Evaluation of use of 3D Maps in virtual navigation

Marcio Augusto Reolon Schmidt

Luciene Stamato Delazari

André Luiz de Alencar Mendonça

ABSTRACT: The use of cartographic representations in 3D views accumulates the advantages of technological advances, but faces a lack of cartographic knowledge needed to build these representations. Consequences include misconceptions in map design that can inhibit or even impair the understanding of the features represented and their spatial relations. A common task in 3D map-use is virtual navigation supported by 3D topographical maps. This geographical task gathers different knowledge schema, whereby someone uses it to determine their position and orientation related to other elements in the landscape and uses these elements to move to other locations. However, the determination of relative orientation and the selection of reference points are not trivial tasks in virtual environments. This problem is exacerbated by the lack of knowledge of how users react to the new perspective and perceptive differences proposed by it. There is a need for the adaptation of cartographic representations into 3D to improve the communication offered by this kind of map. However, the internal representation from the map-user does not match cartographic maps, but some features must have a visual correlation to allow the information present in both representations to be related. The strategy adopted in this research, therefore, is to compare the 3D sketch maps with conventional 2D topographic maps, and identify which features can be used for doing it. To achieve this goal, we developed a testing methodology which combines a qualitative think-aloud protocol and evaluation by questionnaires in a community of expert users, i.e. cartographers and geographers. By identifying the number of reference points, the topology between them and the orientation for the whole sketch map we were able to find evidence of the success in the proposal to navigate with 3D topographical maps. In this research 43 volunteers were selected and their 179 sketch maps were evaluated by the qualitative methods described above as well as by the Kruskall-Wallis statistical method.

KEYWORDS: 3D topographical maps, virtual navigation, user-centered design

1. Introduction

The use and dynamism of 3D maps are empowered by the manipulation and data storage abilities of computers associated with the interactivity and changes in viewpoint, which are fundamental to the creation of a sense of virtual reality. In non-immersive virtual reality (VR) the representations are created by software able to read input data and to create a perspective image on screen, and the visualization of 3D scenes is performed by monitors, keeping users out of the scene. However, the cartographic knowledge needed to build these representations has not developed in the same way as technological development. Depending on the level of detail, solutions of map generalization, symbology, interactivity, interface design and deformations caused by the perspective view, the result can be a representation that is inconsistent and difficult to understand.

The construction of 3D representations and its impact on users have been discussed in the literature by several authors over recent years, especially with respect to geographical use-tasks as virtual navigation in 3D topographical maps. Examples of such research are Vinson (1999), Darken and Peterson (2001), Haeberling (2002), Haeberling et al. (2008), among others. However, the determination of relative orientation and distance is not a trivial task in virtual environments. The authors' hypothesis is that a 3D symbology should allow users to determine their relative position and orientation, estimate distances and the positions of global and local landmarks, to make tactical and strategic decisions when moving from one place to another.

In order to contribute to this subject, this paper presents the results of applying thematic cartographic techniques on the differentiation of symbols in 3D topographical maps to work as landmarks in non-immersive virtual environments. To assess the visual proposition, 43 volunteers, chosen from geographers and cartographers, were selected to participate in the test sessions. Each session was composed by four situations were the user has to read the map with a different visual variable configuration and draw a sketch map. The test results present how this kind of symbology is perceived, and how the spatial distribution of cartographic symbols is stored in the user's cognitive map.

2. Background

Darken and Siebert (1993) define navigation as the process by which the user determines its position and orientation relative to other elements of the landscape and uses this knowledge to get to other places. This process involves the declarative knowledge necessary to identify what exists in the field of vision, configurational knowledge to determine the spatial relationship among features and the procedural knowledge to take decisions during navigation. In addition, navigation is heavily based on reading maps to explore the region. In order to offer 3D topographic maps for navigation it is therefore necessary to understand how people navigate, and how to relate their knowledge of map reading.

