tasks grouped together (T = 187.500, p = .971, r = -.004) as well as for the tasks when the representation types are grouped together (T = 319.500, p = .157, r = .158). A paired-samples t-test (BCa) confirms those findings: representations (t(39) = .277, p = .783, r = .044); and tasks (t(39) = -1.507, p = .140, r = .235). The stated confidence by the participants in the two different representations and the task conditions are therefore similar.

For between-group differences, the data was analyzed for homogeneity of variance and normality (Appendix 41, Appendix 42, Appendix 43, Appendix 44 and Appendix 45) as described in Section 4.2 on page 58. Many of the groups had either non-normal distributions, non-homogeneous variances or both. Therefore, a Kolmogorov-Smirnov Z-test was applied. No significant difference in the participants' confidence could be reported, if they belonged to a particular spatial ability group (median split: *KS-Z* = .949, p = .329, r = .150; extreme groups: *KS-Z* = 1.015, p = .254, r = .209) or because of gender

(*KS-Z* = 1.087, $p = .188$, $r = .172$). A significant difference could only be found for gender in the 2D representation (see Appendix 46). Interestingly, the independent-samples t-test (BCa) yields conflicting results for some cases (see Appendix 47). According to the independent-samples t-test, women stated not only (as revealed with the Kolmogorov-Smirnov Z-test) lower confidence ratings in the 2D representation but also for the task 1 as well as overall. A divergent finding is also reported for spatial ability (median split) for task 1, with participants in the low spatial ability group supplying significantly lower scores than participants in the high spatial ability group.

For the UP group, significant differences are found in the overall confidence ratings: *KS-Z* = 1.502, $p = .022$, $r = .238$ as well as in the task 2 and the 3D subgroup (see Appendix 46). According to the independent-samples t-test, the findings for overall and for the 3D representation can be confirmed. However, the three other combinations show opposite results to the Kolmogorov-Smirnov Z test.

Individual Differences

Figure 4.10 Confidence on individual interaction representation and task level
Error bar: 1 *SE*

Figure 4.10 on the previous page shows various differences between the two representation types (2D and 3D) split at the task level.

Parametric approach A repeated-measures factorial ANOVA was conducted and exhibited no significant main effect of representation ($F(1, 39) = .077$, $p = .783$, $r = .044$) or task ($F(1, 39) = 2.272$, $p = .140$, $r = .235$). A significant interaction effect, thought, is seen ($F(1, 39) = 6.825$, $p = .013$, $r_{\text{representation vs. task}} = .235$). The confidence ratings are similar for task 1 and task 2 in the 3D representation but significantly higher for task 2 than task 1 in the 2D representation.

For between-group differences, the split data was analyzed for homogeneity of variance as well as normality as described previously (see results in Appendixes 41 to 45). As is visible, all groups are negatively skewed and platy- or leptokurtic with different powerful effects. For most groups, normality is not apparent. Homogeneity of variance is, according to the more robust Hartley's test, not present in all cases.

A mixed design ANOVA confirmed the significant main effect of gender ($F(1, 38) = 5.804$, $p = .021$, $r = .364$). Overall, women reported lower confidence ratings than men (confirming the independent-samples t-test). No significant interaction between the representation type and gender ($F(1, 38) = .184$, $p = .670$, $r_{\text{gender vs. representation}} = .069$), task and gender ($F(1, 38) = 1.429$, $p = .239$, $r_{\text{gender vs. task}} = .190$) or in interaction with both ($F(1, 38) = 2.075$, $p = .158$, $r_{\text{gender vs. representation vs. task}} = .228$) could be found. Therefore, the confidence ratings supplied by women and men are not different for those two groups depending on the used representation, task or in combination, but on an overall basis.

For spatial ability (median split), no significant main effect was observed ($F(1, 38) = 3.858$, $p = .057$, $r = .306$). This result supports the findings from the Kolmogorov-Smirnov Z-test and is in opposition to the independent-samples t-test. For representation ($F(1, 38) = .147$, $p = .704$, $r_{\text{sa-m vs. representation}} = .062$) and task ($F(1, 38) = 2.738$, $p = .106$, $r_{\text{sa-m vs. task}} = .259$), no significant interaction effect for spatial ability (median split) was seen. The representation × task interaction, however, is different for the low and the high spatial ability (median split) groups ($F(1, 38) = 7.293$, $p = .010$, $r_{\text{sa-m vs. task vs. representation}} = .401$). The low spatial ability group provided similar confidence ratings for the two tasks in the 3D representation and different ratings for task 1 (lower) and task 2 (higher) in the 2D representation whereas the high spatial ability group reported the same confidence rating for both tasks in the 2D representation and different ratings for task 1 (higher) than task 2 (similar to the 2D representation) in the 3D representation.

Spatial ability with the extreme group approach had no significant main effect on the confidence rating ($F(1, 38) = 1.413$, $p = .245$, $r = .189$. Once more, no significant interaction effect for the spatial ability (extreme split) group was seen with representation ($F(1, 38) = .265$, $p = .611$, $r_{\text{sa-e vs. representation}} = .083$); task ($F(1, 38) = 3.449$, $p = .075$, $r_{\text{sa-e vs. task}} = .259$) and also for the representation × task interaction ($F(1, 38) = 4.029$, $p = .055$, $r_{\text{sa-e vs. task vs. representation}} = .310$).

Finally, UP shows a significant main effect on the confidence rating ($F(1, 38) = 4.132$, $p = .049$, $r = .313$. No significant interaction effect forUP can be found for representation ($F(1, 38) = 1.232$, $p = .274$, $r_{\text{up vs. representation}} = .177$); task ($F(1, 38) = .003$, $p = .956$, $r_{\text{up vs. task}} = .009$) and also for the representation × task interaction ($F(1, 38) = .011$, $p = .917$, $r_{\text{up vs. task vs. representation}} = .017$). Therefore, the ratings between urban planners and non-urban planners are different (participants who considered themselves as UP had overall higher confidence ratings), but between the representation or task conditions no different effect can be found related to the group.

Non-parametric approach The GEE affirmed the findings from the Wilcoxon signed-rank test and the paired-samples t-test (BCa) – no significant effect of representation types (*Wald* $\chi^2(1) = .079$, $p = .779$) or task (*Wald* $\chi^2(1) = 2.331$, $p = .127$) were found. With *Wald* $\chi^2(1) = 7.001$, $p = .008$, a significant interaction between task and representation for the confidence ratings is present. Pairwise comparison (Bonferroni adjusted), however, revealed at the sublevel comparison (task vs. representation; representation vs. representation; task vs. task) that no significant mean differences exist between different task and representation configurations.

Gender again shows a significant main effect (*Wald* $\chi^2(1) = 5.570$, $p = .018$) but not on representation (*Wald* $\chi^2(1) = .163$, $p = .686$), task (*Wald* $\chi^2(1) = 1.206$, $p = .272$) or in the interaction with representation and task (*Wald* $\chi^2(1) = 1.963$, $p = .161$). Pairwise comparison (Bonferroni adjusted) also shows, in contrast to the Kolmogorov-Smirnov Z-test, that women had significantly lower confidence ratings than men $M_{\text{W-M}}(1) = -.48$, $p = .032$.

For the median split spatial ability groups, a significant effect overall (*Wald* $\chi^2(1) = 4.061$, $p = .044$) and in the interaction with task × representation (*Wald* $\chi^2(1) = 7.677$, $p = .006$) could be reported. No significant effect is found on representation (*Wald* $\chi^2(1) = 2.883$, $p = .090$) or task (*Wald* $\chi^2(1) = 2.883$, $p = .090$). Pairwise comparisons (Bonferroni adjusted) demonstrated that participants in the high spatial ability group reported higher confidence than participants in the low spatial ability group $M_{\text{H-L}}(1) =$

.40, $p = .044$. For the task × representation interaction, pairwise comparisons showed revealed no relevant difference.

The extreme split spatial ability group did not have any significant effects overall (*Wald* $\chi^2(1) = 1.563$, $p = .211$), on representation (*Wald* $\chi^2(1) = .289$, $p = .591$) or task (*Wald* $\chi^2(1) = 3.817$, $p = .051$). In interactions with both, though, a significant effect was found (*Wald* $\chi^2(1) = 4.725$, $p = .030$). According to the Bonferroni-adjusted pairwise comparison, those differences are not of interest for one of the cases (i.e. low vs. high spatial ability). Hence, the ratings stated by the participants if they belonged to one particular spatial ability group are similar and also the changes between the task or representation conditions are similar for the groups.

The findings for the UP case are confirmed: A significant overall effect of UP can be stated (*Wald* $\chi^2(1) = 4.181$, $p = .041$). No significant effect is found on representation (*Wald* $\chi^2(1) = 1.128$, $p = .288$), task (*Wald* $\chi^2(1) = 003$, $p = .958$) or in interaction with both (*Wald* $\chi^2(1) = .011$, $p = .915$).

4.5 Interaction

Table 8 Descriptives of overall interaction of all participants

	N	*M*	*SE*	*Mdn*	*IQR*	*Min*	*Max*
Value	40	1.508	.196	1.250	2.234	.000	4.125

Interaction is measured as the number of rotations conducted by the participants. The mean number of interactions per task are shown in in Table 8.

Outliers

According to the z-score values, no extreme outliers could be found in the data (see Table 9 on the next page) and so there is no reason to correct the data.

Main Differences

The (averaged) numbers of interactions per group are listed in Figure 4.11 on page 76 and in Appendix 48. According to the $z_{skewness}$ and $z_{kurtosis}$ values (available in Appendix 49), all groups are positively skewed and slightly platykurtic. A visual interpretation of

Table 9 Outliers interaction in relation to the individual representation- and task types

	2D T1	2D T2	3D T1	3D T2	2D	3D	T1	T2	All
Extreme	0	0	0	0	0	0	0	0	0
Probable	0	0	0	0	0	0	0	0	0
Potential	1	2	2	2	0	2	2	2	2
Normal	39	38	38	38	40	38	38	38	38

Extreme: z-score > 3.29; Probable: z-score 2.58–3.29; Potential: z-score 1.96–2.57; Normal: z-score < 1.96 according to Field (2014, 179)
$N = 40$

the graphs as well as a Kolmogorov-Smirnov test ($D(40)$ = [48], p = [48]) revealed that for the interaction data, there was a significant shift from a normal distribution in most of the cases (see also Section 4.2 on page 56).

As a consequence of the heterogeneous pattern in the data, none of the familiar transformations were efficient. Possible λ (Box-Cox parameter) ranged from -.01 to .53. As shown by Osborne (2010, 4), a λ of .00 is equivalent to the familiar natural log transformation and a λ of .50 is equivalent to the square root transformation. A tested "optimal" λ value of .31 (similar to a cube root transformation (Osborne, 2010, 4)) anchored at 1 (Osborne, 2002, n.d.) revealed only a marginal overall positive effect for a normal distribution. Therefore, no transformation was applied for the confidence data.

As depicted in Figure 4.11 on the following page, a clear difference in the number of interactions could be expected with more interactions in the 3D representation versus the 2D representation. For the tasks, only a small difference was visible. This idea was confirmed with a Wilcoxon signed-rank test, uncovering a significant difference between the number of interactions for the two representation types (2D and 3D) with both tasks grouped together ($T = 575.500$, $p = .000$, $r = .676$) as well as when the representation types are grouped together ($T = 390.000$, $p = .050$, $r = .310$). A paired-samples t-test (BCa) confirmed those findings for the representations ($t(39) = -4.981$, $p = .001$, $r = .624$) but not for the tasks ($t(39) = -1.141$, $p = .291$, $r = .180$). The number of interactions by the participants is therefore significantly higher in the 3D

[48] The test statistics and the p-value are different for the individual groups, the details as well as the results from the Shapiro-Wilk test used for confirmation of the Kolmogorov-Smirnov test are available in Appendix 50

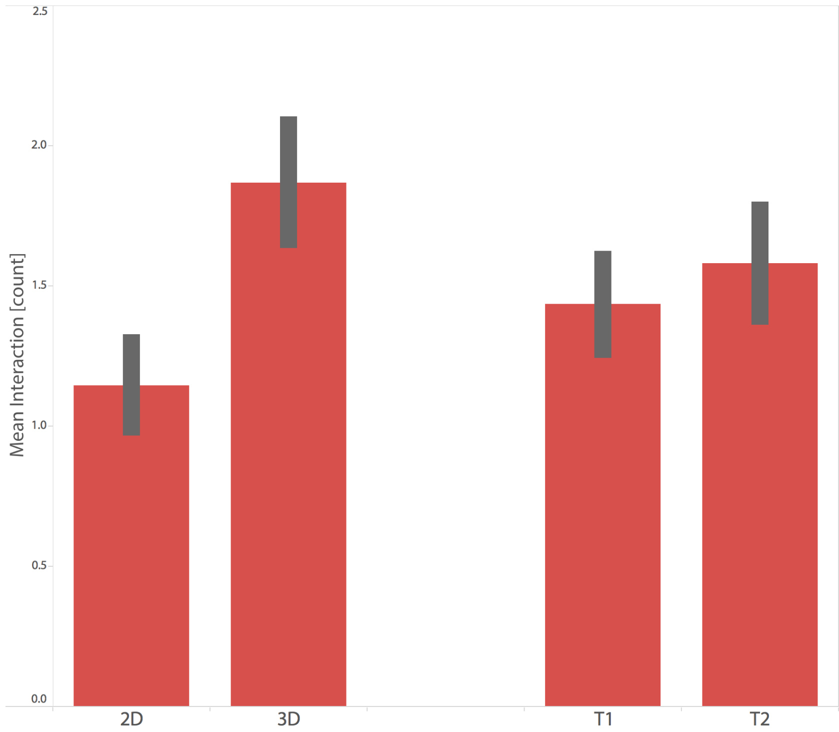


Figure 4.11 Number of interactions on representation (left) and task (right) level
Error bar: 1 *SE*

representation than in the 2D representation, while for the task types, it is also higher, but controversially if a significant difference can be assumed.

For between-group differences, the data was analyzed for homogeneity of variance and normality (Appendix 51, Appendix 52, Appendix 53 and Appendix 54) as described in Section 4.2 on page 58. All groups are positively skewed and platy- or leptokurtic and have similar variances according to the Hartley's test as well as Levene's test (apart from one case in the UP-split). Based on the fact that a number of groups showed non-normal distributions, a Kolmogorov-Smirnov Z-test was employed that exhibited no significant difference on the number of interactions by the participants if they belonged to a particular group (spatial ability, median split: $KS\text{-}Z = .791$, $p = .560$, $r = .125$; extreme groups: $KS\text{-}Z = .131$, $p = .897$, $r = .026$); gender ($KS\text{-}Z = .752$, $p = .497$, $r = .121$); UP: ($KS\text{-}Z = .395$, $p = .063$, $r = .998$). As well, no significant difference in the number of interactions dependent on the groups could be found at the individual sublevels (see Appendix 55 and, in addition, Appendix 56 for the confirming independent-samples t-test).

Individual Differences

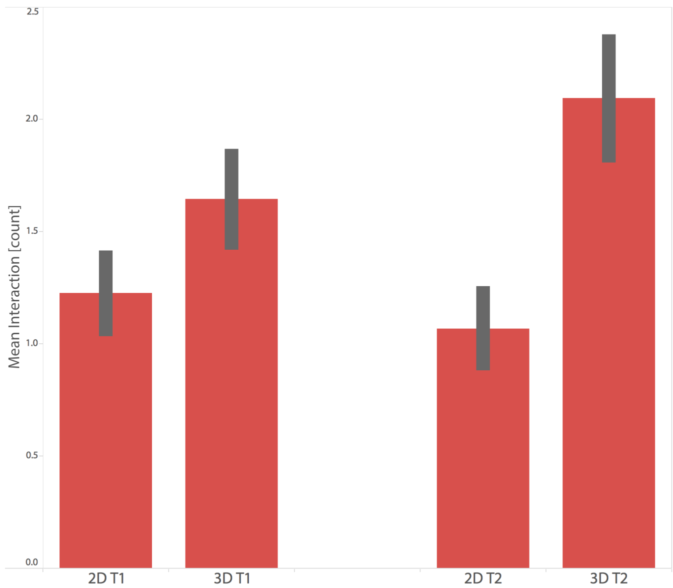


Figure 4.12 Number of interactions on individual interaction representation and task level
Error bar: 1 *SE*

Figure 4.12 shows a number of differences between the two representation types (2D and 3D) split at the task level.

Parametric approach A repeated-measures factorial ANOVA revealed a significant main effect of representation ($F(1, 39) = 20.844$, $p = .000$, $r = .590$) and in interaction ($F(1, 39) = 6.688$, $p = .014$, $r_{\text{representation vs. task}} = .383$) but not of task ($F(1, 39) = 1.301$, $p = .261$, $r = .180$). The findings (on task effect) from the BCa corrected independent-samples t-test are therefore supported (but not the results from the Wilcoxon-signed rank test). Significantly more interactions were evident in the 3D representation compared to the 2D representation but the difference on the task types was not significantly different.

For between-group differences, the split data was analyzed for homogeneity of variance as well as normality as described previously (see results in Appendixes 51 to 54). All groups are positively skewed and platy- or leptokurtic with effects of varying strength. For most groups, normality is not present. Homogeneity of variance is seen in all cases.

A mixed design ANOVA confirmed the non-significant main effect of gender ($F(1, 38) = .471$, $p = .497$, $r = .111$). Overall, the number of interactions by men and women are similar. No significant interaction between the representation type and gender (F(1,

38) = .218, $p = .643$, $r_{\text{gender vs. representation}} = .076$), task and gender ($F(1, 38) = .192$, $p = .664$, $r_{\text{gender vs. task}} = .071$) or in interaction ($F(1, 38) = 1.141$, $p = .292$, $r_{\text{gender vs. representation vs. task}}$ = .171) could be discerned. Therefore, the higher number of interactions in the 3D representation compared to the 2D representation has a similar increase for both women and men and the non-significant change of the number of interactions depended on the task or the task × representation interaction that followed a similar pattern for women and men.

For spatial ability (median split), no significant main effect was reported ($F(1, 38)$ = .297, p = .589, r = .088). No significant interaction between the representation type and spatial ability (median split) ($F(1, 38)$ = .037, p = .849, $r_{\text{sa-m vs. representation}}$ = .031), task and spatial ability (median split) ($F(1, 38)$ = 1.091, p = .303, $r_{\text{sa-m vs. task}}$ = .167) or in interaction ($F(1, 38)$ = .117, p = .734, $r_{\text{sa-m vs. representation vs. task}}$ = .066) was observed.

Further, the extreme group approach had no significant main effect on the number of interaction ($F(1, 38)$ = .017, p = .897, r = .021. Again, no significant interactions effect for the spatial ability (extreme split) group could be found for representation ($F(1, 38)$ = .666, p = .422, $r_{\text{sa-e vs. representation}}$ = .131), task ($F(1, 38)$ = 674, p = .419, $r_{\text{sa-e vs. task}}$ = .132) or in the representation × task interaction ($F(1, 38)$ = .009, p = .927, $r_{\text{sa-e vs. task vs. representation}}$ = .015).

Similarly, for UP, no significant main effect overall ($F(1, 38)$ = .047, p = .830, r = .035 or in interaction with representation ($F(1, 38)$ = 1.983, p = .167, $r_{\text{up vs. representation}}$ = .223) or in representation × task interaction ($F(1, 38)$ = .323, p = .573, $r_{\text{up vs. task vs. representation}}$ = .092) can be found. A significant interaction effect was found for task: $F(1, 38)$ = 4.471, p = .041, $r_{\text{up vs. task}}$ = .325. Pairwise comparison reveals that participant's who stated that they are urban planners interacted more in the task 2 condition than in the task 1 condition whereas it was vice versa for non-urban planners.

Non-parametric approach The GEE confirmed the already derived findings with a significant effect of representation types on the number of interactions (*Wald* $\chi^2(1)$ = 25.447, p = .000) and in interaction (*Wald* $\chi^2(1)$ = 6.859, p = .009) but not on task (*Wald* $\chi^2(1)$ = 1.334, p = .248). Pairwise comparison (Bonferroni adjusted) revealed a significantly stronger interactions in 3D over 2D for task 2 ($M_{\text{T2-3D–T2-2D}}(1)$ = 1.03, p = .000) but not for task 1 ($M_{\text{T1-3D–T1-2D}}(1)$ = .42, p = .065).

Gender showed no significant main effect (*Wald* $\chi^2(1)$ = .500, p = .480) on representation (*Wald* $\chi^2(1)$ = .242, p = .623), task (*Wald* $\chi^2(1)$ = .168, p = .682) or in interaction with representation and task (*Wald* $\chi^2(1)$ = 1.132, p = .287).

For the median split spatial ability groups, no significant effect overall (*Wald* $\chi^2(1) = .313$, $p = .576$), on representation (*Wald* $\chi^2(1) = .039$, $p = .844$), task (*Wald* $\chi^2(1) = 1.149$, $p = .284$) or in interactions (*Wald* $\chi^2(1) = .124$, $p = .725$) can be reported.

The same non-significant effects may be reported for the spatial ability (extreme groups) main effect (*Wald* $\chi^2(1) = .018$, $p = .893$), on representation (*Wald* $\chi^2(1) = .716$, $p = .397$), task (*Wald* $\chi^2(1) = .727$, $p = .394$) or in interactions (*Wald* $\chi^2(1) = .010$, $p = .921$).

As such, the number of interactions by the participants are similar if they belonged to one particular group (spatial ability or gender), and the same applies to the changes between the task or representation conditions that are similar for the groups.

For UP, the findings from the mixed ANOVA are confirmed with: Main effect (*Wald* $\chi^2(1) = .047$, $p = .828$), on representation (*Wald* $\chi^2(1) = 2.366$, $p = .124$); task (*Wald* $\chi^2(1) = 3.965$, $p = .046$) and in interaction (*Wald* $\chi^2(1) = .263$, $p = .608$). Pairwise comparison reveals also here that the profile interaction was different for both groups, however, no significant differences can be reported for sub-level interactions.

4.6 Preferences

The participants stated their preference for the 2D or the 3D representation with respect to task. They also answered several additional questions and were able to state anything they desired.

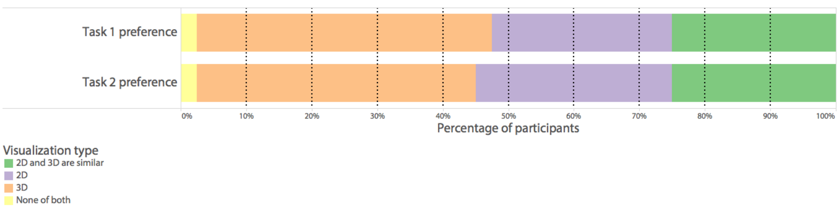


Figure 4.13 Preference ratings stated by the participants related to task

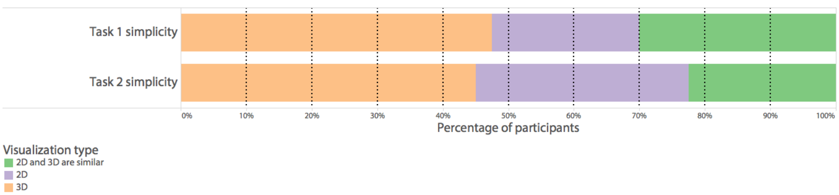


Figure 4.14 Simplicity ratings stated by the participants related to task

As can be understood from Figure 4.13 on the previous page, there is a clear preference stated by the participants for 3D representation compared to 2D representations. One participant noted that both representation types are not useful and around 25% had no clear preference for either representation type. According to Figure 4.14 on the preceding page, a higher proportion of the participants stated that the tasks were easier to solve with the 3D representation compared to the 2D representation. Spearman's correlation analysis showed that the stated simplicity by one particular participant is the same for both tasks ($r_s = .787$, $p < .01$) whereas the stated preference does not show such a strong effect ($r_s = .318$, $p = .045$). As described in Figure 4.15 and Figure 4.16,

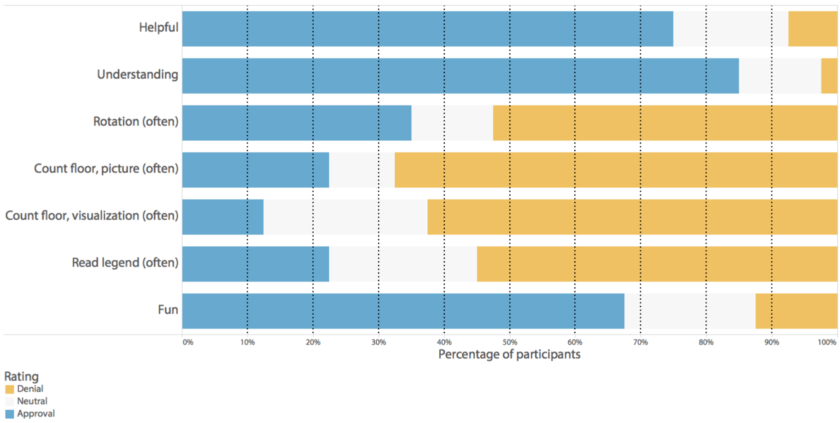


Figure 4.15 Statements for the 2D representation
Data aggregated: Denial (1–2), Neutral (3), Approval (4–5)

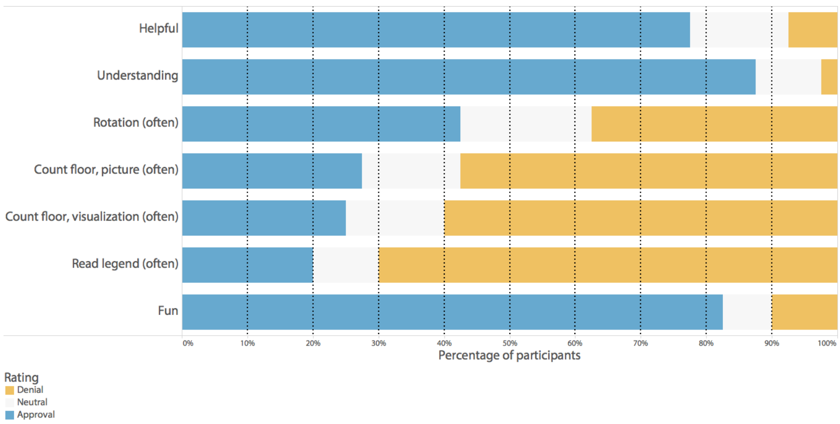


Figure 4.16 Statements for the 3D representation
Data aggregated: Denial (1–2), Neutral (3), Approval (4–5)

both representation types were similarly helpful in solving the task and were easy to understand. Validating the findings from Section 4.5, the participants also commented that they rotated the view more often in the 3D representation compared to the 2D representation. A slightly higher percentage of the participants noted that they counted the floors on the picture more often in the 3D representation. This counting of floors is naturally more apparent in the 3D representation than in the 2D representation. The legend was not used as much in the 3D representation compared to the 2D representation and, finally, it seems that it was more enjoyable, as judged by the participants' ratings, to use the 3D representation rather than the 2D representation.

The stated ratings were further statistically analyzed. As no outliers were present (Appendix 57), no prior corrections of the data were made. A Box-Cox transformation was tested but had no positive effect on the kurtosis or skew of the data. Therefore, no transformation was utilized. Based on the non-normal distribution (see Appendix 58 and Appendix 59), a Wilcoxon-signed rank test confirmed the visual findings – there are indeed significant differences in the stated median agreement by the participants for the number of rotations ($T = 16$, $p = .006$, $r = .307$), the use of the legend ($T = 11$, $p = .004$, $r = -.323$) and the enjoyment ($T = 137$, $p = .016$, $r = .269$). The other categories showed no significant differences (see Appendix 60). These findings were verified by an paired samples-t test as explained in Appendix 61 for the case of rotation and the use of the legend but not for the enjoyment.

Apart from that, the participants were able to mention any related comment if they wished. Those comments are not included in the Results section but are covered in the Discussion.

4.7 Summary

The statistical analysis of the data in the preceding Sections 4.1 to 4.6 on pages 49–79, indicate that most of the participants in this study are around 27 years old and have different and distinctive backgrounds educationally and professionally. Most of the participants were used to 2D representations, albeit a portion were also familiar with 3D representations. Despite the fact that most of the participants seldom participated in Urban Planning (UP) related tasks, they stated strong interest in the topic as well as knowledge about it. For the Mental Rotation Test (MRT) test, a clear difference between women and men was found, though women scored lower than men.