The primary tool for navigation and map reading is vision. According to Marr's theory, view can be understood as a process that begins with visual stimuli as chemical reactions of the eye due to differences in light intensity reflected by objects. In a second step these stimuli are grouped in separate rows and areas as a way to create a primary sketch of the scene. Then some internal processes of the brain start the process of recognition and interpretation of these images in an attempt to discriminate and locate objects in the image.

This discrimination of features represented on the map or in reality occurs through the arsenal available for the human visual system that includes the group of Gestalt factors and the separation figure-background. These parameters are applied in the first two steps of Marr. As a result what you see are whole features and symbols and not its constituent parts. In addition to the closure of the visual units provided by Gestalt, figure-background separation exists with its parameters, among which we highlight the relative contrast and contour. In real environments such in a map reading task, objects are more or less prominent depending on their variation of position, hue, saturation and value. The combination of visual variables catches the selective attention and stimulates the selection of features or objects and their recording in the short-term memory. Thus, the first proposition of this research is that it is possible to create a symbology in order to drive the selective attention to certain features and map symbols through visual variables applied to 3D symbols, and foster their relationship in the short-term memory.

The next step is to create a general structure of the scene that is passed to the short-term memory under the influence of selective attention. With repetition or habituation, more details are added to the users' memory so the spatial relationships of features represented in the cognitive map of the user are enhanced. From the cognitive map, in its various degrees of completeness, schemes of knowledge are applied (declarative, organizational and procedural) that allow a person to successfully navigate. As the internal representations are updated and enhanced with periodic and continuous exhibitions, it is possible to pass from the landmark knowledge scheme to the route knowledge scheme and then to the higher one, the terrain knowledge scheme.

These different internal representations or cognitive maps are stored in a macrostructure and, according to Pinker (2009), it aggregates a series of representations at different scales that mainly relate among themselves through the landmarks. Thus the landmarks can be divided into two groups: local and global references. This is in reference to Vinson (1999), who recommends that global landmarks are perceived as the same feature in different scales. Therefore, in order to successfully navigate people should plan their moves using a combination of spatial knowledge acquired about the environment and stored in the mental map representative of the area. Golledge (1992) identifies the basic components of spatial knowledge as identity, location, magnitude and temporality of the phenomenon. Location becomes essential to navigation because from it are derived the concepts of distance, relative angle and direction (azimuth), sequence of reference points and extreme of routes and connecting routes and landmarks.

Even if the cognitive maps are not cartographically equivalent due to internal processes to register the memory, the spatial relationship of landmarks present in the representation and the real world must be correct. Just as a map will only be effective insofar as the user recognizes landmarks in representation and in its real environment, the same comparison between 2D and 3D representations is valid in the context of this research. This is the second proposition to symbology, because it is possible to create a representation to promote the potential memorability of the symbol in the user's short-term memory.

3. Method

3.1. Building of 3D topographical maps

The cartographic design considered data classification according to Brazilian National (Systematic) Mapping at 1:50,000. The basic data were obtained from the cartographic base map of Curitiba, year 2007 at 1:10,000 scale, and the contours were reduced to 1:50,000. An important issue is that the region was entirely new to the volunteers, to prevent anyone from recognizing the region in advance which could influence the results. For this, the land use pattern was modified based on photointerpretation the Uberlândia (MG), about 1000 km north of Curitiba.

The proposal for the construction of symbols followed the proposal of Haeberling (2002), and it consists of three steps: geometric proposition, visual proposition and display proposition. The first step, disregarding the computational issues, can be understood as the definition of objects in wireframe mode such as in CAD and its distribution in the representation. Also involved is the relative position of objects that help the user extract and understand the information represented as a grid of coordinates and toponyms. The visual proposition works with visual variables. This group is concerned about the shape, size, color and brightness, texture and pattern, orientation, and special graphics features. The last step refers to those aspects that influence the perception of symbols, such as scene lighting, shading and shadows, atmospheric and environmental effects and the structure of the sky (color and fading), camera parameters such as aperture and depth of field, and level of detail.

In this research, the aspects selected were shape, size and position of features as graphic aspects, color value as visual aspects, and camera parameters (FOV and attitude), and color of the sky and scene illumination as display aspects. Figure 1 shows a scheme of the steps involved in cartographic design. The variables tested in the differentiation of the symbols of reference points are indicated in medium gray, in dark gray are the common variables to the general representation, and finally, in light gray are the color variations of the sky and the camera settings which can influence the perception of other variables. Each of these expresses different effects in the arrangement or appearance of 3D objects in topographical maps, which are built in different variations in the appearance of the resulting product.

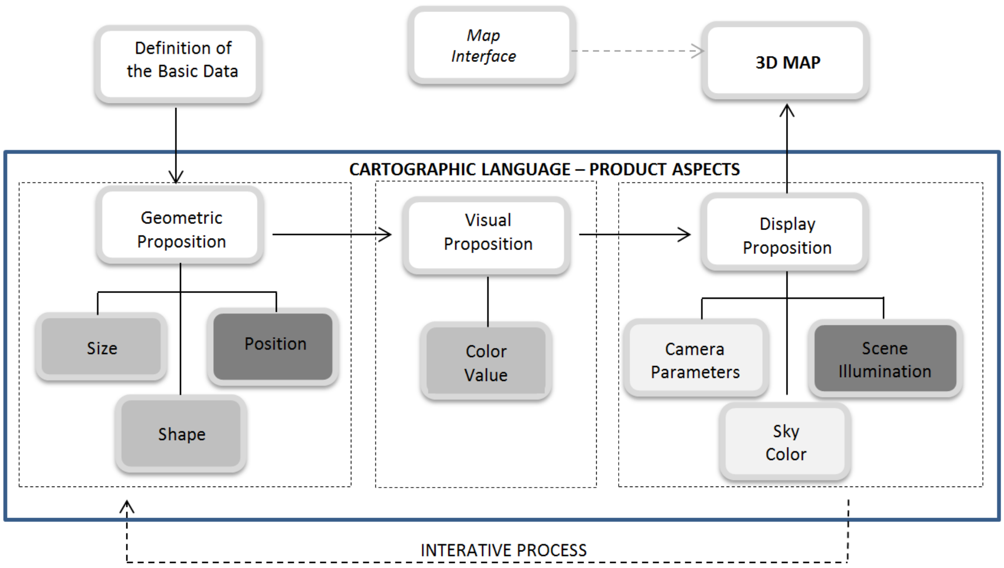

Figure 1: Structure of the 3D Map proposition. Source: Author.

However, there are many possibilities to combine aspects of each group, and each change in its spectrum of variation produces a specific effect (Haeberling, 2002). As a result, the symbology of 3D cartographic representations must be constructed similarly to the thematic map design, because the map use becomes important to guide the solutions that the cartographer can take during the map construction process. The proposal also considers the geometric degree of realism, which is the cartographic generalization applied to symbols. The proposition was carried out as a more abstract proposition than that of Petrovic and Masera (2004), and more realistic symbols than the use of height in conventional topographic symbols. The resulting map's visual variables are shown in Figure 2.