No differences in the percentage of correctly solved tasks dependent on the representation types (2D or 3D) could be found, however, the two tested task types showed differences through higher scores in the *orientation* task than in the *visualization* task. Gender, spatial ability and urban planning expertise had no impact on effectiveness. On an individual task-representation level, the *visualization* task reached slightly (but non significantly) higher scores in the 3D than in the 2D representation, for the *orientation* task it was vice versa, the 2D representation scored higher than the 2D representation. Women reached significantly higher scores in task 2 than task 1.

A similar pattern was seen with the time it took participants to solve the tasks. No significant difference was found for the representations but a clear difference for the two task types. Spatial ability as well as gender and urban planning had a definitive effect – women, participants in the low spatial ability group and non-urban planners took longer to solve the tasks compared to men, participants with a high spatial ability and urban planners.

Participants were similarly confident about their decisions in both representations as well as both task types. Divergent statistical results (see Discussion) were found, but it could be said that women as well as people in the low spatial ability group stated lower confidence values versus men and people in the high spatial ability group. Additionally, urban planners reported higher confidence values than non-urban planners.

Participants interacted more in the 3D representation than in the 2D representation, though no difference was exhibited for the task types or based on gender or spatial ability.

Finally, a higher proportion (over 40%) of the participants preferred the 3D representation over the 2D representation. They used the legend less often in the 3D representation than in the 2D representation, but the former was more often rotated than the latter. A trend towards more enjoyment in the 3D representation can be observed, as well.

5 Discussion

The findings from case study are discussed, first, in respect to the Research Questions postulated in Section 1.2 and, second, in a broader view focused on the representation respectively the task, and, third, in respect to group differences. Some of the results are interesting but not statistically significant, if this is the case it is annotated in the discussion.

5.1 RQ 1 – Visualization

Is there a difference between the representation methods (i.e., 2D representation and oblique aerial views of a 3D representation) in participant performance in representation-to-environment matching *tasks?*

Effectiveness As postulated in Section 1.2, the accuracy for the *visualization* (representation-to-environment) task was slightly higher for the 3D representation than for the 2D representation. This finding would support the statement by many studies in the field of UP (e.g., Wanarat & Nuanwan, 2013, 688 or Drettakis, 2007, 330 and particularly Herbert & Chen, 2015, 29), which propose that a 3D representation is more helpful to understand and imagine (i.e., visualize) a scene. This was also postulated in the working hypothesis. However, the findings in this study are only marginal and not statistically significant, therefore this statement has to be made with caution. But it can be said that the findings are not contradictory to prior research.

In terms of the individual groups, no differences can be reported for gender, urban planning professionals or spatial abilities. This is quite interesting. Apparently the mental transformation to imagine the view in the egocentric view from the top down view (in the 2D representation) was not more difficult to achieve for low spatial performers and there is also no difference in respect to the different representation types. Urban planners, as experts in those task, seem not to perform better than lay participants.

Efficiency It should be noted that the time it took the participants to solve the task was not one of the main interests within this study. Both tasks are in most cases not time critical, therefore, the participants solved the tasks not under time pressure. However, the analysis of time data can yield some insight in the performance: when a task is solved correctly and fast, the participant had definitely no problem to solve it, however, when the answers is right but it took the participant a long time, it could be that the participant was either unsure about the solution (see results for the confidence rating) or the task was demanding.

The same pattern as for the effectiveness data can be reported: the visualization task was solved slightly faster in the 3D representation compared to the 2D representation (but not statistically significant). Therefore, the task difficulty (effectiveness) in respect to the complexity (efficiency) is comparable and the interpretation given in Section 5.1 on the preceding page is supported. Additionally, also no between-group differences can be reported.

Confidence The confidence ratings are quite similar, a marginal trend towards higher confidence in the 3D representation can be noted but is statistically not significant. If this trend would be more distinct it would support the statements for example by Herbert and Chen (2015), namely that the 3D representation is easier to imagine. No between-group differences in the confidence, related only to this task, can be reported.

Interaction The pattern of the interaction on a task sub level reveals more interactions in the 3D representation than in the 2D representation. This was expected from the design, mainly based on the oblique aerial view that, in one sense, shows more elements but in the same moment hides everything behind the camera. To see those areas, the user has to rotate the camera. Therefore, interaction is an important element in the 3D representation (Schultz et al., 2008).

5.2 RQ 2 – Orientation

Is there a difference between the representation methods (i.e., 2D representation and oblique aerial views of a 3D representation) in viewer performance in environment-to-representation orientation *tasks?*

Effectiveness Similar to the findings in navigation-research (e.g., Warren, 1994, 88) the self-location and *orientation* task (the self-location was not necessary since the position was given), reached slightly higher scores in the 2D than in the 3D representation. As with the visualization task, this result is in terms of effectiveness not statistically significant. However, the statement from the working hypothesis, that the 2D representation is better suited for the orientation task than for the visualization task, can be supported with a significant difference in respect to the representation: the scores reached in the 2D representation are clearly higher for the orientation task than for the visualization task, therefore, findings from prior research, for example by Coors et al. (2005); Herbert and Chen (2015); Oulasvirta et al. (2009, 2007), can partially be confirmed in terms of task but not definitely in terms of representation – for orientation, a 2D representations seems (at least based on the accuracy) to be more applicable.

Related to the group differences, no effect of spatial ability on the orientation-scores can be reported, contrary to the results by Liben et al. (2010, 125). Urban planners had also similar scores than non-experts. The only finding can be reported for gender; women had in the orientation task higher scores than in the visualization task. Therefore, the problem-solving task seems to be easier for women than the visualization and imagination task.

Efficiency The same pattern as for the effectiveness data can be reported also in the case of the orientation task – the task was solved slightly (but not statistically significant) faster in the 2D representation compared to the 3D representation. The interpretation given in Section 5.1 on page 83 is applicable. In terms of group differences, participants in the high spatial ability group solved this task, somewhat surprisingly, faster in the 3D representation than in the 2D representation. This finding is in line for example with a study by Huk (2006), who reported that participants with high spatial abilities benefit more from 3D models than low spatial performers. He notes that this is maybe because of the fact that low spatial performers are cognitively overloaded with the presence of 3D models (Huk, 2006, 392). Therefore, the same can be stated here. However, also with some caution as spatial ability had only an effect on the time it took the participants to solve the task but not on the effectiveness.

Confidence The confidence ratings are quite similar, a marginal trend towards higher confidence in the 2D representation can be noted. No between-group differences in the confidence related only to this task can be reported.

Interaction The pattern of the interaction on this task sub level reveals more interactions in the 3D representation than in the 2D representation. This is, as mentioned in the case of effectiveness, not unexpected.

5.3 Task – General Discussion

The two tested tasks are both equally valid in map-reading, however, they were discussed separately in the previous subsections because they are not interchangeable. As postulated in the working hypothesis, the tasks result in different performance depending on the representation type used. However, both tasks can also be investigated irrespective of the representation used giving new insights.

Effectiveness It emerges that the orientation task resulted in higher scores than the visualization task. Following this finding, the more problem-solving oriented task where cues (Davies & Peebles, 2007, 140) were matched from the environment to the representation, is simpler than the visualization task that is more focused on the cognitively demanding mental transformation from the representation to the environment. This finding was, with reference to the literature, expected.

With respect to group differences, the two tasks are in terms of experience (UP), gender and especially spatial ability similarly demanding, this is a bit a surprising finding as it was expected that the more on mental rotation focused task (visualization) is related to the spatial ability of a participant.

Efficiency When both tasks are grouped together, the orientation task was solved faster than the visualization task. This finding was also expected since the visualization task is cognitively more demanding than the simple orientation task.

Some group differences can be reported: overall, low spatial performer had longer to solve the tasks than high spatial performer. This finding is hardly surprising and is in line for example with Liben et al. (2010). On a sub level, some interesting findings can be revealed: low spatial performers solved the orientation task faster in the 2D representation than the visualization task but there was no difference within the 3D representation for the two tasks. This finding supports also the problem of low spatial performers with 3D models (see Huk (2006)) as the (cognitively) more demanding visualization task was solved slower than the simpler orientation task in the 2D representation but this difference was not present in the 3D representation.

Confidence Overall, the confidence ratings for the two task types were similar. Additionally, no between-group differences were found.

Interaction Only marginal differences in respect of the task can be reported, slightly more interactions, but not statistically significant, were performed in the orientation task. In respect of group differences, only one difference was found, urban-planners interacted in the orientation task more than in the visualization task, whereas it was vice versa for non-urban planners.

5.4 Representation – General Discussion

Effectiveness The representations can also be investigated irrespective of the tasks. In this case, no difference can be found between the 2D and the 3D representation. Therefore, both are equally valid if the tasks are considered together.

The same findings as for the case of the task in terms of group differences is also true for the representation: the results indicate that 2D and 3D representations are similarly difficult.

Efficiency The tasks were solved in both representations in nearly the same amount of time, therefore, both types are similarly difficult. Additionally, no between-group differences can be reported.

Confidence Overall, the confidence ratings for the two representation types were similar. However, on a sub level, the confidence ratings stated for the 2D representation were higher for the orientation task than for the visualization task, this holds not true for the 3D representation. This finding is again confirming the general trend that 2D representations are more suitable than the 3D representation for the orientation task.

Group differences were found in respect to spatial ability: low performer were similar confident in the 3D representation but in the 2D representation more confident when solving the orientation compared to the visualization task. High spatial ability participants stated similar confidence in the 2D representation for both task types but were more confident in the visualization task than in the orientation task in the 3D representation. This finding supports again the hypothesis of the cognitive overload that affect low spatial persons when using 3D models according to Huk (2006).

Interaction As expected from the design and already stated, the 3D representation had more interactions than the 2D representation. No between-group differences were present.

5.5 General Discussion – Between-group differences

Effectiveness The score reached by participants overall is similar irrespective of gender, UP-professional or spatial ability.

Efficiency Overall, women had longer to solve the tasks. This could be because women found the task more difficult than men, this would imply that their accuracy was fairly high but they had longer to find the right solution. Another, and maybe more reasonable cause can be found when this result is interpreted together with the confidence-statements. As women were less-confident in solving the tasks they may were also longer reasoning about the right solution, and therefore the solving-time was extended. This is irrespective of the accuracy. It is widely accepted that women are in general less-confident than men, irrespective if the solution to a question is right or wrong (see for example Lundeberg, Fox, and Punćcohaŕ (1994)).

Additionally, urban planners were faster to solve the orientation task than non-urban planners. This was expected since urban planners should be used to the presented representations and the orientation task is quite common, therefore, this finding is not surprising but contributes to the validity of the case study.

A quite weak but still statistically significant effect was found for spatial ability (median split): participants in the low spatial ability group were slower in solving the tasks than participants in the high spatial ability group. This finding is also not surprising since it was expected that the mental transformation and the cue matching can be performed faster by people with a good spatial ability and thus the findings from Liben et al. (2010) or also Huk (2006) can be confirmed.

Confidence The statistical results are partially difficult to interpret. But overall it can be stated that women and low spatial performers stated lower confidence. This finding is, as noted before, not surprising. Both groups had also longer to solve the task and it is meaningful that there is an interaction between confidence and time for reasoning about a solution.

Contrary, urban planners reported higher confidence ratings than non-urban planners. This finding is expected as urban planners are used to the representations shown and the topic is nothing new for them.

Interaction No difference can be found in respect to gender, UP or spatial ability.

5.6 Preference

Is there a difference in participants' preferences between the tested representations? The participants stated in the questionnaire a preference towards the 3D representation. Additionally, some differences in the use of the features provided within the web viewer (legend, interactivity) were found. The preference of 3D representations over 2D representations by the user is in accordance with the literature (e.g., Smallman and St. John (2005)). Apart from the questionnaire with a 5-point Likert scale, participants were able to state any comment related to the representations and a short interview was conducted. Those two elements, despite they were not formally analyzed, give a suitable and helpful insight in the mind of the user and help to interpret the quantitative data from the case study.

Statements by the Participants The advantages and disadvantages of 3D representations as given in Section 2.2 on page 7 were also brought up by the participants. Irrespective of the task type, they mentioned often, related to the 3D representation that: "this is nearer to reality", "occludes other elements", "additional content (building height) visible and it is not necessary to consult the legend", "visually pleasing", "the shape of the building is easier to recognize", "easier to imagine the surrounding", "rotation reveals clearly where the buildings are", "easier to interpret", "gives more confidence", "difficult if the details are not exactly shown in the representation", "in theory simpler, but due to the perspective sometime bewildering", "difficult because of the orientation in space". And, towards the 2D representation: "mental rotation in the ego-perspective is difficult", "better overview", "simpler orientation", "familiar map", "faster".

5.7 Limitations of the Study

As in most studies, also this project has some limitations that should be shortly discussed:

Task Design The visualization and a self-location or orientation tasks are common in navigation research and, as the two map reading tasks necessary to understand the scene incorporate those tasks, it was straightforward to use this two tasks. The detailed design of the tasks was carefully evaluated from literature. The self-localization task by Warren et al. (1986) and the one by Liben et al. (2010) incorporated no position on the map and resulted in quite a low scoring and therefore a floor effect was present in those studies. The solution with a given position and a field of view was incorporated. Therefore, the visualization task was simplified to the point that the mental transformation from the representation to the scene has still to be done, but it was clear where the photographer has taken the image and in which direction he was facing. The orientation task has several field of views oriented around the given position. This solution was tested with three pilot-runs and it was also discussed if the solution is too simple and some other ideas for the task design were tested. Finally, it was decided that the task should be solvable and that therefore the used representation of the orientation is appropriate. However, as visible in the result, the study has in terms of the effectiveness a ceiling effect, this could imply that the task was in the end too simple. This weakness lead to another issue.

Statistics Based on the ceiling effect, a strongly skewed distribution of the data resulted. This is for statistical analyses not optimal. However, the used approach with several statistical analysis revealed that the result is robust. Only in the case of the confidence data, the analysis was not straightforward and resulted in somewhat diverging results.

Another drawback of the ceiling effect was, that not all intended statistical analysis were possible. For example, the literature stated a strong alignment effect. The alignment (i.e., is the view of the map oriented to the represented scene) was also recorded during the study and a clear alignment can be reported, however, statistical analysis was not possible as the ceiling effect resulted in meaningless calculations with the χ^2-test incorporated, therefore, those results are not shown.

Representations As apparent from the literature review, cartography is already versatile. The incorporation of the 3D-element expands this field on, at least, one dimension. We believe that the decisions made and described in the Methods section are valid and grounded on theory, but it is clear that for the 2D as well as for the 3D representation other, maybe better suitable, solutions are possible. To name only one topic: The viewing angle for the camera in a 3D representation has to be carefully evaluated as there are nearly no fixed guidelines available (apart from Häberling et al., 2008).

Another aspect of the representation is the scene shown. As an real environment was used within this study (otherwise no real images can be incorporated and the idea should also be applicable), it is not possible to keep the information content within the different locations constant. An evaluation of the four used locations showed that three locations had extremely similar results but one location has slightly lower scores overall. Therefore, one location seems not to have the exact same information content as the others. Another reason could be that the used images were not equally difficult to mach to the environment.

Mental Rotation Test and Spatial Ability As shown by Hegarty and Waller (2004, 175), spatial ability can be measured with mental rotation tests. However, there are differences in terms of perspective taking ability and mental rotation itself. The orientation task within the study is maybe more related to the perspective taking test. However, Hegarty and Waller (2004) showed that those tests are highly correlated. Therefore, only the MRT was used. An additional remark regarding to the MRT should be made that the incorporated test setting (time limit or not as well as the scoring system) can result in different results, see (Goldstein, Haldane, & Mitchell, 1990; Peters, 2005; Peters et al., 1995; Voyer, 1997).

As described, spatial ability groups were created with two approaches, the median split and the extreme group approach. According to theory, the extreme group approach can be used to reveal also weaker differences. In the case of this study, however, the extreme group hat sometimes weaker results than the median split group despite the fact that the contrary was expected. Based on those two statements, the findings related to the spatial ability should be interpreted with caution.

Participants Most of the participants are around the same age and had some connection to an university, a lot also to geography, therefore, it is questionable if the results can be generalized to a wider public. Additionally, only eight person were urban planners, the results in the group differences are therefore weak.

The web viewer Despite the fact that literature sometimes states that today computer technology is not a boundary, there are a lot of limitations when a technology-based approach is used. Many limitations had to be considered and the development of the web viewer was time consuming.

Eyetracking Connected to technology and their limitations, the eyetracker needs to be mentioned. Data analysis was not possible with reasonable effort because of the software design incorporated in Tobii Studio. This is mainly due to the interactivity used within the web viewer (i.e., rotation). Of course, the eyetracker data would be interesting to interpret, but this would need another setup.

6 Conclusion

This study provided an overview over the research in 3D representations. Such 3D representations are a clear trend in the last years. Apart from other fields, they are particularly popular in Urban Planning (UP), where it is often claimed that this representations facilitate the imagination of a proposed design by the public. However, the legally accepter form of representation is so far still the 2D zoning plan. To understand such a plan, regardless of whether it is a 2D or a 3D representation, it is necessary to imagine how the depicted representation will look like in reality. This task is basically a well-known map-reading task, namely visualization, and, in a second step, self-localization with orientation in the scene. To derive insight which representation type, a classic 2D zoning plan or a modern 3D zoning plan with an oblique aerial view, works better in terms of visualization and orientation, a user study was conducted. For this user study, the representations were developed in an online 3D globe. 40 participants tested the system to derive insights if a 2D representation or a 3D representation is more suitable for the visualization as well as the orientation task. The measurements include effectiveness, efficiency, confidence, interaction and personal preference. The results indicate that both representation types are applicable as the participants showed a good performance. However, as it is often the case in cartography, the most suitable representation is task dependent. For the visualization-task, this means the representation-to-environment matching (Lobben, 2004, 277), the 3D representation seems overall to be more suitable than the 2D representation. However, the difference to the 2D representation is only marginal. On the other hand, the performance within the orientation task, this means the environment-to-representation matching (Lobben, 2004, 277) was slightly better with the 2D representation. Additionally it is important to keep in mind that representation types are not suited more for one task or another, but that there are also difference in terms of the user. The study has shown that participants with a low spatial ability according to the Mental Rotation Test (MRT) were slower in solving the task than participants with a good spatial ability. Additionally, low spatial performers were struggling with the 3D representation, this finding is align with Huk (2006), who noted that this could be due to cognitive overload. Additionally, gender differences were found in terms of spatial ability (men have a higher spatial ability than women) as well as confidence ratings (men were more confident than women). Some effects were also found in terms of expertise with the topic of urban planning. However, the influence on the performance was only marginal and performance was overall excellent.

In line with other research (e.g., Lai et al., 2010), a preference by the users towards the more realistic and visually pleasing 3D representation can be mentioned. However, contrary to findings by Smallman and St. John (2005), naïve realism was not an issue within this study. This could be since the 3D representation was not photo-realistic but represented in a more abstract form that avoided clutter and ambiguity or other distractors as far as possible. To sum it up, this study introduced a full functional prototype of a 3D web viewer based on Cesium and evaluated two different representations, a 2D as well as a 3D, presented within this web viewer. Contrary to other studies, the 3D representation resulted in this study not in general worser performance by the participants, but it was also not better. Therefore, the gain in the use of a 3D zoning plan in this case seems to be particularly in the enjoyment and motivation of the users, whilst the performance is not affected.

However, there are many fields open and a lot of questions seek for an answer. Future research should for example be directed towards a better taxonomy of 3D cartography, a field that seems still to be technology-driven and not by user-needs. With 3D representations, way more dimensions have to be considered, it is not just the z-axis. Questions related to different levels of realism, interactivity or perspective view seem to be still unanswered.

List of Abbreviations

ASTER Advanced Spaceborne Thermal Emission and Reflection Radiometer

ANOVA Analysis of Variance

ART Aligned Rank Transform

CLT Central Limit Theorem

CSS Cascading Style Sheet

DSM Digital Surface Model

EML Eye Movement Recording Lab

EU-DEM Digital Elevation Model over Europe

GDEM Global Digital Elevation Model

GEE Generalized Estimating Equation

GIS Geographic Information System

GIUZ Institute of Geography University of Zurich

GLM Generalized Linear Model

HTML Hypertext Markup Language

ICA International Cartographic Association

LBS Location Based Services

MRT Mental Rotation Test

OSM Open Street Map

SPSS IBM Statistical Package for the Social Sciences

TMS Tile Map Service

UP Urban Planning

REML restricted maximum likelihood

RT Rank Transform

SRTM Shuttle Radar Topography Mission

VE Virtual Environment

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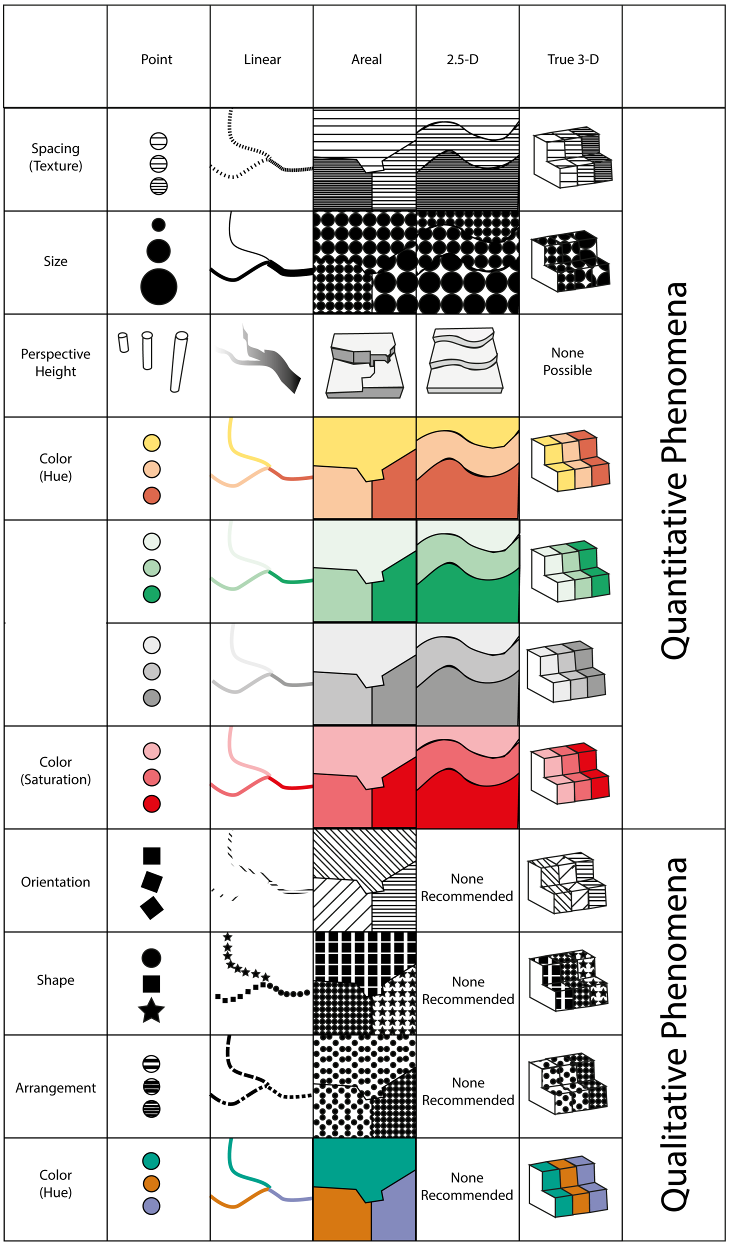
Appendix

1. Visual variables

(Source: Own illustration after Slocum et al. (2009, 82f)



2. Consent form for the study given to the participants

Universität Zürich - **Teilnehmendeninformation und Einwilligungsformular** Evaluierung von 2D/3D-Geovisualisierungen: Eine Fallstudie mit Augenbewegungsanalyse
. Juni 2015
Teilnehmendennummer:

Zweck der Studie

Sie sind eingeladen, an einer Studie über die Evaluation von interaktiven digitalen 2D- und 3D Visualisierungen teilzunehmen. Wir möchten dabei Informationen über die Gestaltung und Benutzerfreundlichkeit von interaktiven digitalen Visualisierungen gewinnen.

Ablauf der Studie und damit verbundene Risiken

Falls Sie sich entscheiden an der Studie teilzunehmen, füllen Sie zuerst einen kurzen Fragebogen aus, in dem Sie unter anderem Angaben zu Ihrer Person machen. Im Anschluss daran werden Sie gebeten einige Aufgaben am Computer zu lösen. Dazu benützen Sie eine vorgegebene digitale Visualisierung. Währenddessen wird Ihre Interaktion mit dem Computer mit Hilfe einer Kamera, eines Mikrofons, eines Blickregistrierungssystems sowie eines Maus-Loggers aufgezeichnet. Das Blickregistrierungssystem ermöglicht es, Ihre Augenbewegungen ohne jeglichen Körperkontakt aufzuzeichnen. Dazu wird nicht sichtbares Licht im nahen Infrarotbereich verwendet das keine unangenehmen Auswirkungen hat. Nach der Aufzeichnung werden Sie einen zweiten Fragebogen ausfüllen.

Der Versuch dauert ungefähr 60 Minuten und beinhaltet keinerlei Risiken für Sie.

Vertraulichkeit der Daten

Jegliche Information, die während der Studie in Verbindung mit Ihnen gebracht werden kann, wird vertraulich behandelt und nur mit Ihrer ausdrücklichen Erlaubnis an Dritte weitergegeben. Mit Ihrer Unterschrift erlauben Sie uns, die Ergebnisse des Versuchs mehrmals zu publizieren. Dabei werden keinerlei Informationen veröffentlicht, die es ermöglichen, Sie zu identifizieren.

Abfindung

Wir bieten keine Entschädigung für die Teilnahme an der Studie an. Auch Kosten, die Ihnen für die Teilnahme an der Studie entstehen, werden nicht erstattet.

Bekanntgabe der Ergebnisse

Wenn Sie über die Ergebnisse der Studie auf dem Laufenden gehalten werden möchten, bitten wir Sie, dem Versuchsleiter Ihre Anschrift zu hinterlassen. Eine Kopie der Publikation(en) wird Ihnen daraufhin zugestellt.

Einwilligung

Ihre Entscheidung, an der Studie teilzunehmen oder nicht, wird etwaige zukünftige Beziehungen mit der Universität Zürich nicht beeinträchtigen. Entscheiden Sie sich dafür, an der Studie teilzunehmen, steht es Ihnen jederzeit frei, die Teilnahme ohne Begründung abzubrechen.

Sollten Sie Fragen haben, zögern Sie bitte nicht, uns diese zu stellen. Sollten zu einem späteren Zeitpunkt Fragen aufkommen, wird Dr. Arzu Coltekin (044 635 54 40, arzu@geo.uzh.ch) diese gerne beantworten.

Sie erhalten eine Kopie dieses Dokuments.

Universität Zürich - **Teilnehmendeninformation und Einwilligungsformular** Evaluierung des Benutzeroberflächendesigns in Geovisualisierungen: Eine Fallstudie mit Augenbewegungsanalyse
. Juni 2015
Teilnehmendenummer:

Mit Ihrer Unterschrift bestätigen Sie, oben stehende Informationen gelesen und verstanden zu haben und willigen ein, unter den dort beschriebenen Bedingungen am Experiment teilzunehmen.

…………………………………… ……………………………………

Unterschrift der teilnehmenden Person — Unterschrift des Experimentleiters

…………………………………… Martin Zahner

Vor- und Nachname in Blockschrift — Vor- und Nachname in Blockschrift

……………………………………

Ort / Datum

Universität Zürich - **Teilnehmendeninformation und Einwilligungsformular** Evaluierung des Benutzeroberflächendesigns in Geovisualisierungen: Eine Fallstudie mit Augenbewegungsanalyse
. Juni 2015
Teilnehmendennummer:

WIDERRUF DER EINWILLIGUNG

Hiermit möchte ich meine Einwilligung, an der oben beschriebenen Studie teilzunehmen, widerrufen.

…………………………………… ……………………………………

Unterschrift — Ort / Datum

……………………………………

Vor- und Nachname in Blockschrift

Mit dem Widerruf der Einwilligung beeinträchtigen Sie in keiner Weise Ihre Beziehungen mit der Universität Zürich. Der Widerruf kann jederzeit und ohne Angabe von Gründen beantragt werden.

Den Widerruf der Einwilligung bitte an *Dr. Arzu Coltekin, Geographische Informationsvisualisierung und Analyse, Departement für Geographie, Universität Zürich, Winterthurerstrasse 140, 8057 Zürich* senden.