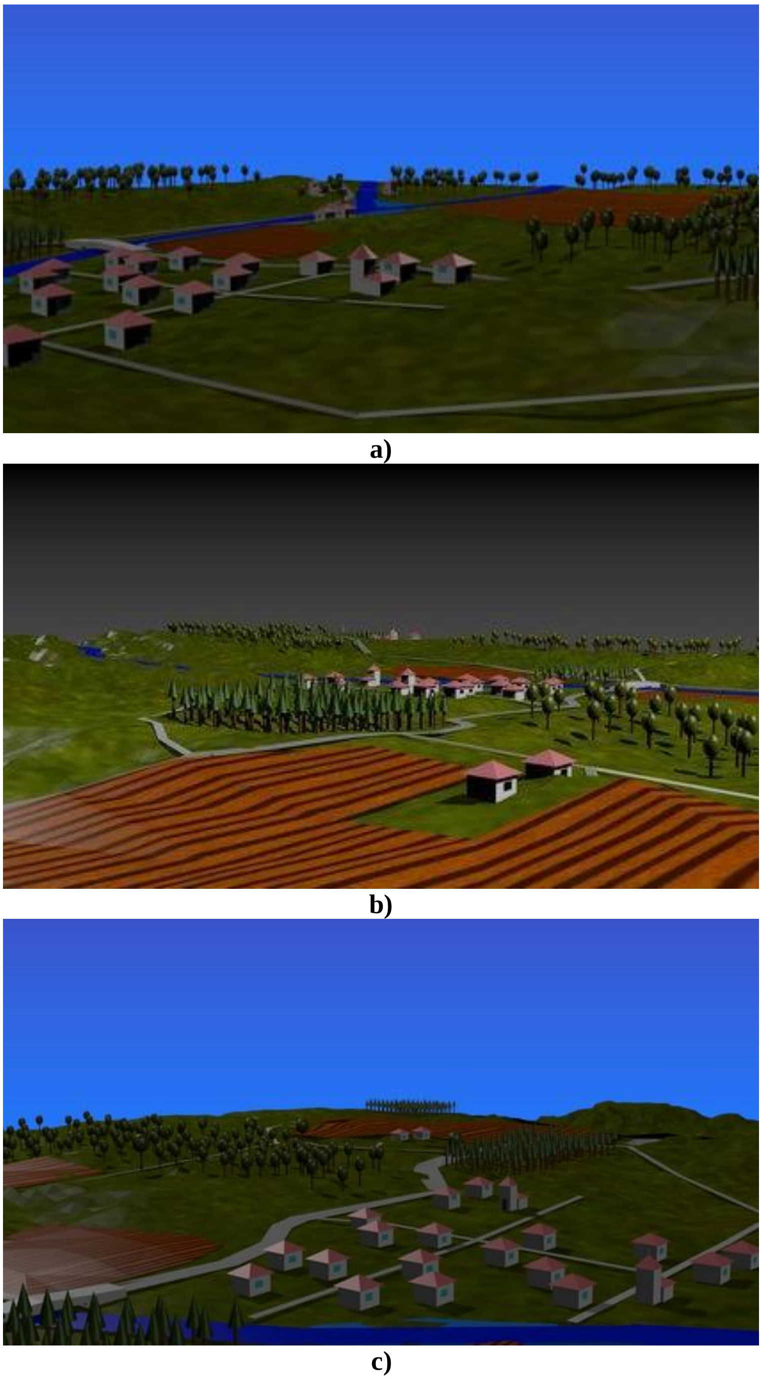

Figure 2: Samples from 3D Maps used during testing: a) visual variable Shape, b) visual variable Color value, c) visual variable Size. Source: Author

3.2. Testing Sessions

We developed four tests to assess the influence of the FOV and attitude of the camera, and the characteristics of points used as reference in the navigation capability of the users. In total there were 43 volunteers, 22 from the Federal University of Paraná (UFPR) and 21 from the Federal University of Uberlândia (UFU). The volunteers generated 179 sketch maps and 43 forms that were analyzed according to the criteria of the number of landmarks and the differences in the estimates of position, relative distance and orientation. Each test was run in sequence within the same test session.

The tests began with a user profile through multiple-choice questions. These questions attempted to identify the cartographic level of instruction, user's navigation habits while driving or walking, training and working time in map production, and age, among others. This information may contribute to the variation in spatial cognition (Montello, 2002) and, although it is difficult to establish relationships between these characteristics, they should not be discarded because the goal is to show defects in map reading or other problems in its use of which the user themself may be unaware.

The first test examined the influence of the FOV in the perception of relative distances in two situations: with and without the presence of a grid similar to the coordinate grid of the UTM projection. The users read maps for about 1 minute and then drew sketch maps. The geographic task in this test was to identify the shortest path between the three available in the image. In the first part of the test, three images with fields of view (FOV) of 42º, 46º and 54º were used. The value of 46 was set by Haeberling et al. (2008), and variations of ± 4 ° simulate the variation in peripheral vision.