Seite 2 von 2

3. Written protocol used during the experiment

1) Start PC + Monitor and Login
2) Start Eyetracker
3) Close unnecessary tasks (Teamviewer etc.)
4) Open Internet Explorer
5) Delete all History, Cache, Data etc. (Options -> Safety -> Delete browsing History)
6) Load Preloader 1_s, 2_s and 3_s completely + load a second time.
7) Close IE
8) Start Tobii and Load Project (needs some time…)
9) Prepare Mouselogger (until start message appears)
10) Set White Background
11) Light to full power
12) Participant_Number
13) Mobile on Airmode, Mouse + Second Keyboard on Table

---

14) Participant arrives, introduce him to system etc.
    a. Sign: Experiment in Progress
    b. Check if consent form is filled. One copy for Participant, one copy for me.
    c. Tell about the two keyboards and that they will be switched in between.
    d. Ask to switch of mobile phone.
    e. Tell about technology ☺ Be patient
    f. Tell that browser alerts/messages can appear, just click OK or Yes before doing anything else.
    g. Smalltalk.
15) Start Recording -> New Participant and Calibration -> tell that a red circle appears on the upper left -> follow this circle with the eyes.
16) Start mouselogger and then start recording
17) Rotation Intro: Check if the rotate, wait and then rotate again!
18) After Mouse video: Keyboard change
19) After Prequest: Keyboard change + Timer start (Part 1)
20) After Part 1: Timer start (MRT)
21) After MRT: Timer start (Part 2)
22) After think aloud: Keyboard change
23) End, thanks, snack

4. Complete procedure with all questions of the experiment

Hallo

Das Experiment besteht aus verschiedenen Einzelteilen und dauert insgesamt rund 60 Minuten.

Falls Sie generelle Fragen zum Ablauf haben, stellen sie diese bitte jetzt. Andernfalls können Sie mit der F9 Taste auf der Tastatur fortfahren.

Sobald die nächste Darstellung erscheint:

- Schauen Sie auf den blauen Kreis.
- Platzieren Sie den Mauszeiger auf dem gelben Kreis in der Mitte des blauen Kreises.

Bleiben Sie mit dem Mauszeiger und den Augen auf dem blauen Kreis wenn sich dieser bewegt.

Klicken Sie F9 um zu starten.

Gut, wir starten nun mit dem ersten Fragebogen.

Klicken Sie F9.

Teilnehmendennummer
(wird von der Testleitung ausgefüllt)

Weiter

In diesem Fragebogen werden wir verschiedene Fragen bezüglich Ihnen und Ihrer Erfahrung mit verschiedenen Thematiken stellen. Klicken Sie auf «Weiter» um den Fragebogen zu starten, am Ende drücken sie bitte «Beenden».

Weiter

Geschlecht:

- Weiblich
- Männlich

Alter:

Benutzen Sie eine Brille oder Kontaktlinsen?

- Ja
- Nein

Nutzen Sie diese jetzt?

- Ja, Brille
- Ja, Kontaktlinsen
- Nein

Kommentar

Wurde ihnen von einem Arzt o.ä. eine Farbfehlsichtigkeit diagnostiziert?

- Ja
- Nein

Kommentar

Wie viele Stunden haben Sie in der letzten Nacht geschlafen?

Welches ist ihre höchste abgeschlossene Schulbildung?

- Sekundarstufe 1
- Sekundarstufe 2: Gymnasium
- Sekundarstufe 2: Berufslehre
- Pädagogische Hochschule, Fachhochschule, Höhere Fachschule
- Bachelor o.ä.: Universität/ETH
- Master o.ä.: Universität/ETH
- Doktorat o.ä.: Universität/ETH

Kommentar

Bitte bewerten Sie ihre Deutschkenntnisse.

1 Minimales Verständnis	2	3	4	5 Muttersprache
○	○	○	○	○

Bitte bewerten Sie ihre Ausbildung in den folgenden Gebieten:

	1 Keine	2	3	4	5 Professionell
Kartographie	○	○	○	○	○
Raumplanung / Stadtplanung	○	○	○	○	○
GIScience	○	○	○	○	○
Andere Gebiete der Geographie	○	○	○	○	○
Computer Grafik	○	○	○	○	○
3D Computer/video Spiele	○	○	○	○	○
Bildanalyse / Bildinterpretation	○	○	○	○	○
Fotografie	○	○	○	○	○

Bitte bewerten Sie ihre Erfahrung in den folgenden Gebieten:

	1 Keine	2	3	4	5 Professionell
Kartographie	○	○	○	○	○
Raumplanung / Stadtplanung	○	○	○	○	○
GIScience	○	○	○	○	○
Andere Gebiete der Geographie	○	○	○	○	○
Computer Grafik	○	○	○	○	○
3D Computer/video Spiele	○	○	○	○	○
Bildanalyse / Bildinterpretation	○	○	○	○	○
Fotografie	○	○	○	○	○

Wie oft benutzen Sie die folgenden Arten von Visualisierungen?

	1 Nie	2	3	4	5 Täglich
2D Visualisierung (Karte digital oder gedruckt, Plan, andere Grafiken...)	○	○	○	○	○
3D Visualisierung (Stadtmodell, Geländemodell, Software wie Google Earth...)	○	○	○	○	○

Wie oft waren Sie bisher in folgenden Raumplanungs-Aktivitäten involviert?

	1 Nie	2	3	4	5 Täglich
(Online) Diskussion (z.B. Ihre Meinung über einen vorgeschlagenen Plan kommunizieren)	○	○	○	○	○
Workshop Teilnahme (z.B. Einen vorgeschlagenen Plan mit anderen Personen diskutieren)	○	○	○	○	○
Entscheidfindung (z.B. Einem vorgeschlagenen Plan zustimmen oder diesen ablehnen)	○	○	○	○	○

Bitte präzisieren Sie die Aktivitäten.

Wie stark sind Sie an Thematiken der Raumplanung interessiert?

1 Kein Interesse	2	3	4	5 Hohes Interesse
○	○	○	○	○

Kommentar

Wie bekannt ist Ihnen das Raumplanungssystem der Schweiz?

1 Tief	2	3	4	5 Hoch
○	○	○	○	○

Kommentar

Würden Sie sich selbst als Experte/-in in Raumplanung bezeichnen (z.B. arbeiten Sie als Raumplaner/-in)?

○ Ja

○ Nein

Bitte nennen Sie Ihre Berufsbezeichnung und/oder Ihren Arbeitgeber:

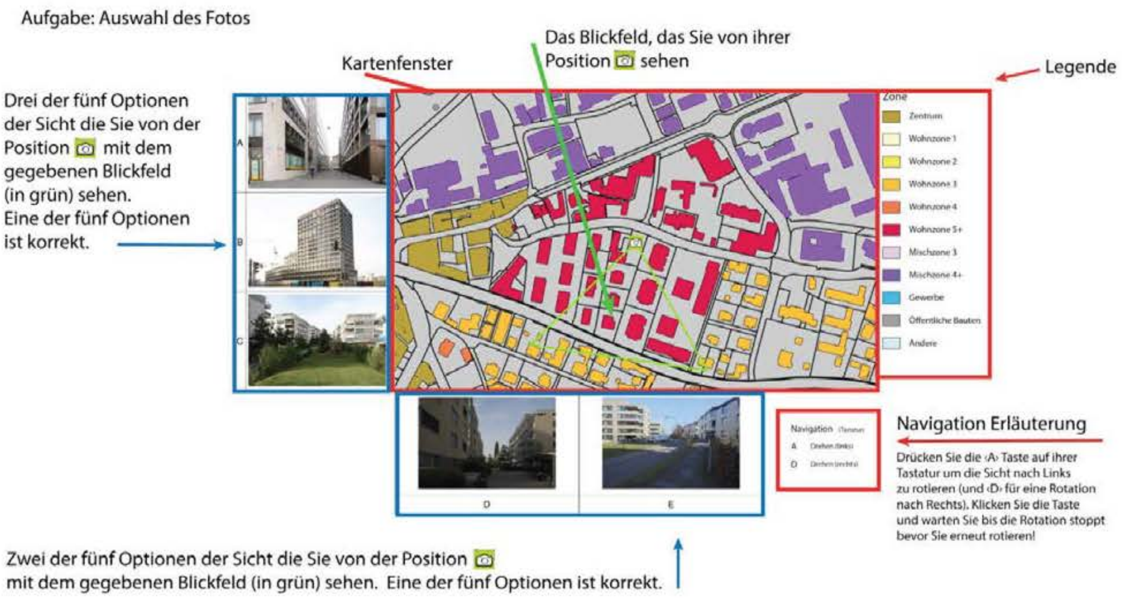
Beenden

Sie haben diesen Abschnitt beendet.

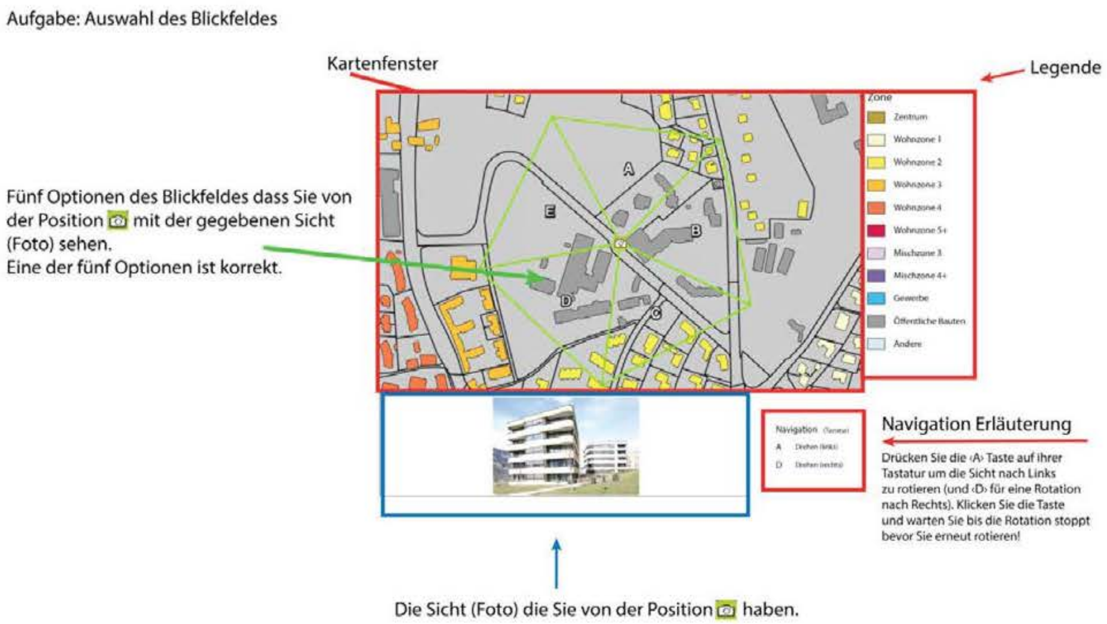
Im nächsten Teil werden Sie 8 Fragen beantworten. Sie haben 12 Minuten Zeit. In der Hälfte der Zeit und eine Minute vor Ablauf der Zeit werden Sie informiert.

Bitte beantworten Sie die Fragen so rasch aber auch so gut wie möglich.

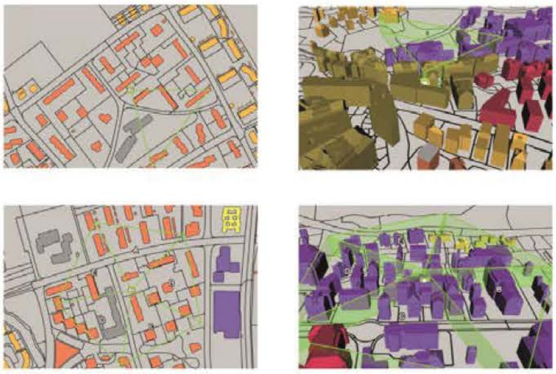
Mit F9 gelangen Sie zu den Test-Erläuterungen.



Klicken Sie F9 um fortzufahren.



Klicken Sie F9 um fortzufahren.



Sie befinden sich an dieser Position und schauen in die Richtung des grünen Blickfeldes.

Wohnzone 2

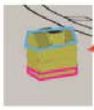
Die Legende hilft Ihnen zu verstehen welcher Typ von Gebäude in der Darstellung zu sehen ist.

- Wohnzonen
- Mischzonen (Wohnen und Gewerbe)
- Gewerbe
- Öffentliche Bauten (Schule, Kirche, Spital...)
- Andere (Landwirtschaft, Forstwirtschaft, undefiniert)

Sofern eine Nummer angegeben ist definiert diese die maximal mögliche Anzahl Stockwerke.

Parzellen Information

Ein Gebäude der Wohnzone 3



Ein Gebäude der Wohnzone 2

Das Teilweise sichtbare Kellergeschoss (hier in pink umrandet) und das Dach (hier blau) zählen nicht als Stockwerk.

Klicken Sie F9 um fortzufahren.

Rotieren Sie die Ansicht mit A (links) und D (rechts). Bitte drücken Sie die jeweilige Taste und warten Sie bis die Rotation beendet ist!

Bitte lesen Sie die verschiedenen Wörter laut vor.

Rotieren Sie die Ansicht mit A (links) und D (rechts). Bitte drücken Sie die jeweilige Taste und warten Sie bis die Rotation beendet ist!

Üben Sie die Rotation auch an diesem Beispiel

Wir starten nun mit dem Test.

Wenn Sie sich für eine Antwort entschieden haben:

- Doppelklicken Sie mit der Maus auf den gewünschten Buchstaben.
- Nennen Sie diesen Buchstaben.

Klicken Sie F9 um zu starten.

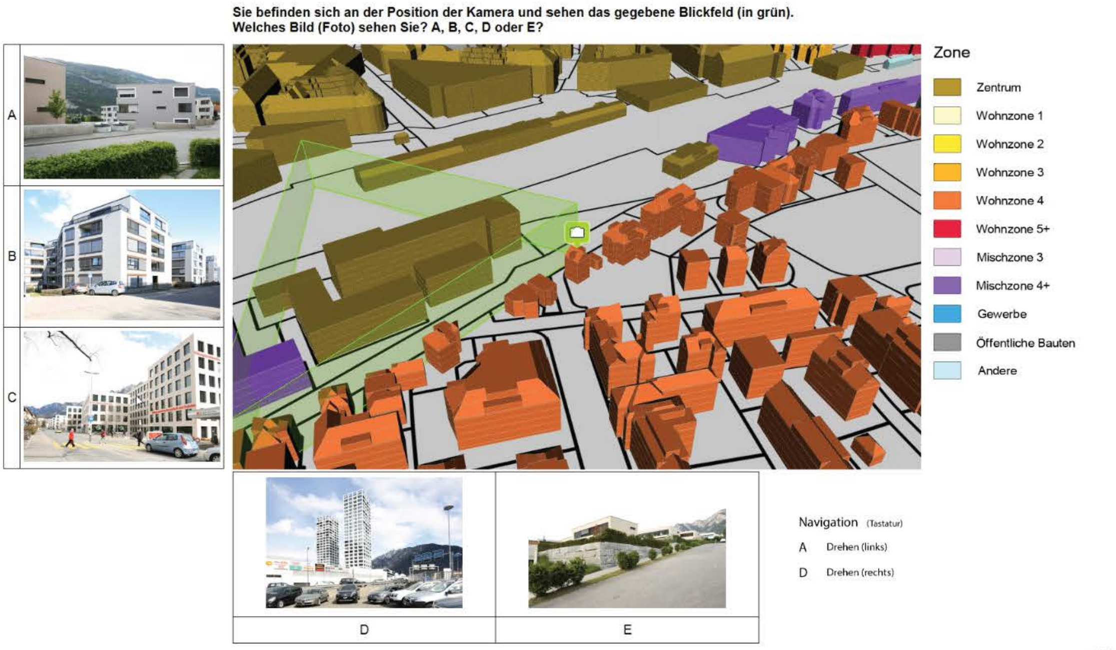

LOADING


Sie befinden sich an der Position der Kamera und sehen das gegebene Blickfeld (in grün).
Welches Bild (Foto) sehen Sie? A, B, C, D oder E?
A
B
C
D
E
Zone
Zentrum
Wohnzone 1
Wohnzone 2
Wohnzone 3
Wohnzone 4
Wohnzone 5+
Mischzone 3
Mischzone 4+
Gewerbe
Öffentliche Bauten
Andere
Navigation (Tastatur)
A Drehen (links)
D Drehen (rechts)
ZTD

Wie überzeugt sind Sie von Ihrer Entscheidung?

- ○ 1 Tief
- ○ 2
- ○ 3
- ○ 4
- ○ 5 Hoch

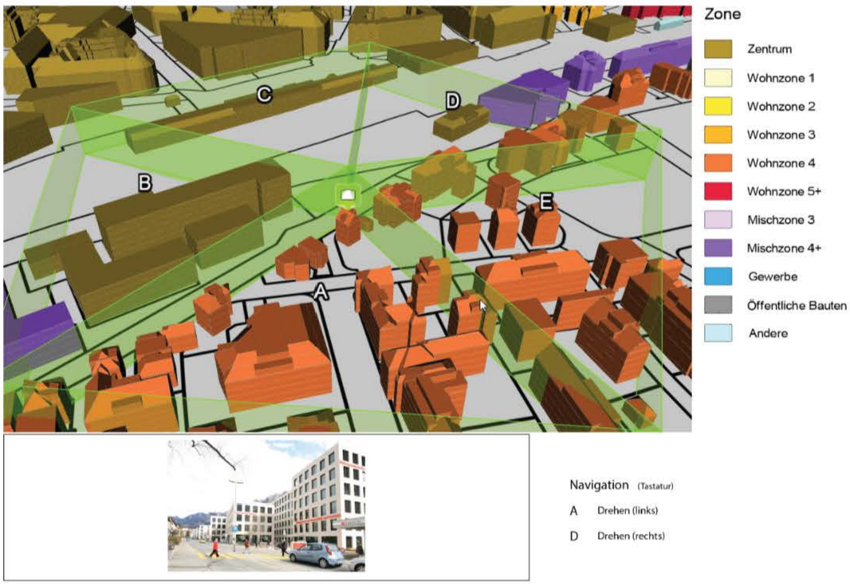
[Finished]



Sie befinden sich an der Position der Kamera mit dem gegebenen Bild (Foto).
Welches Blickfeld (in grün) sehen Sie? A, B, C, D oder E?

2LM

Sie befinden sich an der Position der Kamera mit dem gegebenen Bild (Foto).
Welches Blickfeld (in grün) sehen Sie? A, B, C, D oder E?



AQ2

Sie befinden sich an der Position der Kamera und sehen das gegebene Blickfeld (in grün).
Welches Bild (Foto) sehen Sie? A, B, C, D oder E?

Sie befinden sich an der Position der Kamera und sehen das gegebene Blickfeld (in grün).
Welches Bild (Foto) sehen Sie? A, B, C, D oder E?

Sie befinden sich an der Position der Kamera mit dem gegebenen Bild (Foto).
Welches Blickfeld (in grün) sehen Sie? A, B, C, D oder E?

D3L

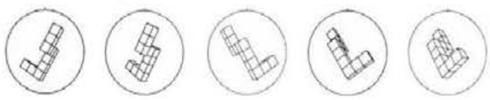
Sie befinden sich an der Position der Kamera mit dem gegebenen Bild (Foto).
Welches Blickfeld (in grün) sehen Sie? A, B, C, D oder E?

P3N

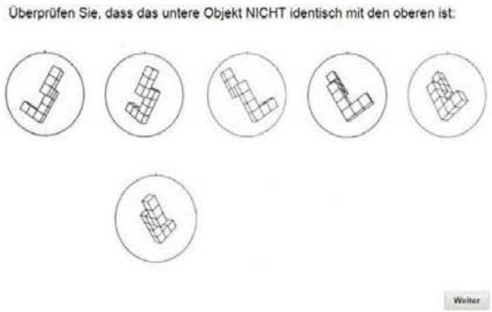
Sie haben diesen Teil beendet.

Klicken Sie F9 um die Einführung in den nächsten Teil zu starten.

In der untenstehenden Abbildung ist dasselbe Objekt in 5 verschiedenen Ansichten abgebildet. Bitte versichern Sie sich, dass es stets dasselbe Objekt ist.



Weiter


Überprüfen Sie, dass das untere Objekt NICHT identisch mit den oberen ist:
Weiter


Bestimmen Sie, welche 2 der 4 Objekte identisch mit dem Objekt im grünen Kreis sind. Stets 2 Objekte sind identisch und 2 sind es nicht. In der untenstehenden Abbildung sind die beiden identischen Objekte bereits markiert. Die anderen beiden Objekte sind gespiegelt oder sonst wie ungleich. Überprüfen Sie dies an den Objekten.
Weiter

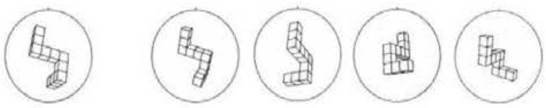

Übungsaufgabe 1
Wählen Sie die beiden Objekte, die identisch mit der linken Figur sind
A
B
C
D
Weiter


Übungsaufgabe 2
Wählen Sie die beiden Objekte, die identisch mit der linken Figur sind
A
B
C
D
Weiter

Übungsaufgabe 3

Wähle die beiden Objekte, die identisch mit der linken Figur sind

☐ A ☐ B ☐ C ☐ D



Weiter

Sehr gut. Klicken Sie nun auf «Beenden» um mit dem effektiven Test zu beginnen.

Fertig

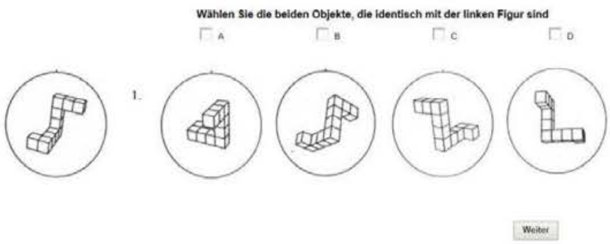
Nummer der teilnehmenden Person.
(wird von der Testleitung ausgefüllt)

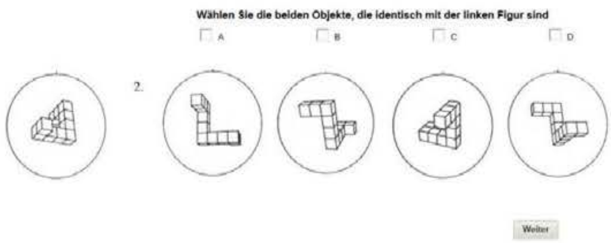
Weiter

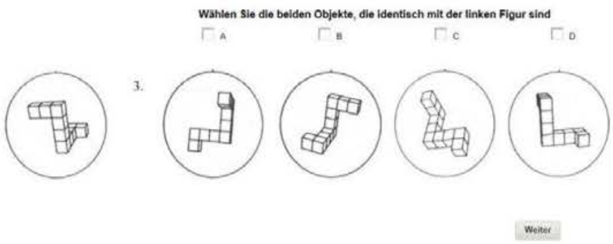
Sie haben insgesamt 6 Minuten um so viele Beispiele wie möglich zu lösen.
Nach 6 Minuten wird die Testleitung den Fragebogen beenden.

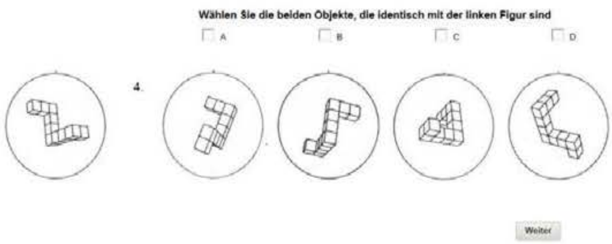
Wenn Sie bereit sind, klicken Sie auf «Weiter», um den Test zu beginnen.

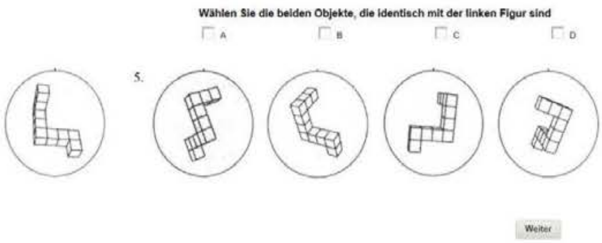
Weiter

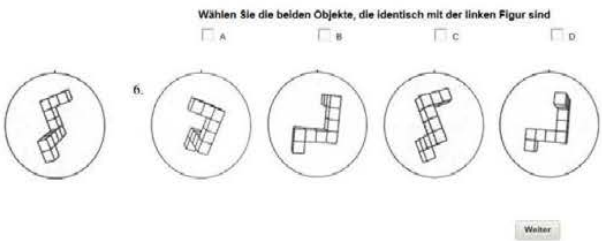

Wählen Sie die beiden Objekte, die identisch mit der linken Figur sind
A
B
C
D
1.
Weiter

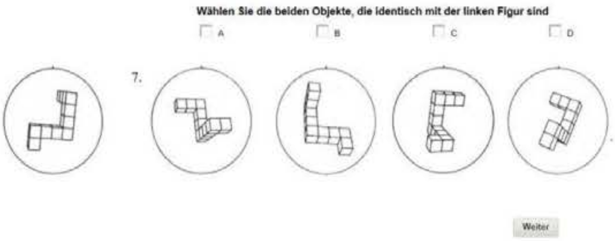

Wählen Sie die beiden Objekte, die identisch mit der linken Figur sind
A
B
C
D
2.
Weiter

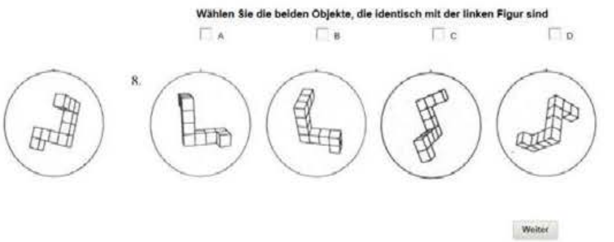

Wählen Sie die beiden Objekte, die identisch mit der linken Figur sind
A
B
C
D
3.
Weiter

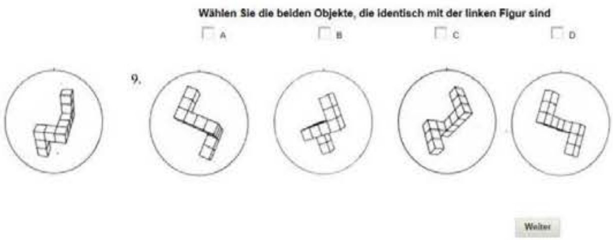

Wählen Sie die beiden Objekte, die identisch mit der linken Figur sind
A
B
C
D
4.
Weiter

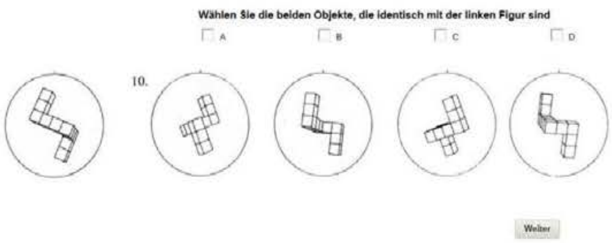

Wählen Sie die beiden Objekte, die identisch mit der linken Figur sind
A
B
C
D
5.
Weiter

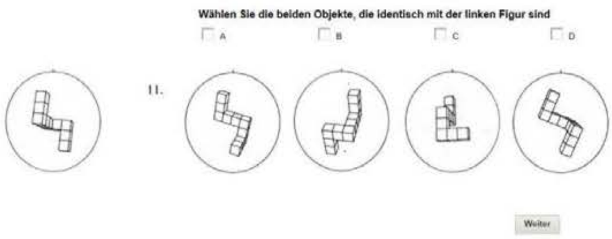

Wählen Sie die beiden Objekte, die identisch mit der linken Figur sind
A
B
C
D
6.
Weiter

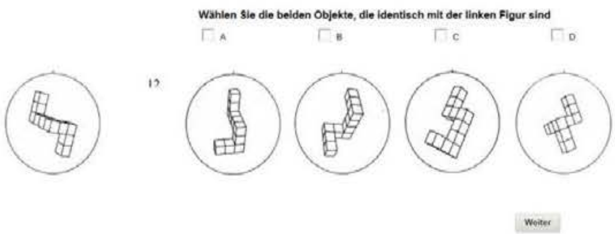

Wählen Sie die beiden Objekte, die identisch mit der linken Figur sind
A
B
C
D
7.
Weiter

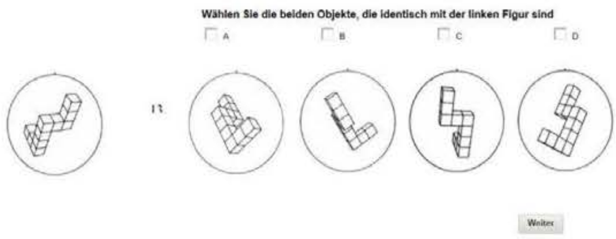

Wählen Sie die beiden Objekte, die identisch mit der linken Figur sind
A
B
C
D
8.
Weiter

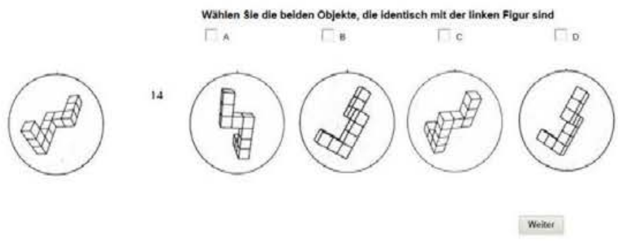

Wählen Sie die beiden Objekte, die identisch mit der linken Figur sind
A
B
C
D
9.
Weiter

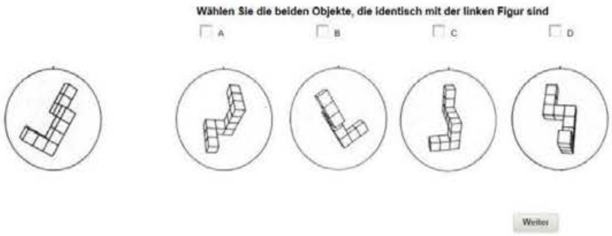

Wählen Sie die beiden Objekte, die identisch mit der linken Figur sind
A
B
C
D
10.
Weiter

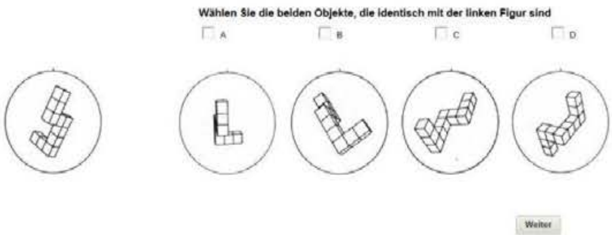

Wählen Sie die beiden Objekte, die identisch mit der linken Figur sind
A
B
C
D
11.
Weiter

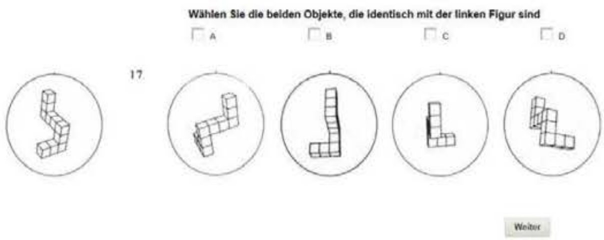

Wählen Sie die beiden Objekte, die identisch mit der linken Figur sind
A
B
C
D
12
Weiter

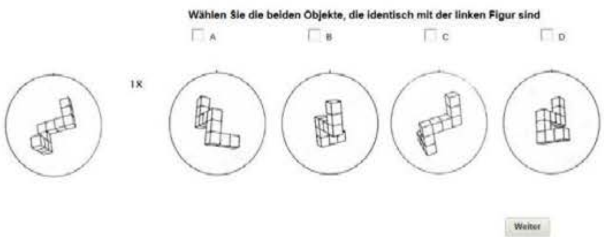

Wählen Sie die beiden Objekte, die identisch mit der linken Figur sind
A
B
C
D
13
Weiter

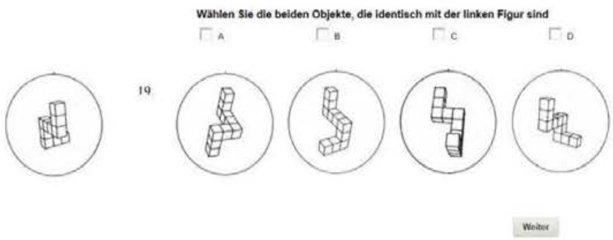

Wählen Sie die beiden Objekte, die identisch mit der linken Figur sind
A
B
C
D
14
Weiter

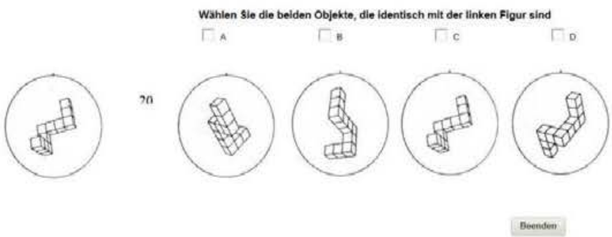

Wählen Sie die beiden Objekte, die identisch mit der linken Figur sind
A
B
C
D
Weiter


Wählen Sie die beiden Objekte, die identisch mit der linken Figur sind
A
B
C
D
Weiter


Wählen Sie die beiden Objekte, die identisch mit der linken Figur sind
A
B
C
D
17
Weiter


Wählen Sie die beiden Objekte, die identisch mit der linken Figur sind
A
B
C
D
18
Weiter


Wählen Sie die beiden Objekte, die identisch mit der linken Figur sind
A
B
C
D
19
Weiter


Wählen Sie die beiden Objekte, die identisch mit der linken Figur sind
A
B
C
D
20
Beenden

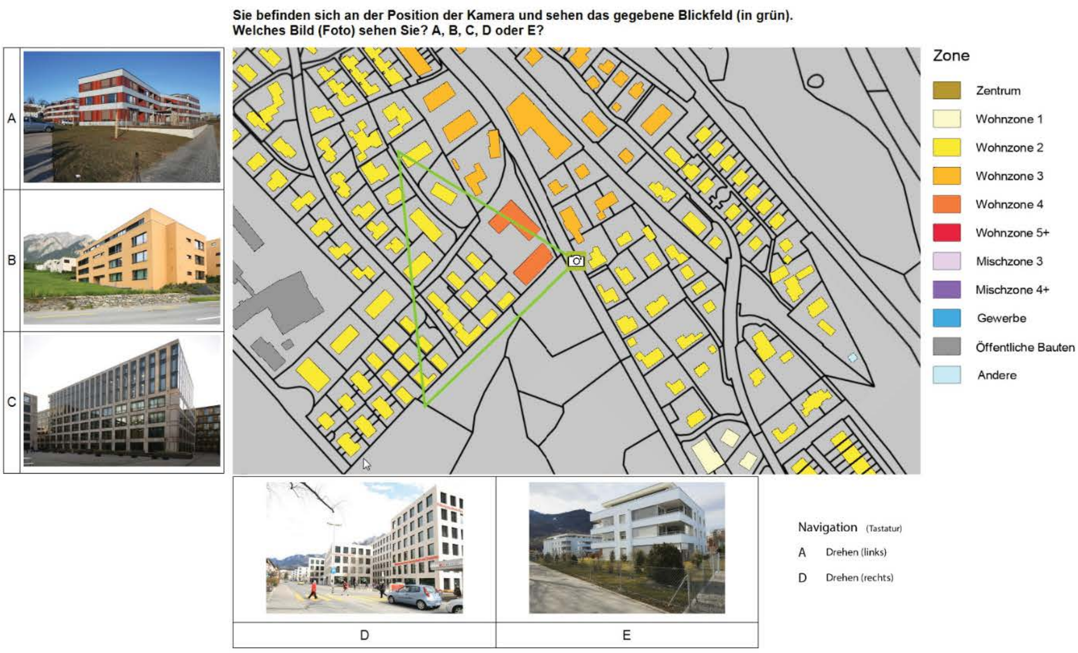
In diesem Teil werden Sie 8 Fragen beantworten. Sie haben 12 Minuten Zeit, in der Hälfte der Zeit und eine Minute vor Ablauf der Zeit werden Sie informiert.

Bitte beantworten Sie die Fragen so rasch aber auch so genau wie möglich.

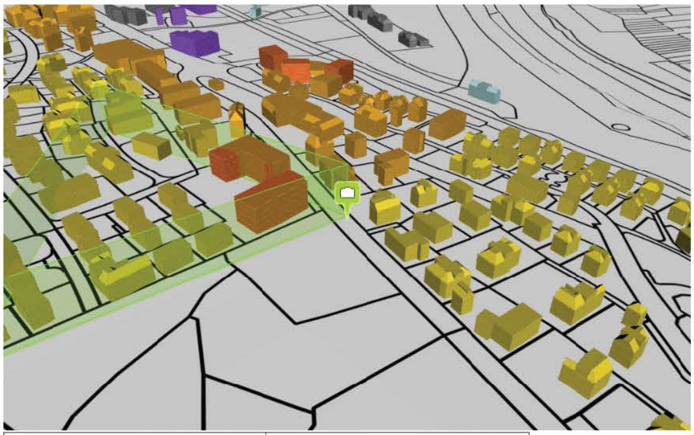
Wenn Sie sich für eine Antwort entschieden haben:

- Doppelklicken Sie mit der Maus auf den gewünschten Buchstaben.
- Nennen Sie diesen Buchstaben.

Klicken Sie F9 um zu starten.



Sie befinden sich an der Position der Kamera und sehen das gegebene Blickfeld (in grün).
Welches Bild (Foto) sehen Sie? A, B, C, D oder E?



Zone

- Zentrum
- Wohnzone 1
- Wohnzone 2
- Wohnzone 3
- Wohnzone 4
- Wohnzone 5+
- Mischzone 3
- Mischzone 4+
- Gewerbe
- Öffentliche Bauten
- Andere

Navigation (Tastatur)

A Drehen (links)

D Drehen (rechts)

Sie befinden sich an der Position der Kamera mit dem gegebenen Bild (Foto).
Welches Blickfeld (in grün) sehen Sie? A, B, C, D oder E?

Zone

- Zentrum
- Wohnzone 1
- Wohnzone 2
- Wohnzone 3
- Wohnzone 4
- Wohnzone 5+
- Mischzone 3
- Mischzone 4+
- Gewerbe
- Öffentliche Bauten
- Andere

Navigation (Tastatur)

A Drehen (links)

D Drehen (rechts)

Sie befinden sich an der Position der Kamera mit dem gegebenen Bild (Foto).
Welches Blickfeld (in grün) sehen Sie? A, B, C, D oder E?

NN6

Sie befinden sich an der Position der Kamera und sehen das gegebene Blickfeld (in grün).
Welches Bild (Foto) sehen Sie? A, B, C, D oder E?

3K5

Sie befinden sich an der Position der Kamera und sehen das gegebene Blickfeld (in grün).
Welches Bild (Foto) sehen Sie? A, B, C, D oder E?

UEH

Sie befinden sich an der Position der Kamera mit dem gegebenen Bild (Foto).
Welches Blickfeld (in grün) sehen Sie? A, B, C, D oder E?

HQD

Sie sehen nun erneut einige Darstellungen mit Fragen.

Sprechen Sie bitte alle Gedanken laut aus die Ihnen durch den Kopf gehen. Beginnen Sie damit, sobald Sie die Darstellung sehen und fahren Sie so lange fort, bis Sie zu einer Entscheidung zur Beantwortung der Frage gelangt sind.

Wenn Sie sich für eine Antwort entschieden haben:

- Doppelklicken Sie mit der Maus auf den gewünschten Buchstaben.
- Nennen Sie diesen Buchstaben.

Klicken Sie F9 um zu starten.

Sie befinden sich an der Position der Kamera und sehen das gegebene Blickfeld (in grün).
Welches Bild (Foto) sehen Sie? A, B, C, D oder E?

Sie befinden sich an der Position der Kamera und sehen das gegebene Blickfeld (in grün).
Welches Bild (Foto) sehen Sie? A, B, C, D oder E?

Sie befinden sich an der Position der Kamera mit dem gegebenen Bild (Foto).
Welches Blickfeld (in grün) sehen Sie? A, B, C, D oder E?

Sie befinden sich an der Position der Kamera mit dem gegebenen Bild (Foto).
Welches Blickfeld (in grün) sehen Sie? A, B, C, D oder E?

Bitte klicken Sie F9 um zum Fragebogen zu gelangen.

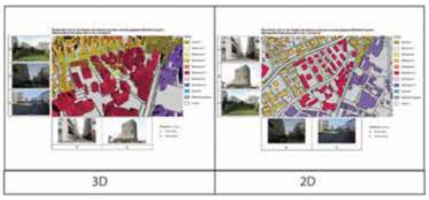
Teilnehmendennummer
(wird von der Testleitung ausgefüllt)

Weiter

Sie haben den Test beendet, wir werden Ihnen nun einige ergänzenden Fragen stellen.

Weiter

In einigen Fragen mussten Sie sich entscheiden, was Sie sehen würden (basierend auf Bild A, B C, D oder E) wenn Sie sich an einer gegebenen Position (markiert mit einer Kamera) befinden und in eine gegebene Richtung (markiert mit einem grünen Blickfeld) sehen würden. Sie haben zwei unterschiedliche Visualisierungs-Arten gesehen, eine 3D Ansicht und eine 2D Ansicht (vgl. Bild).



Welche Visualisierungs Art bevorzugen Sie um ihre Entscheidung zu treffen?

- Keine der beiden
- 2D
- 3D
- Beide sind vergleichbar

Bitte erläutern Sie

Mit welcher Visualisierungs Art war die Aufgabe einfacher?

- 2D
- 3D
- Kein Unterschied

Bitte erläutern Sie

Weiter

In einigen Fragen mussten Sie sich entscheiden in welche Richtung sie sehen (basierend auf grünem Blickfeld A, B, C, D oder E) wenn Sie sich an einer gegebenen Position (markiert mit einer Kamera) befinden und ein gegebenes Bild sehen. Sie haben zwei unterschiedliche Visualisierungs-Arten gesehen, eine 3D Ansicht und eine 2D Ansicht (vgl. Bild).

Welche Visualisierungs Art bevorzugen Sie um ihre Entscheidung zu treffen?

- ○ Keine der beiden
- ○ 2D
- ○ 3D
- ○ Beide sind vergleichbar

Bitte erläutern Sie

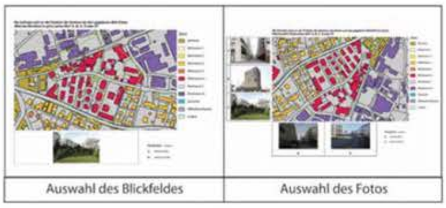
Mit welcher Visualisierungs Art war die Aufgabe einfacher?

- ○ 2D
- ○ 3D
- ○ Kein Unterschied

Bitte erläutern Sie

Weiter

Bitte bewerten Sie die folgenden Aussagen zur 2D Darstellung.



Bitte bewerten Sie die 2D Darstellung.

	1 starke Ablehnung	2	3	4	5 starke Zustimmung
Die Darstellung hat mir geholfen die Aufgaben zu lösen	○	○	○	○	○
Ich habe den Inhalt der Visualisierung verstanden	○	○	○	○	○
Ich habe oft die Darstellung rotiert	○	○	○	○	○
Ich habe oft die Stockwerke auf dem Foto gezählt	○	○	○	○	○
Ich habe oft die Stockwerke in der Visualisierung gezählt	○	○	○	○	○
Ich habe oft die Legende verwendet	○	○	○	○	○
Es hat Spass gemacht die Visualisierung zu nutzen	○	○	○	○	○

Kommentar

Weiter

Bitte bewerten Sie die folgenden Aussagen zur 3D Darstellung.

Bitte bewerten Sie die 3D Darstellung.

	1 starke Ablehnung	2	3	4	5 starke Zustimmung
Die Darstellung hat mir geholfen die Aufgaben zu lösen.	○	○	○	○	○
Ich habe den Inhalt der Visualisierung verstanden.	○	○	○	○	○
Ich habe oft die Darstellung rotiert.	○	○	○	○	○
Ich habe oft die Stockwerke auf dem Foto gezählt.	○	○	○	○	○
Ich habe oft die Stockwerke in der Visualisierung gezählt.	○	○	○	○	○
Ich habe oft die Legende verwendet.	○	○	○	○	○
Es hat Spass gemacht die Visualisierung zu nutzen.	○	○	○	○	○

Kommentar

Weiter

Wie viele verschiedene Örtlichkeiten / Lokalitäten (Nachbarschaften) haben Sie insgesamt während den Tests (inklusive dem abschliessenden Test als Sie das Vorgehen kommentierten) betrachtet?

Weiter

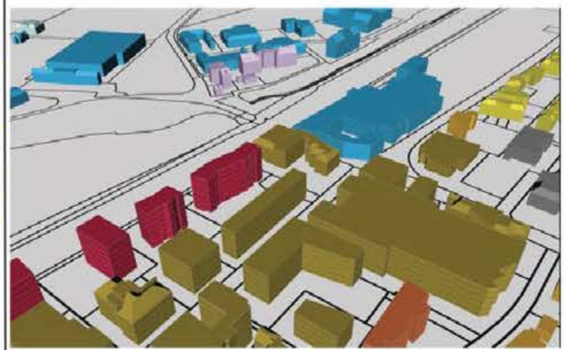
Weitere Kommentare:

Beenden

Bitten warten Sie nun auf weitere Instruktionen.


Zone
Zentrum
Wohnzone 1
Wohnzone 2
Wohnzone 3
Wohnzone 4
Wohnzone 5+
Mischzone 3
Mischzone 4+
Gewerbe
Öffentliche Bauten
Andere
Navigation (Tastatur)
A Drehen (links)
D Drehen (rechts)


Zone
Zentrum
Wohnzone 1
Wohnzone 2
Wohnzone 3
Wohnzone 4
Wohnzone 5+
Mischzone 3
Mischzone 4+
Gewerbe
Öffentliche Bauten
Andere
Navigation (Tastatur)
A Drehen (links)
D Drehen (rechts)

	
2D	3D

Besten Dank für Ihre Zeit.

Bittte beenden Sie mit F9.

5. Code example of a 2D representation in Cesium (for task type 1)

```
<!-- 2D Chur 1 - 1-->
<!DOCTYPE html>
<html lang="en">
<head>
  <!-- Use correct character set. -->
  <meta charset="utf-8">
  <!-- Tell IE to use the latest, best version (or Chrome Frame if pre-IE11). -->
  <meta http-equiv="X-UA-Compatible" content="IE=Edge,chrome=1">
  <title>Location</title> <!--1-->
  <!-- Loads Cesium Library -->
  <script src="../../../../Cesium/Build/Cesium/Cesium.js"></script>
  <!-- CSS Styling of the Site -->
  <link href="../../../Web/styles/styles2.css" type="text/css" rel="stylesheet">
  <style>
      @import url(../../../../Cesium/Build/Cesium/Widgets/widgets.css);
      @import url(../../../../Cesium/Build/Cesium/Widgets/BaseLayerPicker
/BaseLayerPicker.css); /* loads the widget for the baseLayer Picker; this is with a div
set to the background. Only necessary due to a bug in cesium 1.9*/
  </style>
</head>
<body>
  <div id="wrapper">
    <div id="loading_screen" style="visibility:visible">  <!-- loading screen -->
         <article class="preloader">
            <header><h1>LOADING</h1></header>
            <section class="satelite"></section>
            <section class="earth day"></section>
         </article>
    </div>
    <!-- to have exactly the same color in the legend it is necessary to create a
legend in Cesium from .geojson-->
    <div id="legende">  <!-- to have exactly the same color in the legend it is
necessary to create a legend in Cesium from .geojson-->
        <script>
        var viewerx = new Cesium.Viewer('legende', {
        baseLayerPicker: false, //not load the basic baseLayerPicker; a manual one is
loaded afterwards
        animation: false,
        fullscreenButton: false,
        geocoder: false,
        homeButton: false,
        infoBox: false,
        sceneModePicker: false,
        selectionIndicator: false,
        timeline: false,
        navigationHelpButton: false,
        navigationInstructionInitiallyVisible: false,
        imageryProvider: false, //necessary due to a bug in C 1.9 (avoids load of bing
maps)
        targetFrameRate: 20,
      });
        //Some styling
      viewerx.scene.globe.baseColor = Cesium.Color.WHITE; //set Color for Background
      //Defines viewing options (center, distance etc.)
      viewerx.scene.globe.maximumScreenSpaceError = 1;
      var centerx = Cesium.Cartesian3.fromDegrees(-0.1626, 44.89154);
      var headingx = Cesium.Math.toRadians(0.0);
      var pitchx = Cesium.Math.toRadians(-90.0);
      var rangex = 400.0;
      viewerx.camera.lookAt(centerx, new Cesium.HeadingPitchRange(headingx, pitchx,
rangex));
      //Options for lightning
      var scenex = viewerx.scene;
      scenex.skyBox = scenex.skyBox.destroy();
      scenex.skyAtmosphere = scenex.skyAtmosphere.destroy();
      scenex.sun = scenex.sun.destroy();
      scenex.moon = scenex.moon.destroy();
      scenex.screenSpaceCameraController.enableRotate = false;
      scenex.screenSpaceCameraController.enableTranslate = false;
      scenex.screenSpaceCameraController.enableZoom = false;
      scenex.screenSpaceCameraController.enableTilt = false;
      scenex.screenSpaceCameraController.enableLook = false;
      viewerx.entities.add({
        position : Cesium.Cartesian3.fromDegrees(-0.1625, 44.89013),
        label : {
            text : 'Andere                    ',
```

```
            fillColor : Cesium.Color.BLACK,
            scale: 0.6,
            horizontalOrigin : Cesium.HorizontalOrigin.CENTER,
            verticalOrigin : Cesium.VerticalOrigin.CENTER
        }
    });
      viewerx.entities.add({
        position : Cesium.Cartesian3.fromDegrees(-0.1625,44.89043),
        label : {
            text : 'Öffentliche Bauten',
            fillColor : Cesium.Color.BLACK,
            scale: 0.6,
            horizontalOrigin : Cesium.HorizontalOrigin.CENTER,
            verticalOrigin : Cesium.VerticalOrigin.CENTER
        }
    });
      viewerx.entities.add({
        position : Cesium.Cartesian3.fromDegrees(-0.1625, 44.89073),
        label : {
            text : 'Gewerbe               ',
            fillColor : Cesium.Color.BLACK,
            scale: 0.6,
            horizontalOrigin : Cesium.HorizontalOrigin.CENTER,
            verticalOrigin : Cesium.VerticalOrigin.CENTER
        }
    });
    viewerx.entities.add({
        position : Cesium.Cartesian3.fromDegrees(-0.1625, 44.89103),
        label : {
            text : 'Mischzone 4+        ',
            fillColor : Cesium.Color.BLACK,
            scale: 0.6,
            horizontalOrigin : Cesium.HorizontalOrigin.CENTER,
            verticalOrigin : Cesium.VerticalOrigin.CENTER
        }
    });
    viewerx.entities.add({
        position : Cesium.Cartesian3.fromDegrees(-0.1625, 44.89133),
        label : {
            text : 'Mischzone 3          ',
            fillColor : Cesium.Color.BLACK,
            scale: 0.6,
            horizontalOrigin : Cesium.HorizontalOrigin.CENTER,
            verticalOrigin : Cesium.VerticalOrigin.CENTER
        }
    });
    viewerx.entities.add({
        position : Cesium.Cartesian3.fromDegrees(-0.1625, 44.89163),
        label : {
            text : 'Wohnzone 5+        ',
            fillColor : Cesium.Color.BLACK,
            scale: 0.6,
            horizontalOrigin : Cesium.HorizontalOrigin.CENTER,
            verticalOrigin : Cesium.VerticalOrigin.CENTER
        }
    });
    viewerx.entities.add({
        position : Cesium.Cartesian3.fromDegrees(-0.1625, 44.89193),
        label : {
            text : 'Wohnzone 4          ',
            fillColor : Cesium.Color.BLACK,
            scale: 0.6,
            horizontalOrigin : Cesium.HorizontalOrigin.CENTER,
            verticalOrigin : Cesium.VerticalOrigin.CENTER
        }
    });
    viewerx.entities.add({
        position : Cesium.Cartesian3.fromDegrees(-0.1625, 44.89223),
        label : {
            text : 'Wohnzone 3          ',
            fillColor : Cesium.Color.BLACK,
            scale: 0.6,
            horizontalOrigin : Cesium.HorizontalOrigin.CENTER,
            verticalOrigin : Cesium.VerticalOrigin.CENTER
        }
    });
    viewerx.entities.add({
```

```
        position : Cesium.Cartesian3.fromDegrees(-0.1625, 44.89253),
        label : {
            text : 'Wohnzone 2            ',
            fillColor : Cesium.Color.BLACK,
            scale: 0.6,
            horizontalOrigin : Cesium.HorizontalOrigin.CENTER,
            verticalOrigin : Cesium.VerticalOrigin.CENTER
        }
    });
    viewerx.entities.add({
        position : Cesium.Cartesian3.fromDegrees(-0.1625, 44.89283),
        label : {
            text : 'Wohnzone 1            ',
            fillColor : Cesium.Color.BLACK,
            scale: 0.6,
            horizontalOrigin : Cesium.HorizontalOrigin.CENTER,
            verticalOrigin : Cesium.VerticalOrigin.CENTER
        }
    });
    viewerx.entities.add({
        position : Cesium.Cartesian3.fromDegrees(-0.1625, 44.89313),
        label : {
            text : 'Zentrum                    ',
            fillColor : Cesium.Color.BLACK,
            scale: 0.6,
            horizontalOrigin : Cesium.HorizontalOrigin.CENTER,
            verticalOrigin : Cesium.VerticalOrigin.CENTER
        }
    });
    viewerx.entities.add({
        position : Cesium.Cartesian3.fromDegrees(-0.1636, 44.8935),
        label : {
            text : 'Zone',
            fillColor : Cesium.Color.BLACK,
            scale: 0.8,
            horizontalOrigin : Cesium.HorizontalOrigin.CENTER,
            verticalOrigin : Cesium.VerticalOrigin.CENTER
        }
    });
       viewerx.dataSources.add(Cesium.GeoJsonDataSource.load('http://wp12212843.server-he.ch/MSc/Data/Web/symbole.geojson', {
        stroke: Cesium.Color.BLACK,
        strokeWidth: 4
      }));
        </script>
        <div id="masking_legend"> <!-- masking of the cesium logo -->
        </div>
    </div>
    <!-- end of legend (cesium)-->
    <!-- legend for the navigation instructions -->
    <div id="legende_navigation">
        <img src="../../../Web/legende_navigation.png" width="200" height="200" alt="Legende">
    </div>
    <div id="images">
    <!-- loads image below the map (an additional div is used in the task 1 condition) -->
        <style type="text/css">
          .tg  {border-collapse:collapse;border-spacing:0;}
          .tg td{font-family:Arial, sans-serif;font-size:20px;padding:5px 5px;border-style:solid;border-width:1px;overflow:hidden;word-break:normal;}
          .tg th{font-family:Arial, sans-serif;font-size:20px;font-weight:normal;padding:5px 5px;border-style:solid;border-width:1px;overflow:hidden;word-break:normal;}
          .tg .tg-031e{text-align:center}
        </style>
        <table class="tg">
          <tr>
            <th class="tg-031e">A</th>
            <th class="tg-031e"><img src="../../images/IMG_0301.JPG" width="300" height="200" alt="Legende"></th>
          </tr>
          <tr>
            <td class="tg-031e">B<br></td>
            <td class="tg-031e"><img src="../../images/IMG_0270.JPG" width="300" height="200" alt="Legende"><br></td>
          </tr>
```

```
          <tr>
            <td class="tg-031e">C<br></td>
            <td class="tg-031e"><img src="../../images/IMG_9988.JPG" width="300" height="200" alt="Legende"><br></td>
          </tr>
        </table>
    </div>
    <div id="images2">
      <style type="text/css">
        .te  {border-collapse:collapse;border-spacing:0;}
        .te td{font-family:Arial, sans-serif;font-size:20px;padding:8px 8px;border-style:solid;border-width:1px;overflow:hidden;word-break:normal;}
        .te th{font-family:Arial, sans-serif;font-size:20px;font-weight:normal;padding:8px 50px;border-style:solid;border-width:1px;overflow:hidden;word-break:normal;}
        .te .te-031e{text-align:center}
      </style>
      <table class="te">
        <tr>
          <th class="te-031e"><img src="../../images/IMG_0554.JPG" width="300" height="200" alt="Legende"><br></th>
          <th class="te-031e"><img src="../../images/IMG_8639.JPG" width="300" height="200" alt="Legende"></th>
        </tr>
        <tr>
          <td class="te-031e">D</td>
          <td class="te-031e">E</td>
        </tr>
      </table>
    </div>
    <!-- defines the main map window with all contents-->
    <div id="cesiumContainer">
      <div id="baseLayerPickerContainer"> <!-- the div for the manual baselayerpicker (not called explicitly in 2D since no 3D models have to be drawn, but included to hide)-->
      </div>
      <div id="masking_top" style="visibility:hidden">  <!-- sets the content to the center and places the question-->
          <p style="font-family: Arial; font-size: 20px; font-weight: bold;">Sie befinden sich an der Position der Kamera und sehen das gegebene Blickfeld (in grün). <br> Welches Bild (Foto) sehen Sie? A, B, C, D oder E?</p>
      </div>
      <div id="masking_down">  <!-- sets the content to the center and hides the credits-->
      </div>
    <!-- Starts Cesium Scripting for the main map :) -->
      <script>
      //Defines Cesium viewer with all options
      var viewer = new Cesium.Viewer('cesiumContainer', {
        baseLayerPicker: false, //not load the basic baseLayerPicker; a manual one is loaded afterwards
        animation: false,
        fullscreenButton: false,
        geocoder: false,
        homeButton: false,
        infoBox: false,
        sceneModePicker: false,
        selectionIndicator: false,
        timeline: false,
        navigationHelpButton: false,
        navigationInstructionInitiallyVisible: false,
        imageryProvider: false, //necessary due to a bug in C 1.9 (avoids load of bing maps)
        targetFrameRate: 20,
      });
      //Some styling
      viewer.scene.globe.baseColor = Cesium.Color.GAINSBORO; //set Color for Background
      //Defines viewing options (center, distance etc.)
      viewer.scene.globe.maximumScreenSpaceError = 1;
      var center = Cesium.Cartesian3.fromDegrees(9.52846000000000792, 46.85444166999998572);
      var heading = Cesium.Math.toRadians(0.0);
      var pitch = Cesium.Math.toRadians(-90.0);
      var range = 500;
      viewer.camera.lookAt(center, new Cesium.HeadingPitchRange(heading, pitch, range));
```

```
      viewer.camera.rotate(Cesium.Cartesian3.UNIT_Z, 175*Math.PI/180); //rotates the view by 175°
      //Options for lightning
      var scene = viewer.scene;
      scene.skyBox = scene.skyBox.destroy();
      scene.skyAtmosphere = scene.skyAtmosphere.destroy();
      scene.sun = scene.sun.destroy();
      scene.moon = scene.moon.destroy();
      //options for navigation
      var canvas = viewer.canvas;
      canvas.setAttribute('tabindex', '0'); // needed to put focus on the canvas
      canvas.onclick = function() {
            canvas.focus();
      };
      scene.screenSpaceCameraController.enableRotate = false;
      scene.screenSpaceCameraController.enableTranslate = false;
      scene.screenSpaceCameraController.enableZoom = false;
      scene.screenSpaceCameraController.enableTilt = false;
      scene.screenSpaceCameraController.enableLook = false;
      viewer.trackedEntity = undefined;
      //Manual input for navigation
      var flags = {
        rotateLeft : false,
        rotateRight : false
      };
      function getFlagForKeyCode(keyCode) {
       switch (keyCode) {
        case 'D'.charCodeAt(0):
          return 'rotateRight';
        case 'A'.charCodeAt(0):
          return 'rotateLeft';
        default:
          return undefined;
        }
      }
      document.addEventListener('keydown', function(e) {
        var flagName = getFlagForKeyCode(e.keyCode);
           if (typeof flagName !== 'undefined') {
              flags[flagName] = true;
              setTimeout(function(){flags[flagName] = false}, 2500) //rotates for 2.5 sec.
           }
        }, false);
      var deltaAngle = 0.9*Math.PI/180; //defines the rotation speed for 45° (1/8 of the circle) based on the framerate (20fps)
      viewer.clock.onTick.addEventListener(function(clock) {
        var camera = viewer.camera;
        if (flags.rotateLeft) {
            camera.rotate(Cesium.Cartesian3.UNIT_Z, deltaAngle);
            }
        if (flags.rotateRight) {
            camera.rotate(Cesium.Cartesian3.UNIT_Z, -deltaAngle);
            }
        });
      // TileMapService tile provider
      var layers = viewer.scene.imageryLayers;
      layers.addImageryProvider(new Cesium.TileMapServiceImageryProvider({
        url : '../../tiles/Chur_grey',
        fileExtension: 'png',
        minimumLevel: 10,
        maximumLevel: 22,
        tileWidth: 512,
        tileHeight: 512
      }));
      //load Buildings
      viewer.dataSources.add(Cesium.GeoJsonDataSource.load('../ZP/ZP_Chur_S.geojson', {
        stroke: Cesium.Color.BLACK,
        strokeWidth: 4
      }));
      //Field of View
      var fov = viewer.entities.add({
        corridor : {
        positions :  Cesium.Cartesian3.fromDegreesArray([
                        9.52846000000000792, 46.85444166999998572, 9.52974054746666077, 46.85571908025641363, 9.53059437212863791, 46.85392580387229344, 9.52846000000000792, 46.85444166999998572]),
        material : Cesium.Color.CHARTREUSE,
```

```
        width: 2,
        height: 10,
        cornerType: Cesium.CornerType.MITERED,
        }
      });
      var cameraPin = viewer.entities.add({
        position : Cesium.Cartesian3.fromDegrees(9.52846000000000792, 46.85444166999998572, 25),
        billboard : {
          image: '../../../Web/camera_2D.png',
          width: 30,
          height: 30
              }
          });
            setTimeout(function(){document.getElementById('loading_screen').style.visibility="hidden"; document.body.style.backgroundColor = "white"; document.getElementById('masking_top').style.visibility="visible"},15000); //removes the loading screen after 15 seconds.
      images.ondblclick=function(){alert("Bitte drücken Sie nun F9 um fortzufahren.");};
      images2.ondblclick=function(){alert("Bitte drücken Sie nun F9 um fortzufahren.");};
      </script>
    </div>
  </div>
  <div id="keyplacer">
    ZTD <!--solution key, derived with random.org !-->
  </div>
</body>
</html>
```