The aim of the other tests was to identify which of the selected visual variables are more or less efficient in attracting the user’s attention and stimulating the correct symbol identification. The tests indicate the influence or adaptation of visual perception according to the variable adopted, the general proposition was used followed by a proposition with different landmarks.

The first visual variable tested was size. A region different from that shown in the previous test was presented to the user with the general proposition of the 3D topographic map, and then he or she received the instruction of the navigation task. In this test the instruction was: “Follow the road from the church located in the north and head to the woods located south." After which the modified image was presented under the same test conditions and a new sketch map was drawn. The volunteer should also indicate whether they could perceive any class hierarchy in the image. The second visual variable tested was the color value. Another 3D map sample was displayed with the changes in the symbology applied to the roads and to some of the trees near crossroads. The task in this test was describing the path between two points visible on the map as if the person was driving. Again, two images were presented; one with a general symbology and the other with the modification to the visual variable. The procedure was repeated in the third test which considered the visual variable shape. The top of trees that are near a river fork and buildings near the line of sight of the camera were modified. In this case, the question of order does not make sense because it is a nominal variable.

The strategy was to compare the sketch maps to the 2D and 3D maps of the same region drawn by the same person, to obtain evidence about map perception. Therefore, in the final test session a conventional topographic map at 1:50,000 scale was presented and the volunteers once again drew sketch maps. Please note that to reduce the analysis variables, such as ability to interact and use of navigation tools that are not relevant to this research, tests were performed with printed 3D topographic maps. From the sketch maps and questionnaires the frequency of the responses according to the criteria of amount of features represented, their characteristics and their estimated position were analyzed.

Five participants were selected for the Think Aloud protocol. This number of volunteers is due to the large demand of time and resources that the method requires for its performance and analysis. The protocol was run individually in the laboratory with the user sitting at a table in which different images of the 3D maps of each test were shown. As the user read the 3D map they were recorded as he or she narrated their actions and impressions aloud. Information obtained by this type of analysis was useful to identify which reference points are used to perform the task of navigation, since points are not necessarily those in the sketch, since by drawing the users could remember, process and apply their mental schemes in determining the position and characteristics of the features remembered.

4. Results

The questionnaires show that the group of participants is mostly composed of professors and doctors (54%), followed by master's degree students (21%) and a small fraction of undergraduate students in their last year of Cartography and GIS courses, and 60% of the volunteers have professional experience. The questions dealing with map use and knowledge about map projects indicate that 86% of the volunteers confirmed that they use maps very often, but only occasionally build them personally. When they build maps they are generally created through digital atlases, CAD, and with a predominance of GIS (46.5%). Nevertheless, most participants claimed to have little experience with topographic map production. Another group of answers indicated that 95% of volunteers claimed to know how to localize and navigate using maps, although 32.5% have difficulties in using topographic maps for navigation. With respect to their navigation habits, 76.8% frequently go walking and 90.6% drive daily or very often.
One of the first issues that stand in the sketch maps is that 93% of volunteers drew it according to the point of view of the scene, that is in perspective view the features located above the ground are drawn in perspective. When the sketch of the conventional topographic maps was requested, the same features were designed in an exocentric view. The number of events stand out, although they are not statistically significant ($p < 0.156038$).

The results may indicate that users unfamiliar with 3D representations do not perform any transformation between the egocentric and exocentric views. As consequence,the symbols are seen next to the outline of the primary sketch of Marr's theory. The analysis of the sketches also provides evidence that in 3D maps the symbols over the DTM, i.e. houses and trees, are most frequently adopted as landmarks. Moreover, when using conventional 2D maps the drawings assume an exocentric viewpoint, and representations are grouped by area and not by individual symbols.