6. Code example of a 3D representation in Cesium (for task type 2)

```
<!-- 3D Chur 1 - 2-->
<!DOCTYPE html>
<html lang="en">
<head>
  <!-- Use correct character set. -->
  <meta charset="utf-8">
  <!-- Tell IE to use the latest, best version (or Chrome Frame if pre-IE11). -->
  <meta http-equiv="X-UA-Compatible" content="IE=Edge,chrome=1">
  <title>Location</title> <!--1-->
  <!-- Loads Cesium Library -->
  <script src="../../../../Cesium/Build/Cesium/Cesium.js"></script>
  <!-- CSS Styling of the Site -->
  <link href="../../../Web/styles/styles2.css" type="text/css" rel="stylesheet">
  <style>
      @import url(../../../../Cesium/Build/Cesium/Widgets/widgets.css);
      @import url(../../../../Cesium/Build/Cesium/Widgets/BaseLayerPicker/BaseLayerPicker.css); /* loads the widget for the baseLayer Picker; this is with a div set to the background. Only necessary due to a bug in cesium 1.9*/
  </style>
  <!-- Loads JavaScript File with models-->
  <script type="text/javascript" src="../load_models_bhf_s.js"></script>
</head>
<body>
  <div id="wrapper">
    <div id="loading_screen" style="visibility:visible">  <!-- loading screen -->
         <article class="preloader">
            <header><h1>LOADING</h1></header>
            <section class="satelite"></section>
            <section class="earth day"></section>
          </article>
    </div>
    <!-- to have exactly the same color in the legend it is necessary to create a legend in Cesium from .geojson-->
    <div id="legende">
        <script>
        var viewerx = new Cesium.Viewer('legende', {
        baseLayerPicker: false, //not load the basic baseLayerPicker; a manual one is loaded afterwards
        animation: false,
        fullscreenButton: false,
        geocoder: false,
        homeButton: false,
        infoBox: false,
        sceneModePicker: false,
        selectionIndicator: false,
        timeline: false,
        navigationHelpButton: false,
        navigationInstructionInitiallyVisible: false,
        imageryProvider: false, //necessary due to a bug in C 1.9 (avoids load of bing maps)
        targetFrameRate: 20,
      });
      //Some styling
      viewerx.scene.globe.baseColor = Cesium.Color.WHITE; //set Color for Background
      //Defines viewing options (center, distance etc.)
      viewerx.scene.globe.maximumScreenSpaceError = 1;
      var centerx = Cesium.Cartesian3.fromDegrees(-0.1626, 44.89154);
      var headingx = Cesium.Math.toRadians(0.0);
      var pitchx = Cesium.Math.toRadians(-90.0);
      var rangex = 400.0;
      viewerx.camera.lookAt(centerx, new Cesium.HeadingPitchRange(headingx, pitchx, rangex));
      //Options for lightning
      var scenex = viewerx.scene;
      scenex.skyBox = scenex.skyBox.destroy();
      scenex.skyAtmosphere = scenex.skyAtmosphere.destroy();
      scenex.sun = scenex.sun.destroy();
      scenex.moon = scenex.moon.destroy();
      scenex.screenSpaceCameraController.enableRotate = false;
      scenex.screenSpaceCameraController.enableTranslate = false;
      scenex.screenSpaceCameraController.enableZoom = false;
      scenex.screenSpaceCameraController.enableTilt = false;
      scenex.screenSpaceCameraController.enableLook = false;
      viewerx.entities.add({
        position : Cesium.Cartesian3.fromDegrees(-0.1625, 44.89013),
        label : {
```

```
            text : 'Andere                  ',
            fillColor : Cesium.Color.BLACK,
            scale: 0.6,
            horizontalOrigin : Cesium.HorizontalOrigin.CENTER,
            verticalOrigin : Cesium.VerticalOrigin.CENTER
        }
    });
      viewerx.entities.add({
        position : Cesium.Cartesian3.fromDegrees(-0.1625,44.89043),
        label : {
            text : 'Öffentliche Bauten',
            fillColor : Cesium.Color.BLACK,
            scale: 0.6,
            horizontalOrigin : Cesium.HorizontalOrigin.CENTER,
            verticalOrigin : Cesium.VerticalOrigin.CENTER
        }
    });
      viewerx.entities.add({
        position : Cesium.Cartesian3.fromDegrees(-0.1625, 44.89073),
        label : {
            text : 'Gewerbe               ',
            fillColor : Cesium.Color.BLACK,
            scale: 0.6,
            horizontalOrigin : Cesium.HorizontalOrigin.CENTER,
            verticalOrigin : Cesium.VerticalOrigin.CENTER
        }
    });
    viewerx.entities.add({
        position : Cesium.Cartesian3.fromDegrees(-0.1625, 44.89103),
        label : {
            text : 'Mischzone 4+        ',
            fillColor : Cesium.Color.BLACK,
            scale: 0.6,
            horizontalOrigin : Cesium.HorizontalOrigin.CENTER,
            verticalOrigin : Cesium.VerticalOrigin.CENTER
        }
    });
    viewerx.entities.add({
        position : Cesium.Cartesian3.fromDegrees(-0.1625, 44.89133),
        label : {
            text : 'Mischzone 3          ',
            fillColor : Cesium.Color.BLACK,
            scale: 0.6,
            horizontalOrigin : Cesium.HorizontalOrigin.CENTER,
            verticalOrigin : Cesium.VerticalOrigin.CENTER
        }
    });
    viewerx.entities.add({
        position : Cesium.Cartesian3.fromDegrees(-0.1625, 44.89163),
        label : {
            text : 'Wohnzone 5+        ',
            fillColor : Cesium.Color.BLACK,
            scale: 0.6,
            horizontalOrigin : Cesium.HorizontalOrigin.CENTER,
            verticalOrigin : Cesium.VerticalOrigin.CENTER
        }
    });
    viewerx.entities.add({
        position : Cesium.Cartesian3.fromDegrees(-0.1625, 44.89193),
        label : {
            text : 'Wohnzone 4          ',
            fillColor : Cesium.Color.BLACK,
            scale: 0.6,
            horizontalOrigin : Cesium.HorizontalOrigin.CENTER,
            verticalOrigin : Cesium.VerticalOrigin.CENTER
        }
    });
    viewerx.entities.add({
        position : Cesium.Cartesian3.fromDegrees(-0.1625, 44.89223),
        label : {
            text : 'Wohnzone 3          ',
            fillColor : Cesium.Color.BLACK,
            scale: 0.6,
            horizontalOrigin : Cesium.HorizontalOrigin.CENTER,
            verticalOrigin : Cesium.VerticalOrigin.CENTER
        }
    });
```

```
    viewerx.entities.add({
        position : Cesium.Cartesian3.fromDegrees(-0.1625, 44.89253),
        label : {
            text : 'Wohnzone 2           ',
            fillColor : Cesium.Color.BLACK,
            scale: 0.6,
            horizontalOrigin : Cesium.HorizontalOrigin.CENTER,
            verticalOrigin : Cesium.VerticalOrigin.CENTER
        }
    });
    viewerx.entities.add({
        position : Cesium.Cartesian3.fromDegrees(-0.1625, 44.89283),
        label : {
            text : 'Wohnzone 1           ',
            fillColor : Cesium.Color.BLACK,
            scale: 0.6,
            horizontalOrigin : Cesium.HorizontalOrigin.CENTER,
            verticalOrigin : Cesium.VerticalOrigin.CENTER
        }
    });
    viewerx.entities.add({
        position : Cesium.Cartesian3.fromDegrees(-0.1625, 44.89313),
        label : {
            text : 'Zentrum                  ',
            fillColor : Cesium.Color.BLACK,
            scale: 0.6,
            horizontalOrigin : Cesium.HorizontalOrigin.CENTER,
            verticalOrigin : Cesium.VerticalOrigin.CENTER
        }
    });
    viewerx.entities.add({
        position : Cesium.Cartesian3.fromDegrees(-0.1636, 44.8935),
        label : {
            text : 'Zone',
            fillColor : Cesium.Color.BLACK,
            scale: 0.8,
            horizontalOrigin : Cesium.HorizontalOrigin.CENTER,
            verticalOrigin : Cesium.VerticalOrigin.CENTER
        }
    });
       viewerx.dataSources.add(Cesium.GeoJsonDataSource.load('http://wp12212843.server-he.ch/MSc/Data/Web/symbole.geojson', {
        stroke: Cesium.Color.BLACK,
        strokeWidth: 4
      }));
        </script>
        <div id="masking_legend"> <!-- masking of the cesium logo -->
        </div>
    </div>
    <!-- end of legend (cesium)-->
    <!-- legend for the navigation instructions -->
    <div id="legende_navigation">
        <img src="../../../Web/legende_navigation.png" width="200" height="200" alt="Legende">
    </div>
    <!-- loads image below the map (an additional div is used in the task 1 condition) -->
    <div id="images2">
      <style type="text/css">
        .te  {border-collapse:collapse;border-spacing:0;}
        .te td{font-family:Arial, sans-serif;font-size:20px;padding:8px 250px;border-style:solid;border-width:1px;overflow:hidden;word-break:normal;}
        .te th{font-family:Arial, sans-serif;font-size:20px;font-weight:normal;padding:8px 250px;border-style:solid;border-width:1px;overflow:hidden;word-break:normal;}
        .te .te-031e{text-align:center}
      </style>
      <table class="te">
        <tr>
          <th class="te-031e"><img src="../../images/IMG_0301.JPG" width="300" height="200" alt="Legende"><br></th>
        </tr>
      </table>
    </div>
    <!-- defines the main map window with all contents-->
    <div id="cesiumContainer">
```

```
      <div id="baseLayerPickerContainer"> <!-- the div for the manual baselayerpicker -->
      </div>
      <div id="masking_top" style="visibility:hidden">  <!-- sets the content to the center and places the question-->
            <p style="font-family: Arial; font-size: 20px; font-weight: bold;">Sie befinden sich an der Position der Kamera mit dem gegebenen Bild (Foto). <br>
            Welches Blickfeld (in grün) sehen Sie? A, B, C, D oder E?</p>
      </div>
      <div id="masking_down">  <!-- sets the content to the center and hides the credits-->
      </div>
      <!-- Starts Cesium Scripting for the main map :) -->
        <script>
        //Defines Terrain (only necessary for altitude of the models, not used in 2D)
        var terrainProvider = new Cesium.CesiumTerrainProvider({
          url : '//assets.agi.com/stk-terrain/world',
          requestVertexNormals : false
        });
        var pos = [      //Position List for the 5 field of Views (or 1 field of view in Task 1; the 2D version uses a simpler method with "corridor")
          Cesium.Cartographic.fromDegrees(9.52846000000000792, 46.85444166999998572), //defines position list1
          Cesium.Cartographic.fromDegrees(9.52976521645510211, 46.85566708986270612),
          Cesium.Cartographic.fromDegrees(9.53057024105349448, 46.85397277728717569),
          Cesium.Cartographic.fromDegrees(9.52846000000000792, 46.85444166999998572),
          Cesium.Cartographic.fromDegrees(9.52846000000000792, 46.85444166999998572), //defines position list2
          Cesium.Cartographic.fromDegrees(9.52716010400542679, 46.85566922683472768),
          Cesium.Cartographic.fromDegrees(9.529765216455095, 46.85566708986269191),
          Cesium.Cartographic.fromDegrees(9.52846000000000792, 46.85444166999998572),
          Cesium.Cartographic.fromDegrees(9.52846000000000792, 46.85444166999998572), //defines position list3
          Cesium.Cartographic.fromDegrees(9.52635118803423886, 46.85397578129976637),
          Cesium.Cartographic.fromDegrees(9.52716010400541791 ,46.85566922683472768),
          Cesium.Cartographic.fromDegrees(9.52846000000000792, 46.85444166999998572),
          Cesium.Cartographic.fromDegrees(9.52846000000000792, 46.85444166999998572), //defines position list4
          Cesium.Cartographic.fromDegrees(9.52845618529914873, 46.85292618346734628),
          Cesium.Cartographic.fromDegrees(9.52635118803423175, 46.85397578129976637),
          Cesium.Cartographic.fromDegrees(9.52846000000000792, 46.85444166999998572),
          Cesium.Cartographic.fromDegrees(9.52846000000000792, 46.85444166999998572), //defines position list5
          Cesium.Cartographic.fromDegrees(9.53057024105348205, 46.85397277728716148),
          Cesium.Cartographic.fromDegrees(9.52845618529916116 ,46.85292618346734628),
          Cesium.Cartographic.fromDegrees(9.52846000000000792, 46.85444166999998572)
                ];
        var promise = Cesium.sampleTerrain(terrainProvider, 14, pos);  //gest height from terrain server at position
          Cesium.when(promise, function(updatedPositions) {
            });
        //Defines the baseLayerPicker in the background; necessary due to a bug in Cesium 1.9 (otherwise no clipping with models)
        var imageryViewModels = [];
          imageryViewModels.push(new Cesium.ProviderViewModel({
          name : 'STK',
          iconUrl : Cesium.buildModuleUrl('Widgets/Images/ImageryProviders/openStreetMap.png'),
          tooltip : 'Terrain',
          creationFunction : function() {
           return new Cesium.CesiumTerrainProvider({
               url : '//assets.agi.com/stk-terrain/world',
               requestVertexNormals: false
            });
          }
        }));
        //Defines Cesium viewer with all options
        var viewer = new Cesium.Viewer('cesiumContainer', {
          baseLayerPicker: false, //not load the basic baseLayerPicker; a manual one is loaded afterwards as defined above
          animation: false,
          fullscreenButton: false,
          geocoder: false,
          homeButton: false,
          infoBox: false,
          sceneModePicker: false,
          selectionIndicator: false,
```

```
          timeline: false,
          navigationHelpButton: false,
          navigationInstructionInitiallyVisible: false,
          imageryProvider: false, //necessary due to a bug in C 1.9 (avoids load of bing maps)
          targetFrameRate: 20,
        });
        //Loads the manual baseLayerPicker with the defines layer (i.e. TerrainProvider)
       var baseLayerPicker = new Cesium.BaseLayerPicker('baseLayerPickerContainer', {globe:viewer.scene.globe, terrainProviderViewModels:imageryViewModels});
        //Some styling
        viewer.scene.globe.baseColor = Cesium.Color.GAINSBORO; //set Color for Background
        viewer.scene.skyAtmosphere = new Cesium.SkyAtmosphere(); //set Styling for Sky
        //Defines viewing options (center, distance etc.)
        viewer.scene.globe.maximumScreenSpaceError = 1;
        setTimeout(function(){
            var center = Cesium.Cartesian3.fromRadians(pos[0].longitude , pos[0].latitude , pos[0].height);
            var heading = Cesium.Math.toRadians(175.0);
            var pitch = Cesium.Math.toRadians(-35.0);
            var range = 300;
            viewer.camera.lookAt(center, new Cesium.HeadingPitchRange(heading, pitch, range));
          //camera is set again due to a bug in Cesium 1.9 after 3.5 and 12.5 sec to force the system to laod the right LoD data according to the zoom level and finally set the camera correct for the user.
            setTimeout(function(){
              viewer.camera.lookAt(center, new Cesium.HeadingPitchRange(heading, pitch, range));},2000);
            setTimeout(function(){
              viewer.camera.lookAt(center, new Cesium.HeadingPitchRange(heading, pitch, range));},11000);
        }, 1500); //sampleTerrain needs some time.
        //Options for lightning
        var scene = viewer.scene;
        scene.skyBox = scene.skyBox.destroy();
        scene.skyAtmosphere = scene.skyAtmosphere.destroy();
        scene.sun = scene.sun.destroy();
        scene.moon = scene.moon.destroy();
        //options for navigation
        var canvas = viewer.canvas;
        canvas.setAttribute('tabindex', '0'); // needed to put focus on the canvas (for interaction)
        canvas.onclick = function() {
              canvas.focus();
        };
        scene.screenSpaceCameraController.enableRotate = false;
        scene.screenSpaceCameraController.enableTranslate = false;
        scene.screenSpaceCameraController.enableZoom = false;
        scene.screenSpaceCameraController.enableTilt = false;
        scene.screenSpaceCameraController.enableLook = false;
        //Manual input for navigation
        var flags = {
          rotateLeft : false,
          rotateRight : false
        };
        function getFlagForKeyCode(keyCode) {
         switch (keyCode) {
          case 'D'.charCodeAt(0):
            return 'rotateRight';
          case 'A'.charCodeAt(0):
            return 'rotateLeft';
          default:
            return undefined;
          }
        }
        document.addEventListener('keydown', function(e) {
          var flagName = getFlagForKeyCode(e.keyCode);
             if (typeof flagName !== 'undefined') {
                flags[flagName] = true;
                setTimeout(function(){flags[flagName] = false}, 2500) //rotates for 2.5 sec.
             }
          }, false);
```

```
        var deltaAngle = 0.9*Math.PI/180; //defines the rotation speed for 45° (1/8 of the circle) based on the framerate (20fps)
        viewer.clock.onTick.addEventListener(function(clock) {
          var camera = viewer.camera;
          if (flags.rotateLeft) {
              camera.rotate(Cesium.Cartesian3.UNIT_Z, deltaAngle);
              }
          if (flags.rotateRight) {
              camera.rotate(Cesium.Cartesian3.UNIT_Z, -deltaAngle);
              }
          });
        // TileMapService tile provider
        var layers = viewer.scene.imageryLayers;
        layers.addImageryProvider(new Cesium.TileMapServiceImageryProvider({
          url : '../../tiles/Chur_grey',
          fileExtension: 'png',
          minimumLevel: 10,
          maximumLevel: 22,
          tileWidth: 512,
          tileHeight: 512
        }));
        //Field of View with extrusion (simpler version used in 2D)
        setTimeout(function(){
          var fov_down1 = viewer.entities.add({   //draws fov
              wall : {
              positions : Cesium.Cartesian3.fromRadiansArrayHeights([
                  pos[0].longitude , pos[0].latitude , pos[0].height+1,
                  pos[1].longitude , pos[1].latitude , pos[1].height+1,
                  pos[2].longitude , pos[2].latitude , pos[2].height+1,
                  pos[3].longitude , pos[3].latitude , pos[3].height+1]),
              material : Cesium.Color.CHARTREUSE.withAlpha(0),
              outline : true,
              outlineColor: Cesium.Color.CHARTREUSE,
              outlineWidth: 4
              }
            });
          var fov_up1 = viewer.entities.add({   //draws fov
              wall : {
              positions : Cesium.Cartesian3.fromRadiansArrayHeights([
                  pos[0].longitude , pos[0].latitude , pos[0].height+31,
                  pos[1].longitude , pos[1].latitude , pos[1].height+31,
                  pos[2].longitude , pos[2].latitude , pos[2].height+31,
                  pos[3].longitude , pos[3].latitude , pos[3].height+31]),
              material : Cesium.Color.CHARTREUSE.withAlpha(0.2),
              outline : true,
              outlineColor: Cesium.Color.CHARTREUSE,
              outlineWidth: 4
              }
            });
          var fov_down2 = viewer.entities.add({   //draws fov
              wall : {
              positions : Cesium.Cartesian3.fromRadiansArrayHeights([
                  pos[4].longitude , pos[4].latitude , pos[4].height+1,
                  pos[5].longitude , pos[5].latitude , pos[5].height+1,
                  pos[6].longitude , pos[6].latitude , pos[6].height+1,
                  pos[7].longitude , pos[7].latitude , pos[7].height+1]),
              material : Cesium.Color.CHARTREUSE.withAlpha(0),
              outline : true,
              outlineColor: Cesium.Color.CHARTREUSE,
              outlineWidth: 4
              }
            });
          var fov_up2 = viewer.entities.add({   //draws fov
              wall : {
              positions : Cesium.Cartesian3.fromRadiansArrayHeights([
                  pos[4].longitude , pos[4].latitude , pos[4].height+31,
                  pos[5].longitude , pos[5].latitude , pos[5].height+31,
                  pos[6].longitude , pos[6].latitude , pos[6].height+31,
                  pos[7].longitude , pos[7].latitude , pos[7].height+31]),
              material : Cesium.Color.CHARTREUSE.withAlpha(0.2),
              outline : true,
              outlineColor: Cesium.Color.CHARTREUSE,
              outlineWidth: 4
              }
            });
          var fov_down3 = viewer.entities.add({   //draws fov
              wall : {
```

```
              positions : Cesium.Cartesian3.fromRadiansArrayHeights([
                  pos[8].longitude , pos[8].latitude , pos[8].height+1,
                  pos[9].longitude , pos[9].latitude , pos[9].height+1,
                  pos[10].longitude , pos[10].latitude , pos[10].height+1,
                  pos[11].longitude , pos[11].latitude , pos[11].height+1]),
              material : Cesium.Color.CHARTREUSE.withAlpha(0),
              outline : true,
              outlineColor: Cesium.Color.CHARTREUSE,
              outlineWidth: 4
              }
            });
          var fov_up3 = viewer.entities.add({   //draws fov
              wall : {
              positions : Cesium.Cartesian3.fromRadiansArrayHeights([
                  pos[8].longitude , pos[8].latitude , pos[8].height+31,
                  pos[9].longitude , pos[9].latitude , pos[9].height+31,
                  pos[10].longitude , pos[10].latitude , pos[10].height+31,
                  pos[11].longitude , pos[11].latitude , pos[11].height+31]),
              material : Cesium.Color.CHARTREUSE.withAlpha(0.2),
              outline : true,
              outlineColor: Cesium.Color.CHARTREUSE,
              outlineWidth: 4
              }
            });
          var fov_down4 = viewer.entities.add({   //draws fov
              wall : {
              positions : Cesium.Cartesian3.fromRadiansArrayHeights([
                  pos[12].longitude , pos[12].latitude , pos[12].height+1,
                  pos[13].longitude , pos[13].latitude , pos[13].height+1,
                  pos[14].longitude , pos[14].latitude , pos[14].height+1,
                  pos[15].longitude , pos[15].latitude , pos[15].height+1]),
              material : Cesium.Color.CHARTREUSE.withAlpha(0),
              outline : true,
              outlineColor: Cesium.Color.CHARTREUSE,
              outlineWidth: 4
              }
            });
          var fov_up4 = viewer.entities.add({   //draws fov
              wall : {
              positions : Cesium.Cartesian3.fromRadiansArrayHeights([
                  pos[12].longitude , pos[12].latitude , pos[12].height+31,
                  pos[13].longitude , pos[13].latitude , pos[13].height+31,
                  pos[14].longitude , pos[14].latitude , pos[14].height+31,
                  pos[15].longitude , pos[15].latitude , pos[15].height+31]),
              material : Cesium.Color.CHARTREUSE.withAlpha(0.2),
              outline : true,
              outlineColor: Cesium.Color.CHARTREUSE,
              outlineWidth: 4
              }
            });
          var fov_down5 = viewer.entities.add({   //draws fov
              wall : {
              positions : Cesium.Cartesian3.fromRadiansArrayHeights([
                  pos[16].longitude , pos[16].latitude , pos[16].height+1,
                  pos[17].longitude , pos[17].latitude , pos[17].height+1,
                  pos[18].longitude , pos[18].latitude , pos[18].height+1,
                  pos[19].longitude , pos[19].latitude , pos[19].height+1]),
              material : Cesium.Color.CHARTREUSE.withAlpha(0),
              outline : true,
              outlineColor: Cesium.Color.CHARTREUSE,
              outlineWidth: 4
              }
            });
          var fov_up5 = viewer.entities.add({   //draws fov
              wall : {
              positions : Cesium.Cartesian3.fromRadiansArrayHeights([
                  pos[16].longitude , pos[16].latitude , pos[16].height+31,
                  pos[17].longitude , pos[17].latitude , pos[17].height+31,
                  pos[18].longitude , pos[18].latitude , pos[18].height+31,
                  pos[19].longitude , pos[19].latitude , pos[19].height+31]),
              material : Cesium.Color.CHARTREUSE.withAlpha(0.2),
              outline : true,
              outlineColor: Cesium.Color.CHARTREUSE,
              outlineWidth: 4
              }
            });
        // Label
```

```
        viewer.entities.add({
          position : Cesium.Cartesian3.fromDegrees(9.5295984858362015, 46.85469384571661777, pos[0].height+35),
          label : {
              text : 'B',
              style: Cesium.LabelStyle.FILL_AND_OUTLINE,
              fillColor: Cesium.Color.WHITE,
              outlineColor: Cesium.Color.BLACK,
              outlineWidth: 7
          }
        });
        viewer.entities.add({
            position : Cesium.Cartesian3.fromDegrees(9.52916214211755097, 46.85378021025150019, pos[0].height+35),
            label : {
                text : 'C',
                style: Cesium.LabelStyle.FILL_AND_OUTLINE,
                fillColor: Cesium.Color.WHITE,
                outlineColor: Cesium.Color.BLACK,
                outlineWidth: 7
            }
        });
        viewer.entities.add({
            position : Cesium.Cartesian3.fromDegrees(9.52775579111113124, 46.85378121158903042, pos[0].height+35),
            label : {
                text : 'D',
                style: Cesium.LabelStyle.FILL_AND_OUTLINE,
                fillColor: Cesium.Color.WHITE,
                outlineColor: Cesium.Color.BLACK,
                outlineWidth: 7
            }
        });
        viewer.entities.add({
            position : Cesium.Cartesian3.fromDegrees(9.52732376401322156, 46.85469555937816466, pos[0].height+35),
            label : {
                text : 'E',
                style: Cesium.LabelStyle.FILL_AND_OUTLINE,
                fillColor: Cesium.Color.WHITE,
                outlineColor: Cesium.Color.BLACK,
                outlineWidth: 7
            }
        });
        viewer.entities.add({
            position : Cesium.Cartesian3.fromDegrees(9.52846177348684442,46.85525932889913747, pos[0].height+35),
            label : {
                text : 'A',
                style: Cesium.LabelStyle.FILL_AND_OUTLINE,
                fillColor: Cesium.Color.WHITE,
                outlineColor: Cesium.Color.BLACK,
                outlineWidth: 7
            }
        });
      //Icon at centrum
          var pinBuilder = new Cesium.PinBuilder();
          var cameraPin = Cesium.when(pinBuilder.fromUrl('../../../Web/camera_3D.png', Cesium.Color.GREENYELLOW, 60), function(canvas) {
                return viewer.entities.add({
                  position : Cesium.Cartesian3.fromRadians(pos[0].longitude , pos[0].latitude , pos[0].height+10),
                    billboard : {
                      image : canvas.toDataURL(),
                      verticalOrigin : Cesium.VerticalOrigin.CENTER,
                      eyeOffset: new Cesium.Cartesian3(0,0,-6),
                    }
                });
            });
      }, 10000);  //waits 10 sec since sampleTerrain and other functions need some time.
        setTimeout(function(){initone()},300);  //waits 0.3 seconds until init() function is called to avoid a cross-script error
        setTimeout(function(){document.getElementById('loading_screen').style.visibility="hidden"; document.body.style.backgroundColor = "white"; document.getElementById('masking_top').style.visibility="visible"},15000); //removes
```

```
the loading screen after 15 seconds.
        //user feedback after the solution is clicked
        var handler = new Cesium.ScreenSpaceEventHandler(viewer.canvas);
        handler.setInputAction(function(alert){window.alert("Bitte drücken Sie nun F9 
um fortzufahren.");}, Cesium.ScreenSpaceEventType.LEFT_DOUBLE_CLICK);
        </script>
        <!-- end of cesium scripting main visualization!-->
      </div>
    </div>
  <div id="keyplacer">
    AQ2 <!--solution key, derived with random.org !-->
  </div>
</body>
</html>
```

7. JavaScript file for the 3D map

```
//Chur Bahnhof
var link = '../models/bhf_s/qc_bahnhof_Shape_'; //Defines link to model folder (short version for illustration purposes)
buildingsone = new Array(); //Array for data of all Models
var positionsone = []; //Array for variable to put later in the altitude sampling method
//Array[nr]="geb_id, lat, long"
buildingsone[1]=["1",9.533922284,46.85892793];
// List with the number of the building and the location (short version for illustration)
buildingsone[576]=["576",9.534175453,46.85892604];
//End of Array
//Function to place the models
function initone(){
//Loop through array with single models to get the altitude at position from terrain server later
    for (var ione=1; ione<buildingsone.length; ione++){
        var clatone = (buildingsone[ione][1]) //gets lat of the building
        var clongone = (buildingsone[ione][2]) //gets long of the building
        positionsone.push(Cesium.Cartographic.fromDegrees(clatone,clongone,0, new Cesium.Cartographic())); //Push the (transformed) coordinates in the position array
    };
//Update the .height via sampleTerrain to return the altitude as promise data. Wait 2 sec before the funciton is called since otherwise the array is not ready (server lag).
    setTimeout(function(){
        var promiseone = Cesium.sampleTerrain(terrainProvider, 14, positionsone);
        Cesium.when(promiseone, function(updatedpositionsone) {
         //update
        })}, 2000);
//Wait for 5 seconds (sampleTerrain needs some time); then take the data from the building array and the height from the position array (i-1=g=0) and draw the models
    var gone = 0 //counter for positionsone array
    setTimeout(function(){
        for (var ione=1; ione<buildingsone.length; ione++){
            var clatone = (buildingsone[ione][1]) //get lat of buildings
            var clongone = (buildingsone[ione][2]) //get long of building
            var gebone = (buildingsone[ione][0]) //get nr of building
            var hoeheone = (positionsone[gone].height) //gets height of lat/long
            gone++ //count +1
            var centermone=Cesium.Cartesian3.fromDegrees(clatone,clongone,hoeheone); //defines the center bottom of the model (lat, long from array and height from terrain);
            var modelMatrixone=Cesium.Transforms.eastNorthUpToFixedFrame(centermone); //defines the model in respect to coordinate system
            var modelone=scene.primitives.add(Cesium.Model.fromGltf({url:link+gebone+'.gltf',modelMatrix:modelMatrixone,scale:1})); //finally draws the model in the scene (loads the gltf model and adds it to the calculated position)
        }
    },
    5000);
};
```

8. CSS code used for the structure and the styling of the web viewer

```
/* Webviewer styling */
#cesiumContainer {              /* Main div for the cesium (map) viewer */
          width: 1050px;
          height: 700px;
          margin-left: 350px;
          position: absolute;
          top: 100px;
      }
#wrapper {                      /* Necessary for ordering and alignment */
          width: 1650px;
          margin: 0 auto;
      }
#legende {                      /* div for the cesium (legend) viewer */
            width: 300px;
            height: 600px;
            margin-left: 1400px;
            margin-top: 120px;
            background-color: white;
            z-index: 1;
      }
#legende_navigation {       /* div for image to show navigation instructions */
            width: 200px;
            height: 200px;
            background-color: white;
            z-index: 4;
            margin-top: 75px ;
            margin-left: 1200px;
      }
#images {               /* div for images on the left of the map */
            width: 300px;
            height: 600px;
            background-color: white;
            z-index: 5;
            position: absolute;
            top: 125px;
      }
#images2 {            /* div for images below the map */
            width: 700px;
            height: 180px;
            background-color: white;
            z-index: 4;
            position: absolute;
            top: 778px;
            margin-left: 350px;
      }
#masking_down {      /* masks the cesium credits */
          width: 1050px;
          height: 60px;
          position: absolute;
          top: 675px;
          background-color: white;
          z-index: 3;
      }
#masking_top {       /* necessary due to the masking on the bottom, otherwise the map is not centered; also used to display the task question */
          width: 1050px;
          height: 60px;
          position: absolute;
          top: -35px;
          background-color: white;
          z-index: 3;
      }
#masking_legend {   /* masks the cesium credits */
          width: 300px;
          height: 50px;
          position: absolute;
          top: 675px;
          background-color: white;
          z-index: 3;
      }
#baseLayerPickerContainer {   /* manual definition of the base map picker from cesium so that this selection can be hidden (has to be loaded due to a bug) */
            width: 0px;
            height: 0px;
            position: absolute;
            top: 0px;
```

```
            z-index: -1;
      }
#loading_screen {     /* div for the loading screen */
            width: 1050px;
            height: 625px;
            position: absolute;
            top: 0px;
            background-color: white;
            z-index: 10;
      }
#keyplacer {      /* div for the solution key on the far bottom right */
    width: 50px;
    height: 25px;
    position: absolute;
    top: 1050px;
    left: 1800px;
    z-index: 6;
    font-family: "Arial";
    color: #BEBEBE;
      }
body {
          margin: 0;
          padding: 0;
          width:100%;
          height:100%;
          background-color: white
      }

/*Preloader by http://codepen.io/Rachouan/pen/azPxBQ */
*{
  margin:0;
  padding:0;
}
.day{
  background-color: #15A19F;
}
body{
  font-family:Impact;
}
article.preloader{

  z-index: 9998;
  position: fixed;
  width: 100%;
  height: 100%;
  text-align: center;

  background-size: 625px;
  background-position: top;
  background-repeat: repeat;
  background-color: white;

}
article.preloader header{
  position: absolute;
  top: 50%;
  left: 50%;
  width: 300px;
  margin-top: -150px;
  margin-left: -600px;
  color: black;
  text-transform: uppercase;
  font-size: 1em;
  letter-spacing: .2em;

}
article.preloader .earth{

  position: fixed;
  left: 50%;
  top: 60%;
  margin-left: -75px;
  margin-top: -75px;
  width: 150px;
  height: 150px;
  border-radius: 50%;
  background-image: url(http://rachouanrejeb.be/weather/images/assets/earth.png);
```

```
  background-size: cover;
  background-position: top left;
  background-repeat: repeat-x;


  -webkit-animation: earth 5s linear infinite;
  -moz-animation: earth 5s linear infinite;
  -ms-animation: earth 5s linear infinite;
  animation: earth 5s linear infinite;

}

@keyframes earth {
  0% {background-position: 0px 0px;}
  100% {background-position: -193% 0px;}
}
@-moz-keyframes earth {
  0% {background-position: 0px 0px;}
  100% {background-position: -193% 0px;}
}
@-webkit-keyframes earth {
  0% {background-position: 0px 0px;}
  100% {background-position: -193% 0px;}
}
@-ms-keyframes earth {
0% {background-position: 0px 0px;}
  100% {background-position: -193% 0px;}
}
```

9. Correlation of education and experience

Table 10 Correlation of education and experience

	EXP Carto	EXP UP	EXP GIS	EXP GG	EXP CG	EXP 3DG	EXP Image	EXP Photo
EDU Carto	.822**	.487**	.707**	.407**	.368*	.367*	.414**	.125
EDU UP	.549**	.921**	.439**	.259	.249	.124	.247	.035
EDU GIS	.703**	.343*	.900**	.345*	.305	.516**	.341*	.037
EDU GG	.470**	.266	.541**	.719**	.256	.457**	.320*	.135
EDU CG	.691**	.338*	.675**	.362*	.529**	.432**	.433**	.087
EDU 3DG	.492**	-.010	.529**	.273	.378*	.701**	.243	.072
EDU Image	.537**	.300	.602**	.437**	.422**	.421**	.691**	.402*
EDU Photo	.327*	.302	.193	.299	.306	.065	.433**	.622**

* Correlation is significant at the .05 level (2-tailed)
** Correlation is significant at the .01 level (2-tailed)
Data used for correlation analysis was not aggregated

10. Correlation of education

Table 11 Correlation of education

	EDU Carto	EDU UP	EDU GIS	EDU GG	EDU CG	EDU 3DG	EDU Image	EDU Photo
EDU Carto	1.000	.591**	.802**	.616**	.785**	.590**	.647**	.331*
EDU UP		1.000	.439**	.336*	.411**	.084	.294	.255
EDU GIS			1.000	.595**	.720**	.692**	.583**	.218
EDU GG				1.000	.436**	.446**	.460**	.243
EDU CG					1.000	.676**	.654**	.316*
EDU 3DG						1.000	.483**	.252
EDU Image							1.000	.426**
EDU Photo								1.000

* Correlation is significant at the .05 level (2-tailed)
** Correlation is significant at the .01 level (2-tailed)
Data used for correlation analysis was not aggregated

11. Correlation of experience

Table 12 Correlation of experience

	EXP Carto	EXP UP	EXP GIS	EXP GG	EXP CG	EXP 3DG	EXP Image	EXP Photo
EXP Carto	1.000	.549**	.737**	.405**	.446**	.297	.441**	.205
EXP UP		1.000	.382*	.304	.235	.066	.327*	.210
EXP GIS			1.000	.446**	.362*	.444**	.394*	.067
EXP GG				1.000	.404**	.338*	.455**	.300
EXP CG					1.000	.524**	.577**	.363*
EXP 3DG						1.000	.327*	.129
EXP Image							1.000	.583**
EXP Photo								1.000

* Correlation is significant at the .05 level (2-tailed)
** Correlation is significant at the .01 level (2-tailed)
Data used for correlation analysis was not aggregated

12. Correlation of representation use and UP

Table 13 Correlation of visulization use and UP

	VIS 2D	VIS 3D	UP Int[a]	UP Kno[b]	UP Par[c]
VIS 2D	1.000	.487**	.545**	.470**	.361*
VIS 3D		1.000	.467**	.376*	.437**
UP Int[a]			1.000	.881**	.698**
UP Kno[b]				1.000	.659**
UP Par[c]					1.000

* Correlation is significant at the .05 level (2-tailed)
** Correlation is significant at the .01 level (2-tailed)
[a] UP interest
[b] UP knowledge
[c] UP participation (aggregated)
Data used for correlation analysis was not aggregated

13. Descriptives of overall effectiveness of all participants (Winsorized data)

Table 14 Descriptives of overall effectiveness of all participants (percentage)

	n	*M*	*SE*	*Mdn*	*IQR*	*Min*	*Max*
2D T1	40	87.712	3.677	100.000	25.000	8.477	100.000
2D T2	40	96.261	1.679	100.000	.000	50.431	100.000
3D T1	40	91.467	2.638	100.000	18.750	33.690	100.000
3D T2	40	92.938	2.108	100.000	18.750	42.521	100.000
2D	40	92.078	2.463	100.000	12.500	33.115	100.000
3D	40	92.303	2.106	100.000	12.500	42.114	100.000
T1	40	89.675	2.938	100.000	12.500	24.484	100.000
T2	40	94.673	1.678	100.000	12.500	49.411	100.000
All	40	92.234	2.160	100.000	12.500	39.370	100.000

14. $z_{skewness}$ and $z_{kurtosis}$ of the Winsorized effectiveness data

Table 15 $z_{skewness}$ and $z_{kurtosis}$ (effectiveness)

	2D T1	2D T2	3D T1	3D T2	
$z_{skewness}$	-5.254***	-8.008***	-5.406***	-5.160***	
$z_{kurtosis}$	4.472***	12.372***	4.903***	5.212***	
	2D	3D	T1	T2	All
$z_{skewness}$	-6.259***	-5.618***	-5.650***	-6.869***	-6.396***
$z_{kurtosis}$	7.378***	6.318***	5.655***	10.649***	8.090***

* Significant at $p < .05$
** Significant at $p < .01$
*** Significant at $p < .001$

15. Kolmogorov-Smirnov and Shapiro-Wilk test on normality for the Winsorized effectiveness data

Table 16 Kolmogorov-Smirnov and Shapiro-Wilk test (effectiveness)

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
2D T1	.426	40	.000	.600	40	.000
2D T2	.513	40	.000	.400	40	.000
3D T1	.445	40	.000	.574	40	.000
3D T2	.452	40	.000	.565	40	.000
2D	.394	40	.000	.587	40	.000
3D	.368	40	.000	.644	40	.000
T1	.361	40	.000	.631	40	.000
T2	.417	40	.000	.569	40	.000
All	.290	40	.000	.635	40	.000

[a] Lilliefors Significance Correction

16. Descriptives of overall effectiveness of all participants (reciprocal data)

Table 17 Descriptives of overall effectiveness of all participants

	n	*M*	*SE*	*Mdn*	*IQR*	*Min*	*Max*
2D T1	40	1.397	.023	1.478	.200	1.000	1.478
2D T2	40	1.450	.012	1.478	.000	1.147	1.478
3D T1	40	1.416	.018	1.478	.150	1.079	1.478
3D T2	40	1.424	.016	1.478	.150	1.113	1.478
2D	40	1.419	.017	1.478	.111	1.077	1.478
3D	40	1.418	.015	1.478	.111	1.111	1.478
T1	40	1.404	.019	1.478	.111	1.048	1.478
T2	40	1.435	.013	1.478	.111	1.142	1.478
All	40	1.417	.015	1.478	.111	1.100	1.478

17. Kolmogorov-Smirnov and Shapiro-Wilk test on normality for the reciprocal effectiveness data

Table 18 Kolmogorov-Smirnov and Shapiro-Wilk test (effectiveness)

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
2D T1	.440	40	.000	.619	40	.000
2D T2	.516	40	.000	.406	40	.000
3D T1	.455	40	.000	.588	40	.000
3D T2	.459	40	.000	.574	40	.000
2D	.410	40	.000	.625	40	.000
3D	.385	40	.000	.679	40	.000
T1	.380	40	.000	.674	40	.000
T2	.430	40	.000	.603	40	.000
All	.312	40	.000	.694	40	.000

[a] Lilliefors Significance Correction

18. $z_{skewness}$ and $z_{kurtosis}$ of the reciprocal effectiveness data

Table 19 $z_{skewness}$ and $z_{kurtosis}$ (effectiveness)

	2D T1	2D T2	3D T1	3D T2	
$z_{skewness}$	-4.019***	-7.166***	-4.350***	-4.056***	
$z_{kurtosis}$	1.269	8.677***	1.988*	1.573	
	2D	3D	T1	T2	All
$z_{skewness}$	-4.944***	-4.249***	-4.275***	-5.302***	4.955***
$z_{kurtosis}$	3.624***	2.588**	2.231*	5.285***	4.160***

* Significant at $p < .05$
** Significant at $p < .01$
*** Significant at $p < .001$

19. $z_{skewness}$ and $z_{kurtosis}$ of the reciprocal effectiveness data for gender, spatial ability and UP

Table 20 $z_{skewness}$ and $z_{kurtosis}$ (effectiveness)

	2D T1	2D T2	3D T1	3D T2	2D	3D	T1	T2	All
$z_{skewness}$ $gender_{♀}$	-1.436	-4.004***	-1.935	-2.616**	-2.100*	-2.366*	-1.667	-3.235**	-2.376**
$z_{kurtosis}$ $gender_{♀}$	-1.012	3.712***	-.436	.984	.067	.746	-.565	2.382*	.680
$z_{skewness}$ $gender_{♂}$	-4.524***	-7.512***	-3.832***	-3.052**	-5.156***	-3.135**	-4.025***	-3.237***	-4.040***
$z_{kurtosis}$ $gender_{♂}$	4.033***	9.203***	1.660	.172	7.082***	.785	3.458***	1.467	3.942***
$z_{skewness}$ $sa\text{-}m_{low}$	-1.494	-6.383***	-2.789*	-2.664**	-3.094**	-2.955**	-2.326*	-4.121***	-3.369***
$z_{kurtosis}$ $sa\text{-}m_{low}$	-2.770**	10.063***	.873	.795	2.157*	2.021*	.548	4.657***	3.052**
$z_{skewness}$ $sa\text{-}m_{high}$	-4.887***	-4.146***	-3.814***	-3.172**	-4.719***	-3.389***	-4.672***	-3.221**	-4.301***
$z_{kurtosis}$ $sa\text{-}m_{high}$	5.338***	2.798**	2.775**	.705	5.117***	1.822	5.483***	1.422	4.379***
$z_{skewness}$ $sa\text{-}e_{low}$	-1.921	–[a]	-2.883**	-2.028*	-2.078*	-1.538	-1.866	-2.028*	-1.302
$z_{kurtosis}$ $sa\text{-}e_{low}$	-.336	–[a]	.800	-.655	-.250	-.390	-.102	-.655	-.666
$z_{skewness}$ $sa\text{-}e_{high}$	-4.474***	-5.854***	-4.039***	-2.356*	-4.997***	-3.115**	-4.622***	-3.078**	-4.427***
$z_{kurtosis}$ $sa\text{-}e_{high}$	6.291***	10.915***	4.659***	.080	8.164***	2.202*	7.211***	2.317*	6.695***
$z_{skewness}$ UP_{no}	-3.609***	-6.587***	-3.495***	-4.382**	-4.478***	-3.906**	-3.691***	-5.379***	-4.563***
$z_{kurtosis}$ UP_{no}	1.119	8.274***	1.010	2.906**	3.423***	2.310*	1.729	6.253***	3.980***
$z_{skewness}$ UP_{yes}	-2.335*	-3.761***	-3.761***	-.856	-2.875**	-1.532	-2.875**	-1.532	-2.436*
$z_{kurtosis}$ UP_{yes}	1.357	5.402***	5.402***	-1.513	3.024**	.045	3.010**	.045	2.094*

* Significant at $p < .05$
** Significant at $p < .01$
*** Significant at $p < .001$
sa-m Spatial ability median split groups
sa-e Spatial ability extreme (tercile split) groups
[a] All values are constant, i.e. $s = 0$

20. Kolmogorov-Smirnov, Shapiro-Wilk and Hartley's as well as Levene's test for gender reciprocal effectiveness data

Table 21 Kolmogorov-Smirnov, Shapiro-Wilk, Hartley's and Levene's test (effectiveness)

		Test of Normality						Test of Homogeneity of Variance				
		Kolmogorov-Smirnov[a]			Shapiro-Wilk			Hartley's F_{max}[b]		Levene[c]		
		D	df	p	W	df	p	F_{max}	df	F	$df_{1,2}$	p
2D T1	♀	.364	17	.000	.741	17	.000	3.646	22	18.814	1,38	.000
	♂	.494	23	.000	.491	23	.000					
2D T2	♀	.491	17	.000	.498	17	.000	2.981	22	4.624	1,38	.038
	♂	.532	23	.000	.324	23	.000					
3D T1	♀	.397	17	.000	.694	17	.000	3.517	22	14.742	1,38	.000
	♂	.499	23	.000	.463	23	.000					
3D T2	♀	.429	17	.000	.634	17	.000	1.875	22	2.933	1,38	.095
	♂	.479	23	.000	.512	23	.000					
2D	♀	.348	17	.000	.743	17	.000	3.996	22	12.122	1,38	.001
	♂	.460	23	.000	.524	23	.000					
3D	♀	.300	17	.000	.748	17	.000	2.518	22	3.259	1,38	.079
	♂	.448	23	.000	.588	23	.000					
T1	♀	.312	17	.000	.781	17	.001	4.083	22	13.135	1,38	.001
	♂	.439	23	.000	.595	23	.000					
T2	♀	.417	17	.000	.634	17	.000	2.924	22	4.546	1,38	.040
	♂	.450	23	.000	.596	23	.000					
All	♀	.247	17	.000	.778	17	.001	3.646	22	6.656	1,38	.014
	♂	.373	23	.007	.660	23	.000					

$N = 40$, $n_{♀} = 17$, $n_{♂} = 23$
[a] Lilliefors Significance Correction
[b] Critical value for $p = .05$ for $n = 20$ and two groups: 2.46
[c] Based on M

21. Kolmogorov-Smirnov, Shapiro-Wilk and Hartley's as well as Levene's test for spatial ability median split reciprocal effectiveness data

Table 22 Kolmogorov-Smirnov, Shapiro-Wilk, Hartley's and Levene's test (effectiveness)

		Test of Normality						Test of Homogeneity of Variance				
		Kolmogorov-Smirnov[a]			Shapiro-Wilk			Hartley's F_{max}[b]		Levene[c]		
		D	*df*	*p*	*W*	*df*	*p*	F_{max}	*df*	*F*	$df_{1,2}$	*p*
2D T1	low	.367	20	.000	.736	20	.000	1.602	19	4.705	1,38	.036
	high	.502	20	.000	.452	20	.000					
2D T2	low	.523	20	.000	.361	20	.000	1.331	19	.027	1,38	.870
	high	.509	20	.000	.433	20	.000					
3D T1	low	.425	20	.000	.645	20	.000	1.667	19	2.540	1,38	.119
	high	.481	20	.000	.529	20	.000					
3D T2	low	.428	20	.000	.635	20	.000	1.876	19	3.653	1,38	.064
	high	.487	20	.000	.495	20	.000					
2D	low	.346	20	.000	.718	20	.000	1.417	19	1.366	1,38	.250
	high	.467	20	.000	.502	20	.000					
3D	low	.313	20	.000	.738	20	.000	1.507	19	.774	1,38	.384
	high	.450	20	.000	.590	20	.000					
T1	low	.321	20	.000	.769	20	.000	1.587	19	2.213	1,38	.145
	high	.431	20	.000	.550	20	.000					
T2	low	.407	20	.000	.617	20	.000	1.710	19	.787	1,38	.381
	high	.453	20	.000	.583	20	.000					
All	low	.227	20	.008	.766	20	.000	1.407	19	.532	1,38	.470
	high	.395	20	.000	.592	20	.000					

$N = 40$, $n_{low} = 20$, $n_{high} = 20$
[a] Lilliefors Significance Correction
[b] Critical value for $p = .05$ for $n = 20$ and two groups: 2.46
[c] Based on *M*

22. Kolmogorov-Smirnov, Shapiro-Wilk and Hartley's as well as Levene's test for spatial ability extreme groups reciprocal effectiveness data

Table 23 Kolmogorov-Smirnov, Shapiro-Wilk, Hartley's and Levene's test (effectiveness)

		Test of Normality						Test of Homogeneity of Variance				
		Kolmogorov-Smirnov[a]			Shapiro-Wilk			Hartley's F_{max}[b]		Levene[c]		
		D	*df*	*p*	*W*	*df*	*p*	F_{max}	*df*	*F*	$df_{1,2}$	*p*
2D T1	low	.409	15	.000	.668	15	.000	1.043	14	1.133	1,26	.297
	high	.495	13	.000	.454	13	.000					
2D T2	low[d]	–	–	–	–	–	–	–	–	–	–	–
	high	.532	13	.000	.311	13	.000					
3D T1	low	.485	15	.000	.499	15	.000	1.571	14	.053	1,26	.820
	high	.500	13	.000	.465	13	.000					
3D T2	low	.453	15	.000	.561	15	.000	1.090	14	.180	1,26	.675
	high	.470	13	.000	.533	13	.000					
2D	low	.406	15	.000	.667	15	.000	1.556	14	.118	1,26	.675
	high	.487	13	.000	.429	13	.000					
3D	low	.372	15	.000	.714	15	.000	1.842	14	.286	1,26	.597
	high	.457	13	.000	.570	13	.000					
T1	low	.362	15	.000	.737	15	.001	1.358	14	.131	1,26	.720
	high	.434	13	.000	.504	13	.000					
T2	low	.453	15	.000	.561	15	.000	1.642	14	.291	1,26	.594
	high	.460	13	.000	.573	13	.000					
All	low	.276	15	.003	.806	15	.004	2.165	14	.220	1,26	.643
	high	.374	13	.000	.559	13	.000					

$N = 28$, $n_{\text{extreme low}} = 15$, $n_{\text{extreme high}} = 13$
[a] Lilliefors Significance Correction
[b] Critical value for $p = .05$ for $n = 15$ and two groups: 2.86
[c] Based on *M*
[d] All values are constant, i.e. $s = 0$; due to this the statistic can not be computed (not enough spread/level pairs)
Only the two extreme groups (without the third middle group) are analysed and reported

23. Kolmogorov-Smirnov, Shapiro-Wilk and Hartley's as well as Levene's test for UP-groups reciprocal effectiveness data

Table 24 Kolmogorov-Smirnov, Shapiro-Wilk, Hartley's and Levene's test (effectiveness)

		Test of Normality						Test of Homogeneity of Variance				
		Kolmogorov-Smirnova			Shapiro-Wilk			Hartley's F_{max}[b]		Levene[c]		
		D	*df*	*p*	*W*	*df*	*p*	F_{max}	*df*	*F*	$df_{1,2}$	*p*
2D T1	no	.435	32	.000	.626	32	.000	1.322	32	.474	1,38	.495
	yes	.448	8	.000	.607	8	.000					
2D T2	no	.516	32	.000	.408	32	.000	1.308	32	.090	1,38	.766
	yes	.513	8	.000	.418	8	.000					
3D T1	no	.438	32	.000	.623	32	.000	2.973	32	5.489	1,38	.024
	yes	.513	8	.000	.418	8	.000					
3D T2	no	.473	32	.000	.544	32	.000	1.120	32	.638	1,38	.429
	yes	.391	8	.001	.641	8	.000					
2D	no	.401	32	.000	.635	32	.000	1.215	32	.222	1,38	.640
	yes	.436	8	.000	.587	8	.000					
3D	no	.386	32	.000	.672	32	.000	1.677	32	.502	1,38	.483
	yes	.376	8	.001	.727	8	.005					
T1	no	.363	32	.000	.694	32	.000	1.629	32	1.023	1,38	.318
	yes	.436	8	.000	.587	8	.000					
T2	no	.441	32	.000	.572	32	.000	1.078	32	.077	1,38	.782
	yes	.376	8	.001	.727	8	.005					
All	no	.301	32	.000	.694	32	.000	1.310	32	.104	1,38	.749
	yes	.349	8	.005	.695	8	.002					

$N = 40$, $n_{UP_{no}} = 32$, $n_{UP_{yes}} = 8$
[a] Lilliefors Significance Correction
[b] Critical value for $p = .05$ for $n = 32$ and two groups: 2.07
[c] Based on M

24. Kolmogorov-Smirnov Z test for spatial ability, gender and UP differences reciprocal effectiveness data

Table 25 Kolmogorov-Smirnov Z test (effectiveness)

		2D	3D	T1	T2	All
Spatial Ability	Statistic	.632	.632	.632	.158	.791
(median split)[a]	Sig.	.819	.819	.819	1.000	.560
	r	.100	.100	.100	.025	.125
Spatial Ability	Statistic	.474	.447	.447	.203	.595
(extreme groups)[b]	Sig.	.978	.988	.988	1.000	.870
	r	.090	.084	.084	.038	.112
Gender[a]	Statistic	.784	.656	.832	.416	.744
	Sig.	.571	.783	.494	.995	.638
	r	.124	.104	.132	.066	.118
UP[a]	Statistic	.158	.237	.316	.316	.237
	Sig.	1.000	1.000	1.000	1.000	1.000
	r	.025	.038	.050	.050	.038

[a] $N = 40$
[b] $n = 28$

25. Independent samples t-test for spatial ability, gender and UP differences reciprocal effectiveness data

Table 26 Independent samples t-test (effectiveness)

		2D	3D	T1	T2	All
Spatial Ability	Statistic	-1.031	-1.009	-1.294	-.487	-1.087
(median split)[a, b]	df	38	38	38	38	38
	Sig.	.310	.313	.197	.629	.275
	r	.165	.162	.205	.079	.174
Spatial Ability	Statistic	-.454	-.181	-.530	.130	-.381
(extreme groups)[b, c]	df	26	26	26	26	26
	Sig.	.680	.858	.629	.898	.730
	r	.089	.036	.103	.026	.074
Gender[a, b]	Statistic	1.804	1.420	1.983	.857	1.703
	df	21.921	25.194	21.798	23.996	22.474
	Sig.	.119	.189	.095	.407	.146
	r	.281	.225	.306	.138	.266
ZP! [a, d]	Statistic	-.315	-.236	-.677	.391	-.310
	df	38	38	38	38	38
	Sig.	.732	.796	.441	.698	.752
	r	.051	.038	.109	.063	.050

Bootstrapped with bias corrected and accelerated confidence interval based on 1000 bootstrap samples
[a] $N = 40$
[b] Equal variances assumed
[c] $n = 28$
[d] Equal variances not assumed

26. Descriptives of overall efficiency of all participants (Winsorized data)

Table 27 Descriptives of overall efficiency of all participants

	n	*M*	*SE*	*Mdn*	*IQR*	*Min*	*Max*
2D T1	40	37.325	2.243	33.750	23.500	12.000	67.500
2D T2	40	29.344	1.754	28.375	17.938	11.250	62.750
3D T1	40	34.938	2.449	33.375	18.625	13.250	86.500
3D T2	40	32.200	2.339	31.375	18.938	9.000	77.750
2D	40	33.334	1.649	33.813	16.313	11.625	58.125
3D	40	33.569	2.119	31.500	17.469	11.375	73.250
T1	40	36.131	2.106	34.875	21.563	12.875	67.125
T2	40	30.772	1.728	30.188	14.594	10.125	62.750
All	40	33.452	1.729	32.688	14.531	11.50	59.938

27. $z_{skewness}$ and $z_{kurtosis}$ of the Winsorized efficiency data

Table 28 $z_{skewness}$ and $z_{kurtosis}$ (efficiency)

	2D T1	2D T2	3D T1	3D T2	
$z_{skewness}$	.920	2.214*	3.179**	2.669**	
$z_{kurtosis}$	-1.072	1.585	2.711**	1.614	
	2D	**3D**	**T1**	**T2**	**All**
$z_{skewness}$	.225	2.388*	.861	1.690	1.104
$z_{kurtosis}$	-.529	1.241	-.887	.967	.106

* Significant at $p < .05$
** Significant at $p < .01$
*** Significant at $p < .001$

28. Kolmogorov-Smirnov and Shapiro-Wilk test on normality for the Winsorized efficiency data

Table 29 Kolmogorov-Smirnov and Shapiro-Wilk test (efficiency)

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
2D T1	.136	40	.061	.965	40	.251
2D T2	.137	40	.055	.936	40	.025
3D T1	.109	40	.200*	.924	40	.010
3D T2	.116	40	.186	.938	40	.030
2D	.076	40	.200*	.989	40	.959
3D	.105	40	.200*	.950	40	.073
T1	.103	40	.200*	.974	40	.476
T2	.117	40	.183	.971	40	.400
All	.082	40	.200*	.982	40	.773

* Lower bound of the true significance
[a] Lilliefors Significance Correction

29. Descriptives of overall efficiency of all participants (square root data)

Table 30 Descriptives of overall accuracy of all participants (efficiency)

	n	*M*	*SE*	*Mdn*	*IQR*	*Min*	*Max*
2D T1	40	5.998	.186	5.801	1.938	3.464	8.216
2D T2	40	5.325	.159	5.327	1.697	3.354	7.922
3D T1	40	5.779	.198	5.778	1.641	3.640	9.268
3D T2	40	5.535	.201	5.601	1.756	3.000	8.818
2D	40	5.700	.148	5.815	1.428	3.410	7.624
3D	40	5.686	.179	5.611	1.568	3.373	8.559
T1	40	5.908	.178	5.906	1.818	3.589	8.193
T2	40	5.461	.156	5.495	1.323	3.183	7.921
All	40	5.706	.151	5.717	1.254	3.391	7.742

30. Kolmogorov-Smirnov and Shapiro-Wilk test on normality for the square root efficiency data

Table 31 Kolmogorov-Smirnov and Shapiro-Wilk test (efficiency)

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
2D T1	.099	40	.200*	.978	40	.616
2D T2	.101	40	.200*	.968	40	.301
3D T1	.067	40	.200*	.976	40	.531
3D T2	.092	40	.200*	.983	40	.799
2D	.074	40	.200*	.985	40	.851
3D	.066	40	.200*	.986	40	.886
T1	.075	40	.200*	.983	40	.810
T2	.083	40	.200*	.991	40	.985
All	.064	40	.200*	.993	40	.996

* Lower bound of the true significance
[a] Lilliefors Significance Correction

31. $z_{skewness}$ and $z_{kurtosis}$ *(efficiency)* of the square root efficiency data

Table 32 $z_{skewness}$ and $z_{kurtosis}$ (efficiency)

	2D T1	2D T2	3D T1	3D T2	
$z_{skewness}$	.008	.757	1.505	1.051	
$z_{kurtosis}$	-1.044	.105	.581	-.105	
	2D	3D	T1	T2	All
$z_{skewness}$	-.842	.971	-.075	.227	-.160
$z_{kurtosis}$	-.266	.083	-.985	.218	.040

* Significant at $p < .05$
** Significant at $p < .01$
*** Significant at $p < .001$

32. $z_{skewness}$ and $z_{kurtosis}$ of the square root efficiency data for gender, spatial ability and UP

Table 33 $z_{skewness}$ and $z_{kurtosis}$ (efficiency)

	2D T1	2D T2	3D T1	3D T2	2D	3D	T1	T2	All
$z_{skewness}$ *gender* ♀	-.311	1.251	2.115*	-.255	-.044	1.458	.455	.575	.653
$z_{kurtosis}$ *gender* ♀	-.334	1.834	.870	-.498	-.469	.449	-1.008	.491	-.126
$z_{skewness}$ *gender* ♂	.763	.547	.659	2.237*	-.526	1.031	.540	-.106	-.010
$z_{kurtosis}$ *gender* ♂	-.518	-.634	-.949	2.814**	-.494	.048	-.873	-.195	-.000
$z_{skewness}$ $sa\text{-}m_{low}$	-1.350	.688	.717	1.033	-1.195	.525	-1.320	.486	-.684
$z_{kurtosis}$ $sa\text{-}m_{low}$	-.094	.797	1.139	.073	.092	-.218	.228	.139	.368
$z_{skewness}$ $sa\text{-}m_{high}$	1.336	.504	1.736	.713	-.529	1.667	1.197	-.365	.604
$z_{kurtosis}$ $sa\text{-}m_{high}$	.811	-.258	.549	.083	.377	1.119	-.177	-.044	.929
$z_{skewness}$ $sa\text{-}e_{low}$	-.726	1.128	1.095	1.178	-.635	1.621	-.562	.848	.497
$z_{kurtosis}$ $sa\text{-}e_{low}$	-.162	1.135	.254	.145	.006	.023	-.673	.443	.079
$z_{skewness}$ $sa\text{-}e_{high}$	.831	-.260	1.770	.417	-.349	1.271	.984	-.107	.474
$z_{kurtosis}$ $sa\text{-}e_{high}$	.360	-1.008	.656	-.289	-.055	.376	-.353	-.081	-.003
$z_{skewness}$ UP_{no}	-.589	.201	1.319	.734	-1.457	.693	-.222	-.285	-.507
$z_{kurtosis}$ UP_{no}	-1.012	.126	.540	.173	.341	-.124	-.901	.669	.077
$z_{skewness}$ UP_{yes}	1.850	-.093	.561	.368	1.548	-.388	.141	.239	-.737
$z_{kurtosis}$ UP_{yes}	1.529	-1.619	-.498	-.658	.615	-.255	-.994	-.648	-1.001

* Significant at $p < .05$
** Significant at $p < .01$
*** Significant at $p < .001$
sa-m Spatial ability median split groups
sa-e Spatial ability extreme (tercile split) groups

33. Kolmogorov-Smirnov, Shapiro-Wilk and Hartley's as well as Levene's test for gender square root efficiency data

Table 34 Kolmogorov-Smirnov, Shapiro-Wilk, Hartley's and Levene's test (efficiency)

		Test of Normality						Test of Homogeneity of Variance				
		Kolmogorov-Smirnova			Shapiro-Wilk			Hartley's F_{max}[b]		Levene[c]		
		D	*df*	*p*	*W*	*df*	*p*	F_{max}	*df*	*F*	$df_{1,2}$	*p*
2D T1	♀	.097	17	.200*	.977	17	.924	1.332	22	.369	1,38	.547
	♂	.132	23	.200*	.961	23	.474					
2D T2	♀	.157	17	.200*	.943	17	.360	1.331	22	1.199	1,38	.280
	♂	.144	23	.200*	.951	23	.311					
3D T1	♀	.203	17	.060	.899	17	.066	1.092	22	.034	1,38	.856
	♂	.132	23	.200*	.957	23	.398					
3D T2	♀	.115	17	.200*	.967	17	.765	1.262	22	.046	1,38	.832
	♂	.106	23	.200*	.935	23	.141					
2D	♀	.116	17	.200*	.968	17	.784	1.454	22	.839	1,38	.365
	♂	.090	23	.200*	.980	23	.907					
3D	♀	.150	17	.200*	.949	17	.435	1.140	22	.273	1,38	.604
	♂	.129	23	.200*	.974	23	.778					
T1	♀	.151	17	.200*	.950	17	.455	1.514	22	1.021	1,38	.319
	♂	.147	23	.200*	.955	23	.375					
T2	♀	.157	17	.200*	.970	17	.820	1.001	22	.010	1,38	.921
	♂	.068	23	.200*	.992	23	.999					
All	♀	.089	17	.200*	.976	17	.916	1.333	22	.160	1,38	.691
	♂	.098	23	.200*	.984	23	.966					

$N = 40$, $n_{♀} = 17$, $n_{♂} = 23$
* Lower bound of the true significance
[a] Lilliefors Significance Correction
[b] Critical value for $p = .05$ for $n = 20$ and two groups: 2.46
[c] Based on *M*

34. Kolmogorov-Smirnov, Shapiro-Wilk and Hartley's as well as Levene's test for spatial ability square median split square root efficiency data

Table 35 Kolmogorov-Smirnov, Shapiro-Wilk, Hartley's and Levene's test (efficiency)

		Test of Normality						Test of Homogeneity of Variance				
		Kolmogorov-Smirnov[a]			Shapiro-Wilk			Hartley's F_{max}[b]		Levene[c]		
		D	*df*	*p*	*W*	*df*	*p*	F_{max}	*df*	*F*	$df_{1,2}$	*p*
2D T1	low	.132	20	.200*	.945	20	.302	1.049	19	.107	1,38	.746
	high	.195	20	.044	.938	20	.216					
2D T2	low	.118	20	.200*	.959	20	.527	1.034	19	.160	1,38	.692
	high	.134	20	.200*	.960	20	.537					
3D T1	low	.153	20	.200*	.964	20	.636	2.038	19	3.392	1,38	.073
	high	.150	20	.200*	.929	20	.147					
3D T2	low	.117	20	.200*	.968	20	.718	1.095	19	.002	1,38	.965
	high	.120	20	.200*	.981	20	.948					
2D	low	.131	20	.200*	.960	20	.543	1.213	19	.110	1,38	.742
	high	.097	20	.200*	.983	20	.964					
3D	low	.107	20	.200*	.977	20	.893	1.643	19	.895	1,38	.350
	high	.136	20	.200*	.974	20	.324					
T1	low	.139	20	.200*	.953	20	.416	1.580	19	1.218	1,38	.277
	high	.179	20	.094	.948	20	.338					
T2	low	.120	20	.200*	.977	20	.882	1.112	19	.024	1,38	.878
	high	.081	20	.200*	.994	20	1.000					
All	low	.084	20	.200*	.987	20	.990	1.200	19	.006	1,38	.937
	high	.133	20	.200*	.969	20	.731					

$N = 40$, $n_{low} = 20$, $n_{high} = 20$
* Lower bound of the true significance
[a] Lilliefors Significance Correction
[b] Critical value for $p = .05$ for $n = 20$ and two groups: 2.46
[c] Based on *M*

35. Kolmogorov-Smirnov, Shapiro-Wilk and Hartley's as well as Levene's test for spatial ability extreme group square root efficiency data

Table 36 Kolmogorov-Smirnov, Shapiro-Wilk, Hartley's and Levene's test (efficiency)

		Test of Normality						Test of Homogeneity of Variance				
		Kolmogorov-Smirnov[a]			Shapiro-Wilk			Hartley's F_{max}[b]		Levene[c]		
		D	*df*	*p*	*W*	*df*	*p*	F_{max}	*df*	*F*	$df_{1,2}$	*p*
2D T1	low	.142	15	.200*	.971	15	.872	1.676	14	.271	1,26	.607
	high	.219	13	.088	.914	13	.206					
2D T2	low	137	15	.200*	.943	15	.418	1.086	14	.117	1,26	.735
	high	.217	13	.096	.900	13	.132					
3D T1	low	.122	15	.200*	.957	15	.641	3.740	14	4.894	1,26	.036
	high	.194	13	.196	.908	13	.173					
3D T2	low	.131	15	.200*	.958	15	.650	1.079	14	.104	1,26	.749
	high	.119	13	.200*	.979	13	.977					
2D	low	.122	15	.200*	.975	15	.918	1.400	14	.547	1,26	.466
	high	.158	13	.200*	.967	13	.856					
3D	low	.175	15	.200*	.897	15	.085	2.463	14	2.298	1,26	.142
	high	.176	13	.200*	.950	13	.606					
T1	low	.189	15	.156	.945	15	.457	2.834	14	3.316	1,26	.080
	high	.216	13	.099	.927	13	.311					
T2	low	.129	15	.200*	.974	15	.907	1.116	14	.020	1,26	.888
	high	.095	13	.200*	.993	13	1.000					
All	low	.103	15	.200*	.976	15	.932	2.072	14	1.606	1,26	.216
	high	.135	13	.200*	.982	13	.987					

$N = 28$, $n_{\text{extreme low}} = 15$, $n_{\text{extreme high}} = 13$
* Lower bound of the true significance
[a] Lilliefors Significance Correction
[b] Critical value for $p = .05$ for $n = 15$ and two groups: 2.86
[c] Based on *M*
Only the two extreme groups (without the third middle group) are analysed and reported

36. Kolmogorov-Smirnov, Shapiro-Wilk and Hartley's as well as Levene's test for UP-groups square root efficiency data

Table 37 Kolmogorov-Smirnov, Shapiro-Wilk, Hartley's and Levene's test (efficiency)

		Test of Normality						Test of Homogeneity of Variance				
		Kolmogorov-Smirnov[a]			Shapiro-Wilk			Hartley's F_{max}[b]		Levene[c]		
		D	*df*	*p*	*W*	*df*	*p*	F_{max}	*df*	*F*	$df_{1,2}$	*p*
2D T1	no	.091	32	.200*	.968	32	.455	1.066	32	.722	1,38	.401
	yes	.249	8	.156	.876	8	.174					
2D T2	no	.125	32	.200*	.966	32	.408	2.625	32	1.441	1,38	.237
	yes	.233	8	.200*	.819	8	.046					
3D T1	no	.090	32	.200*	.969	32	.480	1.529	32	.509	1,38	.480
	yes	.180	8	.200*	.911	8	.361					
3D T2	no	.100	32	.200*	.988	32	.970	1.675	32	.357	1,38	.554
	yes	.205	8	.200*	.948	8	.688					
2D	no	.102	32	.200*	.972	32	.544	1.477	32	.315	1,38	.578
	yes	.251	8	.147	.900	8	.291					
3D	no	.081	32	.200*	.985	32	.932	1.908	32	1.138	1,38	.293
	yes	.119	8	.200*	.983	8	.978					
T1	no	.081	32	.200*	.980	32	.811	1.619	32	.816	1,38	.372
	yes	.161	8	.200*	.939	8	.599					
T2	no	.101	32	.200*	.987	32	.963	1.976	32	.634	1,38	.431
	yes	.160	8	.200*	.951	8	.718					
All	no	.065	32	.200*	.989	32	.983	2.180	32	.912	1,38	.346
	yes	.219	8	.200*	.890	8	.236					

$N = 40$, $n_{UP_{no}} = 32$, $n_{UP_{yes}} = 8$
* Lower bound of the true significance
[a] Lilliefors Significance Correction
[b] Critical value for $p = .05$ for $n = 32$ and two groups: 2.07
[c] Based on M

37. Independent samples t-test for spatial ability, gender and UP differences square root efficiency data

Table 38 Independent samples t-test (efficiency)

		2D	3D	T1	T2	All
Spatial Ability (median split)[a, b]	Statistic	1.852	1.918	1.842	1.842	2.027
	df	38	38	38	38	38
	Sig.	.072	.063	.073	.073	.050
	r	.288	.297	.286	286	.312
Spatial Ability (extreme groups)[a, c]	Statistic	1.920	1.347	1.520	1.639	1.693
	df	26	26	26	26	26
	Sig.	.066	.190	.141	.113	.102
	r	.352	.255	.286	.306	.315
Gender[a, b]	Statistic	-2.646	-3.145	-3.332	-2.269	-3.193
	df	38	38	38	38	38
	Sig.	.012	.003	.002	.029	.003
	r	.394	.455	.476	.345	.460
UP[a, b]	Statistic	1.318	1.236	.488	2.282	1.364
	df	38	38	38	38	38
	Sig.	.195	.224	.628	.028	.181
	r	.209	.197	.079	.347	.216

[a] Equal variances assumed
[b] $N = 40$
[c] $n = 28$

38. Descriptives of confidence ratings of all participants

Table 39 Descriptives of confidence ratings of all participants (average by group)

	n	*M*	*SE*	*Mdn*	*IQR*	*Min*	*Max*
2D T1	40	4.144	.115	4.250	1.000	2.750	5.000
2D T2	40	4.381	.102	4.625	1.188	2.750	5.000
3D T1	40	4.281	.110	4.375	1.125	2.250	5.000
3D T2	40	4.213	.133	4.500	1.250	2.000	5.000
2D	40	4.263	.099	4.375	.969	2.750	5.000
3D	40	4.247	.118	4.375	1.000	2.500	5.000
T1	40	4.213	.106	4.438	1.094	2.500	5.000
T2	40	4.297	.111	4.500	1.000	2.500	5.000
All	40	4.255	.105	4.406	1.047	2.688	5.000

39. $z_{skewness}$ and $z_{kurtosis}$ of the confidence data

Table 40 $z_{skewness}$ and $z_{kurtosis}$ (confidence)

	2D T1	2D T2	3D T1	3D T2	
$z_{skewness}$	-1.428	-2.457*	-2.845**	-2.548*	
$z_{kurtosis}$	-1.067	-.119	1.053	-.267	
	2D	3D	T1	T2	All
$z_{skewness}$	-2.072*	-2.291*	-1.872	-2.318*	-2.123*
$z_{kurtosis}$	-.138	-.539	-.336	-.356	

* Significant at $p < .05$
** Significant at $p < .01$
*** Significant at $p < .001$

40. Results of the Kolmogorov-Smirnov and Shapiro-Wilk test on normality for the confidence data

Table 41 Kolmogorov-Smirnov and Shapiro-Wilk test (confidence)

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
2D T1	.147	40	.029	.904	40	.003
2D T2	.216	40	.000	.859	40	.000
3D T1	.157	40	.014	.883	40	.001
3D T2	.214	40	.000	.845	40	.000
2D	.147	40	.030	.874	40	.007
3D	.168	40	.006	.919	40	.000
T1	.166	40	.007	.919	40	.007
T2	.216	40	.000	.875	40	.000
All	.143	40	.037	.906	40	.003

[a] Lilliefors Significance Correction

41. $z_{skewness}$ and $z_{kurtosis}$ of the confidence data for gender, spatial ability and UP

Table 42 $z_{skewness}$ and $z_{kurtosis}$ (confidence)

	2D T1	2D T2	3D T1	3D T2	2D	3D	T1	T2	All
$z_{skewness}$ $gender_{♀}$	-.549	-1.053	-1.015	-.822	-1.433	-.604	-.796	-.826	-.953
$z_{kurtosis}$ $gender_{♀}$	-1.277	-.894	.493	-1.115	-.474	-1.358	-.780	-1.178	-.975
$z_{skewness}$ $gender_{♂}$	-1.085	-1.815	-1.620	-2.840**	-1.214	-2.119*	-1.102	-1.944	-1.418
$z_{kurtosis}$ $gender_{♂}$	-1.382	-.443	-.353	1.567	-1.300	.400	-1.336	.162	-.863
$z_{skewness}$ $sa\text{-}m_{low}$	-.506	-2.002*	-1.531	-1.086	-1.494	-.965	-.893	-1.323	-1.197
$z_{kurtosis}$ $sa\text{-}m_{low}$	-1.238	-.032	-.181	-1.019	-.325	-1.237	-.783	-.797	-.849
$z_{skewness}$ $sa\text{-}m_{high}$	-1.088	-1.061	-1.334	-2.713**	-1.127	-1.928	-.934	-1.795	-1.234
$z_{kurtosis}$ $sa\text{-}m_{high}$	-1.421	-1.362	-.669	1.516	-1.231	.231	-1.423	-.162	-.964
$z_{skewness}$ $sa\text{-}e_{low}$	-1.009	-2.824**	-2.919**	-1.498	-2.112*	-1.731	-1.809	-1.745	-2.078*
$z_{kurtosis}$ $sa\text{-}e_{low}$	-.818	2.877**	3.724***	-.467	1.120	.241	.690	-.030	.798
$z_{skewness}$ $sa\text{-}e_{high}$	-.797	-1.049	-.578	-1.924	-.992	-1.356	-.466	-1.372	-.776
$z_{kurtosis}$ $sa\text{-}e_{high}$	-1.330	-.940	-1.027	.951	-.976	.029	-1.500	-.365	-1.150
$z_{skewness}$ UP_{no}	-.978	-2.036	-2.408*	-2.005*	-1.623	-1.780	-1.242	-1.800	-1.573
$z_{kurtosis}$ UP_{no}	-1.262	-.183	.975	-.308	-.328	-.548	-.492	-.372	-.365
$z_{skewness}$ UP_{yes}	-.513	-2.594**	-3.426***	-3.674***	-1.830	-3.693***	-2.472*	-3.484***	-3.338***
$z_{kurtosis}$ UP_{yes}	-1.267	2.164*	4.632***	5.198***	1.336	5.254***	2.683**	4.736***	4.497***

* Significant at $p < .05$
** Significant at $p < .01$
*** Significant at $p < .001$
sa-m Spatial ability median split groups
sa-e Spatial ability extreme (tercile split) groups

42. Kolmogorov-Smirnov, Shapiro-Wilk and Hartley's as well as Levene's test for gender confidence data

Table 43 Kolmogorov-Smirnov, Shapiro-Wilk, Hartley's and Levene's test (confidence)

		Test of Normality						Test of Homogeneity of Variance				
		Kolmogorov-Smirnov [a]			Shapiro-Wilk			Hartley's F_{max} [b]		Levene [c]		
		D	*df*	*p*	*W*	*df*	*p*	F_{max}	*df*	*F*	$df_{1,2}$	*p*
2D T1	♀	.153	17	.200*	.882	17	.035	1.534	22	.915	1,38	.345
	♂	.195	23	.023	.848	23	.002					
2D T2	♀	.227	17	.020	.867	17	.019	2.419	22	6.213	1,38	.017
	♂	.205	23	.014	.852	23	.003					
3D T1	♀	.149	17	.200*	.915	17	.120	3.159	22	5.768	1,38	.021
	♂	.185	23	.040	.885	23	.013					
3D T2	♀	.221	17	.028	.873	17	.025	1.997	22	6.758	1,38	.013
	♂	.203	23	.015	.798	23	.000					
2D	♀	.189	17	.107	.894	17	.053	1.553	22	.346	1,38	.560
	♂	.190	23	.030	.856	23	.003					
3D	♀	.162	17	.200*	.901	17	.070	2.426	22	8.508	1,38	.006
	♂	.175	23	.066	.863	23	.005					
T1	♀	.150	17	.200*	.943	17	.360	1.871	22	1.840	1,38	.183
	♂	.154	23	.166	.869	23	.006					
T2	♀	.225	17	.022	.885	17	.038	2.256	22	6.578	1,38	.014
	♂	.215	23	.007	.871	23	.007					
All	♀	.146	17	.200*	.903	17	.077	1.921	22	3.331	1,38	.076
	♂	.154	23	.168	.885	23	.012					

$N = 40$, $n_♀ = 17$, $n_♂ = 23$
* Lower bound of the true significance
[a] Lilliefors Significance Correction
[b] Critical value for $p = .05$ for $n = 20$ and two groups: 2.46
[c] Based on *M*

43. Kolmogorov-Smirnov, Shapiro-Wilk and Hartley's as well as Levene's test for spatial ability median split confidence data

Table 44 Kolmogorov-Smirnov, Shapiro-Wilk, Hartley's and Levene's test (confidence)

		Test of Normality						Test of Homogeneity of Variance				
		Kolmogorov-Smirnov[a]			Shapiro-Wilk			Hartley's F_{max}[b]		Levene[c]		
		D	*df*	*p*	*W*	*df*	*p*	F_{max}	*df*	*F*	$df_{1,2}$	*p*
2D T1	low	.136	20	.200*	.917	20	.087	1.685	19	1.383	1,38	.247
	high	.248	20	.002	.817	20	.002					
2D T2	low	.227	20	.008	.844	20	.004	1.644	19	.703	1,38	.407
	high	.202	20	.032	.834	20	.003					
3D T1	low	.172	20	.123	.900	20	.040	2.702	19	3.747	1,38	.060
	high	.217	20	.015	.884	20	.021					
3D T2	low	.245	20	.003	.877	20	.015	1.996	19	5.971	1,38	.019
	high	.205	20	.028	.804	20	.001					
2D	low	.140	20	.200*	.918	20	.089	1.545	19	.421	1,38	.520
	high	.179	20	.093	.861	20	.008					
3D	low	.157	20	.200*	.896	20	.035	2.260	19	6.019	1,38	.019
	high	.198	20	.038	.865	20	.010					
T1	low	.167	20	.146	.946	20	.312	1.990	19	2.570	1,38	.117
	high	.178	20	.097	.857	20	.007					
T2	low	.181	20	.084	.892	20	.029	1.760	19	2.541	1,38	.119
	high	.245	20	.003	.858	20	007					
All	low	.149	20	.200*	.912	20	.070	1.883	19	2.562	1,38	.118
	high	.470	20	.131	.881	20	.018					

$N = 40$, $n_{low} = 20$, $n_{high} = 20$
* Lower bound of the true significance
[a] Lilliefors Significance Correction
[b] Critical value for $p = .05$ for $n = 20$ and two groups: 2.46
[c] Based on *M*

44. Kolmogorov-Smirnov, Shapiro-Wilk and Hartley's as well as Levene's test for spatial ability extreme groups confidence data

Table 45 Kolmogorov-Smirnov, Shapiro-Wilk, Hartley's and Levene's test (confidence)

		Test of Normality						Test of Homogeneity of Variance				
		Kolmogorov-Smirnov[a]			Shapiro-Wilk			Hartley's F_{max}[b]		Levene[c]		
		D	*df*	*p*	*W*	*df*	*p*	F_{max}	*df*	*F*	$df_{1,2}$	*p*
2D T1	low	.165	15	.200*	.885	15	.056	1.340	14	.053	1,26	.820
	high	.241	13	.038	.816	13	.011					
2D T2	low	221	15	.047	.824	15	.008	1.456	14	.006	1,26	.938
	high	.210	13	.120	.841	13	.022					
3D T1	low	.205	15	.088	.826	15	.008	2.656	14	.625	1,26	.436
	high	.171	13	.200*	.899	13	.128					
3D T2	low	.288	15	.002	.848	15	.016	1.350	14	.663	1,26	.423
	high	.259	13	.017	.825	13	.014					
2D	low	.183	15	.187	.891	15	.069	1.166	14	.002	1,26	.962
	high	.171	13	.200*	.874	13	.059					
3D	low	.163	15	.200*	.900	15	.095	1.699	14	.767	1,26	.559
	high	.226	13	.068	.863	13	.042					
T1	low	.197	15	.120	.905	15	.115	1.707	14	.350	1,26	.080
	high	.208	13	.129	.841	13	.022					
T2	low	.208	15	.079	.864	15	.027	1.228	14	.081	1,26	.779
	high	.224	13	.073	.866	13	.047					
All	low	.172	15	.200*	.867	15	.030	1.444	14	.130	1,26	.772
	high	.207	13	.130	.865	13	.045					

$N = 28$, $n_{\text{extreme low}} = 15$, $n_{\text{extreme high}} = 13$
* Lower bound of the true significance
[a] Lilliefors Significance Correction
[b] Critical value for $p = .05$ for $n = 15$ and two groups: 2.86
[c] Based on *M*
Only the two extreme groups (without the third middle group) are analysed and reported

45. Kolmogorov-Smirnov, Shapiro-Wilk and Hartley's as well as Levene's test for UP-groups confidence data

Table 46 Kolmogorov-Smirnov, Shapiro-Wilk, Hartley's and Levene's test (confidence)

		Test of Normality						Test of Homogeneity of Variance				
		Kolmogorov-Smirnov[a]			Shapiro-Wilk			Hartley's F_{max}[b]		Levene[c]		
		D	df	p	W	df	p	F_{max}	df	F	$df_{1,2}$	p
2D T1	no	.134	32	.149	.911	32	.012	2.119	32	2.266	1,38	.141
	yes	.208	8	.200*	.849	8	.094					
2D T2	no	.196	32	.003	.885	32	.003	1.340	32	.799	1,38	.377
	yes	.443	8	.000	.601	8	.000					
3D T1	no	.174	32	.015	.909	32	.010	1.801	32	1.615	1,38	.212
	yes	.375	8	.001	.566	8	.000					
3D T2	no	.200	32	.002	.889	32	.003	1.090	32	1.072	1,38	.307
	yes	.407	8	.000	.478	8	.000					
2D	no	.124	32	.200*	.935	32	.053	1.768	32	1.378	1,38	.248
	yes	.212	8	.200*	.822	8	.049					
3D	no	.164	32	.029	.913	32	.014	1.263	32	1.441	1,38	.237
	yes	.470	8	.000	.494	8	.000					
T1	no	.123	32	.200*	.944	32	.099	2.317	32	3.083	1,38	.087
	yes	.265	8	.103	.793	8	.024					
T2	no	.198	32	.003	.912	32	.012	1.101	32	.885	1,38	.353
	yes	.354	8	.004	.548	8	.000					
All	no	.101	32	.200*	.937	32	.061	1.501	32	2.050	1,38	.160
	yes	.392	8	.001	.637	8	.000					

$N = 40$, $n_{UP_{no}} = 32$, $n_{UP_{yes}} = 8$
* Lower bound of the true significance
[a] Lilliefors Significance Correction
[b] Critical value for $p = .05$ for $n = 32$ and two groups: 2.07
[c] Based on M

46. Kolmogorov-Smirnov Z test for spatial ability and gender differences confidence data

Table 47 Kolmogorov-Smirnov Z test (confidence)

		2D	3D	T1	T2	All
Spatial Ability (median split)[a]	Statistic	1.107	.791	1.107	.791	.949
	Sig.	.172	.560	.172	.560	.329
	r	.175	.125	.175	.125	.150
Spatial Ability (extreme groups)[b]	Statistic	.893	.514	.893	.636	1.105
	Sig.	.402	.954	.402	.813	.254
	r	.169	.097	.169	.116	.209
Gender[a]	Statistic	1.399	1.016	1.079	1.063	1.087
	Sig.	.040	.254	.194	.208	.188
	r	.221	.161	.171	.168	.172
UP[a]	Statistic	.949	1.739	1.186	1.423	1.502
	Sig.	.329	.005	.120	.035	.022
	r	.150	.275	.188	.225	.238

[a] $N = 40$
[b] $n = 28$

47. Independent samples t-test for spatial ability, gender and UP differences confidence data

Table 48 Independent samples t-test (confidence)

		2D	3D	T1	T2	All
Spatial Ability (median split)[a, b]	Statistic	-1.974	-1.835	-2.441	-1.401	-1.964
	df	36.333	33.060	34.247	35.322	34.743
	Sig.	.054	.074	.020	.178	.058
	r	.311	.304	.385	.229	.316
Spatial Ability (extreme groups)[c, d]	Statistic	-1.338	-.972	-1.677	-.585	-1.189
	df	26	26	26	26	26
	Sig.	.192	.340	.105	.563	.245
	r	.254	.187	.312	.114	.227
Gender[a, b]	Statistic	2.353	2.096	2.641	1.802	2.295
	df	29.927	25.512	27.963	26.160	27.699
	Sig.	.041	.053	.021	.093	.039
	r	.395	.383	.447	.332	.400
UP[a, b]	Statistic	-2.152	-2.248	-2.589	-1.954	-2.300
	df	13.940	11.853	16.229	11.193	12.832
	Sig.	.049	.044	.020	.076	.039
	r	.499	.548	.541	.504	.540

Bootstrapped with bias corrected and accelerated confidence interval based on 1000 bootstrap samples
[a] $N = 40$
[b] Equal variances not assumed
[c] Equal variances assumed
[d] $n = 28$

48. Descriptives of number of averaged interactions of all participants

Table 49 Descriptives of interactions of all participants (average by group)

	n	*M*	*SE*	*Mdn*	*IQR*	*Min*	*Max*
2D T1	40	1.225	.192	.750	2.438	.000	4.000
2D T2	40	1.069	.188	.750	1.938	.000	4.000
3D T1	40	1.644	.226	1.500	2.438	.000	5.250
3D T2	40	2.094	.286	1.750	2.938	.000	6.500
2D	40	1.147	.180	.688	2.303	0.000	3.250
3D	40	1.869	.235	1.563	2.375	0.000	5.500
T1	40	1.434	.192	1.313	2.219	0.000	4.375
T2	40	1.581	.220	1.313	2.563	0.000	4.375
All	40	1.508	.196	1.250	2.234	0.000	4.125

49. $z_{skewness}$ and $z_{kurtosis}$ of the interaction data

Table 50 $z_{skewness}$ and $z_{kurtosis}$ (interaction)

	2D T1	2D T2	3D T1	3D T2	
$z_{skewness}$	1.599	2.201*	1.511	1.685	
$z_{kurtosis}$	-1.405	-.592	-.595	-.724	
	2D	3D	T1	T2	All
$z_{skewness}$	1.529	1.599	1.471	1.393	1.289
$z_{kurtosis}$	-1.589	-.846	-1.362	-1.360	

* Significant at $p < .05$
** Significant at $p < .01$
*** Significant at $p < .001$

50. Kolmogorov-Smirnov and Shapiro-Wilk test on normality for the interaction data

Table 51 Kolmogorov-Smirnov and Shapiro-Wilk test (interaction)

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
2D T1	.178	40	.003	.865	40	.000
2D T2	.216	40	.000	.844	40	.000
3D T1	.138	40	.053	.914	40	.005
3D T2	.146	40	.031	.920	40	.008
2D	.177	40	.003	.858	40	.000
3D	.117	40	.183	.934	40	.021
T1	.127	40	.101	.925	40	.011
T2	.144	40	.035	.905	40	.003
All	.152	40	.021	.916	40	.006

[a] Lilliefors Significance Correction

51. $z_{skewness}$ and $z_{kurtosis}$ of the interaction data for gender, spatial ability and UP

Table 52 $z_{skewness}$ and $z_{kurtosis}$ (interaction)

	2D T1	2D T2	3D T1	3D T2	2D	3D	T1	T2	All
$z_{skewness}$ gender ♀	.942	1.242	.520	.038	.767	.245	.955	.591	.584
$z_{kurtosis}$ gender ♀	-.969	-.643	-.407	-1.468	-1.313	-.828	-.030	-1.131	-.953
$z_{skewness}$ gender ♂	1.364	2.067*	1.628	2.405	1.501	1.965	1.285	1.466	1.356
$z_{kurtosis}$ gender ♂	-1.257	-.016	-.196	1.074	-1.002	.244	-.922	-.740	-.880
$z_{skewness}$ sa-m $_{low}$	1.479	2.262**	.580	.856	1.438	.648	1.092	1.490	1.037
$z_{kurtosis}$ sa-m $_{low}$	-.725	.513	-.607	-1.309	-.936	-1.063	-.088	-.522	-.911
$z_{skewness}$ sa-m $_{high}$	.940	1.201	1.586	1.732	.981	1.719	1.162	.703	.984
$z_{kurtosis}$ sa-m $_{high}$	-1.468	-.864	-.165	.169	-1.354	.162	-1.025	-1.287	-1.048
$z_{skewness}$ sa-e $_{low}$	1.033	1.698	.124	.376	.957	.310	.740	1.112	.672
$z_{kurtosis}$ sa-e $_{low}$	-.650	.117	-.370	-1.129	-.951	-.814	.300	-1.426	-.710
$z_{skewness}$ sa-e $_{high}$	1.094	.849	1.758	.917	.883	1.545	1.313	.568	1.003
$z_{kurtosis}$ sa-e $_{high}$	-1.153	-1.214	.413	-.657	-1.343	.464	-.802	-1.328	-.918
$z_{skewness}$ UP $_{no}$	1.693	1.621	2.077*	1.130	1.391	1.539	1.814	1.179	1.314
$z_{kurtosis}$ UP $_{no}$	-.922	-1.024	.412	-1.279	-1.511	-.378	-.297	-1.320	-1.115
$z_{skewness}$ UP $_{yes}$	.376	.757	-.850	1.633	.640	.822	-.267	1.015	.347
$z_{kurtosis}$ UP $_{yes}$	-1.365	-1.035	-1.269	1.184	-.986	-.152	-.710	-.168	-1.122

* Significant at $p < .05$
** Significant at $p < .01$
*** Significant at $p < .001$
sa-m Spatial ability median split groups
sa-e Spatial ability extreme (tercile split) groups

52. Kolmogorov-Smirnov, Shapiro-Wilk and Hartley's as well as Levene's test for gender interaction data

Table 53 Kolmogorov-Smirnov, Shapiro-Wilk, Hartley's and Levene's test (interaction)

		Test of Normality						Test of Homogeneity of Variance				
		Kolmogorov-Smirnov[a]			Shapiro-Wilk			Hartley's F_{max}[b]		Levene[c]		
		D	*df*	*p*	*W*	*df*	*p*	F_{max}	*df*	*F*	$df_{1,2}$	*p*
2D T1	♀	.203	17	.062	.883	17	.035	1.317	22	.821	1,38	.370
	♂	.224	23	.004	.844	23	.002					
2D T2	♀	.281	17	.001	.820	17	.004	1.354	22	1.747	1,38	.194
	♂	.186	23	.038	.842	23	.002					
3D T1	♀	.130	17	.200*	.917	17	.131	1.157	22	.077	1,38	.783
	♂	.173	23	.074	.891	23	.017					
3D T2	♀	.168	17	.200*	.903	17	.077	1.044	22	.444	1,38	.509
	♂	.149	23	.200*	.882	23	.011					
2D	♀	.181	17	.141	.863	17	.017	1.210	22	.342	1,38	.562
	♂	.219	23	.006	.852	23	.003					
3D	♀	.131	17	.200*	.958	17	.591	1.254	22	.099	1,38	.754
	♂	.168	23	.091	.898	23	.023					
T1	♀	.104	17	.200*	.944	17	.365	1.026	22	.185	1,38	.670
	♂	.176	23	.064	.898	23	.023					
T2	♀	.124	17	.200*	.926	17	.186	1.181	22	.163	1,38	.689
	♂	.184	23	.041	.896	23	.021					
All	♀	.124	17	.200*	.947	17	.413	1.035	22	.101	1,38	.752
	♂	.181	23	.049	.895	23	.020					

$N = 40$, $n_♀ = 17$, $n_♂ = 23$
* Lower bound of the true significance
[a] Lilliefors Significance Correction
[b] Critical value for $p = .05$ for $n = 20$ and two groups: 2.46
[c] Based on *M*

53. Kolmogorov-Smirnov, Shapiro-Wilk and Hartley's as well as Levene's test for spatial ability median split interaction data

Table 54 Kolmogorov-Smirnov, Shapiro-Wilk, Hartley's and Levene's test (interaction)

		Test of Normality						Test of Homogeneity of Variance				
		Kolmogorov-Smirnov[a]			Shapiro-Wilk			Hartley's F_{max}[b]		Levene[c]		
		D	*df*	*p*	*W*	*df*	*p*	F_{max}	*df*	*F*	$df_{1,2}$	*p*
2D T1	low	.260	20	.001	.824	20	.002	1.343	19	.399	1,38	.531
	high	.237	20	.005	.864	20	.009					
2D T2	low	.321	20	.000	.769	20	.000	1.072	19	.055	1,38	.816
	high	.161	20	.183	.891	20	.028					
3D T1	low	.181	20	.085	.894	20	.033	1.181	19	.061	1,38	.806
	high	.190	20	.058	.891	20	.028					
3D T2	low	.189	20	.061	.872	20	.013	1.011	19	.103	1,38	.750
	high	.113	20	.200*	.923	20	.111					
2D	low	.257	20	.001	.813	20	.001	1.156	19	.108	1,38	.744
	high	.221	20	.012	.875	20	.014					
3D	low	.124	20	.200*	.921	20	.102	1.071	19	.055	1,38	.816
	high	.136	20	.200*	.914	20	.078					
T1	low	.169	20	.137	.907	20	.056	1.042	19	.049	1,38	.826
	high	.202	20	.032	.899	20	.040					
T2	low	.165	20	.156	.877	20	.016	1.094	19	.048	1,38	.828
	high	.191	20	.054	.910	20	.063					
All	low	.145	20	.200*	.909	20	.061	1.078	19	.017	1,38	.896
	high	.177	20	.101	.906	20	.053					

$N = 40$, $n_{low} = 20$, $n_{high} = 20$
* Lower bound of the true significance
[a] Lilliefors Significance Correction
[b] Critical value for $p = .05$ for $n = 20$ and two groups: 2.46
[c] Based on *M*

54. Kolmogorov-Smirnov, Shapiro-Wilk and Hartley's as well as Levene's test for spatial ability extreme groups interaction data

Table 55 Kolmogorov-Smirnov, Shapiro-Wilk, Hartley's and Levene's test (interaction)

		Test of Normality						Test of Homogeneity of Variance				
		Kolmogorov-Smirnov[a]			Shapiro-Wilk			Hartley's F_{max}[b]		Levene[c]		
		D	*df*	*p*	*W*	*df*	*p*	F_{max}	*df*	*F*	$df_{1,2}$	*p*
2D T1	low	.205	15	.090	.880	15	.048	1.232	14	.119	1,26	.732
	high	.291	13	.004	.835	13	.018					
2D T2	low	.264	15	.006	.824	13	.008	1.148	–	.388	1,26	.539
	high	.232	13	.053	.829	13	.016					
3D T1	low	.192	15	.141	.915	15	.161	1.406	14	.125	1,26	.727
	high	.211	13	.117	.864	13	.044					
3D T2	low	.130	15	.200*	.913	15	.148	1.045	14	.045	1,26	.834
	high	.170	13	.200*	.927	13	.309					
2D	low	.177	15	.200*	.872	15	.036	1.055	14	.202	1,26	.657
	high	.241	13	.038	.831	13	.016					
3D	low	.126	15	.200*	.960	15	.697	1.263	14	.055	1,26	.817
	high	.170	13	.200*	.908	13	.172					
T1	low	.121	15	.200*	.944	15	.431	1.222	14	.726	1,26	.402
	high	.241	13	.038	.853	13	.032					
T2	low	.136	15	.200*	.913	15	.153	1.130	14	1.174	1,26	.288
	high	.253	13	.022	.856	13	.035					
All	low	.102	15	.200*	.951	15	.535	1.195	14	.528	1,26	.474
	high	.237	13	.044	.878	13	.037					

$N = 28$, $n_{\text{extreme low}} = 15$, $n_{\text{extreme high}} = 13$
* Lower bound of the true significance
[a] Lilliefors Significance Correction
[b] Critical value for $p = .05$ for $n = 15$ and two groups: 2.86
[c] Based on *M*
Only the two extreme groups (without the third middle group) are analysed and reported

55. Kolmogorov-Smirnov, Shapiro-Wilk and Hartley's as well as Levene's test for UP-groups interaction data

Table 56 Kolmogorov-Smirnov, Shapiro-Wilk, Hartley's and Levene's test (interaction)

		Test of Normality						Test of Homogeneity of Variance				
		Kolmogorov-Smirnov[a]			Shapiro-Wilk			Hartley's F_{max}[b]		Levene[c]		
		D	*df*	*p*	*W*	*df*	*p*	F_{max}	*df*	*F*	$df_{1,2}$	*p*
2D T1	no	.183	32	.008	.862	32	.001	1.445	32	1.199	1,38	.280
	yes	.247	8	.166	.842	8	.079					
2D T2	no	.207	32	.001	.852	32	.000	2.975	32	4.711	1,38	.036
	yes	.303	8	.029	.817	8	.044					
3D T1	no	.142	32	.098	.899	32	.006	1.031	32	.217	1,38	.644
	yes	.292	8	.043	.809	8	.036					
3D T2	no	.180	32	.010	.911	32	.012	1.463	32	.007	1,38	.934
	yes	.238	8	.200*	.888	8	.226					
2D	no	.190	32	.005	.850	32	.000	1.324	32	.791	1,38	.380
	yes	.188	8	.200*	.878	8	.181					
3D	no	.144	32	.092	.926	32	.030	1.088	32	.022	1,38	.883
	yes	.164	8	.200*	.952	8	.736					
T1	no	.150	32	.064	.906	32	.009	1.042	32	.171	1,38	.682
	yes	.157	8	.200*	.950	8	.711					
T2	no	.170	32	.020	.902	32	.007	1.152	32	.419	1,38	.521
	yes	.172	8	.200*	.926	8	.483					
All	no	.173	32	.016	.911	32	.012	1.146	32	.224	1,38	.638
	yes	.142	8	.200*	.912	8	.366					

$N = 40$, $n_{UP_{no}} = 32$, $n_{UP_{yes}} = 8$
* Lower bound of the true significance
[a] Lilliefors Significance Correction
[b] Critical value for $p = .05$ for $n = 32$ and two groups: 2.07
[c] Based on *M*

56. Kolmogorov-Smirnov Z test for spatial ability, gender and UPdifferences interaction data

Table 57 Kolmogorov-Smirnov Z test (interaction)

		2D	3D	T1	T2	All
Spatial Ability	Statistic	1.265	.632	.791	.791	.791
(median split)[a]	Sig.	.082	.819	.560	.560	.560
	r	.200	.100	.125	.125	.125
Spatial Ability	Statistic	.677	.487	.920	.690	.541
(extreme groups)[b]	Sig.	.750	.972	.365	.727	.931
	r	.107	.077	.146	.109	.086
Gender[a]	Statistic	.560	.808	.664	.528	.584
	Sig.	.913	.532	.771	.943	.885
	r	.089	.128	.105	.083	.092
UP[a]	Statistic	.395	.632	.791	.395	.395
	Sig.	.998	.819	.560	.998	.998
	r	.063	.100	.125	.063	.063

[a] $N = 40$
[b] $n = 28$

57. Independent samples t-test for spatial ability, gender and UP differences interaction data

Table 58 Independent samples t-test (interaction)

		2D	3D	T1	T2	All
Spatial Ability (median split)[a, b]	Statistic	-.674	-.395	-.209	-.793	-.545
	df	38	38	38	38	38
	Sig.	.473	.695	.836	.433	.574
	r	.109	.064	.034	.128	.088
Spatial Ability (extreme groups)[b, c]	Statistic	-.153	.349	.429	-.146	.131
	df	26	26	26	26	26
	Sig.	.879	.730	.672	.885	.897
	r	.030	.068	.084	.029	.026
Gender[a, b]	Statistic	-.559	-.718	.670	.689	.752
	df	38	38	38	38	38
	Sig.	.579	.477	.600	.473	.497
	r	.090	.116	.108	.111	.121
UP[a, b]	Statistic	.318	-.607	-.900	.394	-.216
	df	38	38	38	38	38
	Sig.	.752	.560	.374	.696	.830
	r	.052	.099	.148	.112	.035

Bootstrapped with bias corrected and accelerated confidence interval based on 1000 bootstrap samples
[a] $N = 40$
[b] Equal variances assumed
[c] $n = 28$

58. Outliers participant statements

Table 59 Outliers participant statements

	2D helpful	2D under-standing	2D rotation	2D count floor picture	2D count floor vis	2D legend	2D fun
Extreme	0	0	0	0	0	0	0
Probable	0	1	0	0	0	0	1
Potential	2	0	0	4	3	0	0
Normal	38	39	40	36	37	40	39
	3D helpful	**3D under-standing**	**3D rotation**	**3D count floor picture**	**3D count floor vis**	**3D legend**	**3D fun**
Extreme	0	0	0	0	0	0	0
Probable	0	1	0	0	0	0	2
Potential	3	0	0	4	3	2	0
Normal	37	39	40	36	37	38	38

Extreme: z-score > 3.29; Probable: z-score 2.58–3.29; Potential: z-score 1.96–2.57; Normal: z-score < 1.96 according to Field (2014, 179)

59. $z_{skewness}$ and $z_{kurtosis}$ of the participant statements

Table 60 $z_{skewness}$ and $z_{kurtosis}$ (participant statements)

	2D helpful	2D understanding	2D rotation	
$z_{skewness}$	-1.805	-2.642**	.783	
$z_{kurtosis}$	-.385	.521	-1.944	
	2D count floor picture	2D count floor vis	2D legend	2D fun
$z_{skewness}$	2.212*	2.294*	1.513	-1.925
$z_{kurtosis}$	-.765	-.166	-.891	.045
	2D helpful	2D understanding	2D rotation	
$z_{skewness}$	-2.177*	-3.201**	-.243	
$z_{kurtosis}$	-.160	1.337	-1.936	
	2D count floor picture	2D count floor vis	2D legend	2D fun
$z_{skewness}$	1.294	1.372	2.294	-3.979***
$z_{kurtosis}$	-1.393	-1.192	-.566	2.711**

* Significant at $p < .05$
** Significant at $p < .01$
*** Significant at $p < .001$

60. Results of the Kolmogorov-Smirnov and Shapiro-Wilk test on normality for the participant statements data

Table 61 Kolmogorov-Smirnov and Shapiro-Wilk test (participant statements)

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
2D helpful	.239	40	.000	.838	40	.000
2D understanding	.301	40	.000	.774	40	.000
2D rotation	.210	40	.000	.847	40	.000
2D count floor picture	.255	40	.000	.822	40	.000
2D count floor vis	.246	40	.000	.822	40	.000
2D legend	.221	40	.000	.880	40	.001
2D fun	.251	40	.000	.870	40	.000
3D helpful	.234	40	.000	.818	40	.000
3D understanding	.330	40	.000	.743	40	.000
3D rotation	.166	40	.007	.868	40	.000
3D count floor picture	.219	40	.000	.868	40	.000
3D count floor vis	.228	40	.000	.868	40	.000
3D legend	.248	40	.000	.820	40	.000
3D fun	.288	40	.000	.760	40	.000

[a] Lilliefors Significance Correction

61. Wilcoxon-signed rank test on participants statements

Table 62 Wilcoxon-signed rank test (participant statements)

	helpful	under-standing	rotation	count floor picture	count floor vis	legend	fun
Statistic	108.000	28.000	16.000	49.000	138.000	11.000	137.000
Sig.	.583	.492	.006	.146	.207	.004	.016
r	.062	.077	.307	.163	.141	-.323	.269

62. Paired samples t-test on participants statements

Table 63 Paired samples t-test (participant statements)

	helpful	under-standing	rotation	count floor picture	count floor vis	legend	fun
Statistic	-.476	-.771	-2.978	-1.651	-1.478	3.185	-1.864
df	39	39	39	39	39	39	39
Sig.	.644	.460	.009	.107	.121	.010	.075
r	.076	.123	.430	.256	.230	.454	.286

Bootstrapped with bias corrected and accelerated confidence interval based on 1000 bootstrap samples

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.

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September 29, 2015