A possible explanation for these results may be a consequence of the test proposition, because each participant only had one minute to read the image before drawing the sketch maps. The reduced exposure time prevents, at least in part, the internal representation in short-term memory being processed with additional information from previous experience with 3D maps. As a consequence of short exposure, the drawings show a few of these features and are much generalized in relation to the symbol displayed. Another reason is due to the static point of view applied to the images, as an egocentric view in the non-movement of the camera only allows the user to evaluate one side of the symbol. This refers to the Marr theory that states that building the internal representation of an individual symbol requires continued exposure and details of the symbol. It can be assumed that the short exposure to the 3D maps created an image in 2.5D on the participants' internal representation, and the transition from a 2D to 3D view, in fact, presents greater difficulties. These two statements agree with the verbalization of a participant in test 1 who stated that he found it difficult to change the perspective view to an orthographic view.

A third factor that stands out is the association of symbols by the participant and the Gestalt grouping criteria. In 95% of the sketches drawn from 3D images, representations of trees and houses were not perceived as a group. The spatial distribution of these features was not perceived as part of the same class, but as individual features. The results highlight the strong influence that the point of view exercised in the identification and recognition of a symbol.

The results obtained in the first test indicate that the variation of ± 4° in the opening angle of the images does not significantly change the perception of participants, since the number of correct responses was significant at 0.06 ($p < 0.053434$). The test also found that approximately 85% of volunteers prefer the image with a FOV of 42° when making the decision about which path was the shortest, in contrast to the value of 46° obtained by Haeberling et al. (2008). In the second part of this test, 40 volunteers preferred the presence of the grid placed just over the DTM. This preference can be explained by the use as a visual aid, because most of the participants counted the grid intervals to confirm the impressions made for the previous answer to feel more confident about it. Although seven people opted to redo the sketch maps after seeing the grid on the map, the majority decided not to do the drawings again. However, the grid should be positioned close to the DTM, otherwise it may cause confusion, and visualization is not possible. Another important result is that a higher number of features correctly identified were concentrated near the line of sight. These indications show that selective attention is more intense towards the center of the scene.

In tests with the visual variables, the results were influenced by the configuration of the sky and illumination of the scene. These two factors change the user's perception with respect to color hue and color value and, consequently, in the relative contrast to separate figure-background. Moreover, the number of correct answers indicates that variations in color value are the more influential than changes in shape and size. The test with the color value provided 95.4% correct answers compared to the number of reference points identified and their topology. This can be explained by the characteristics of the symbols because size and shape are very susceptible to the symbols' construction process. The results confirmed, or repeated, the results of Forrest and Castner (1985), MacEachren (1995), and others, who demonstrated that some variables are more important for visual searching and others for comparison. In general, the differentiation in landmarks by color value is strongly influenced by the scene illumination provided by the sky color. For instance, when using an image with a blue sky only 32% of the participants reported recognizing this variable in the classes.

The test results with variable size showed that 17 people (40%) correctly reported one of the possible paths, and 26 people (60%) missed the test due to errors in orientation. Although 12 people (28%) recognized the visual variable size, especially when applied to the representation of the roads, no record has been made regarding trees. One reason is that the perspective effect and the scene settings have a strong influence on visual perception, and consequently this variable in the hierarchy of classes, such as roads. This demonstrates the difficulty of using this variable visual in 3D maps. The results of this test showed the worst results for general orientation on sketch maps.

The sketch maps represented with shape present the worst results in the identification of reference points. Only five participants (11.6%) identified changes in shape on the roofs of the churches or in the top of trees, despite these landmarks being concentrated in the line of sight. Furthermore, errors in the number of features shown and topology presented larger distortions than drawn from other variables.

In each test the number of reference points and the topological position of the landmarks were analyzed, and the answers converted into frequencies. These frequencies were compared with those found on the sketch maps from topographic maps. The results for relative orientation were evaluated with the Map Analyst according to Dillemuth (2009). The strategy of this methodology is to identify whether there is a significance between the frequencies obtained, in order to show that the proposal is appropriate for navigation considering the user community and their navigation habits. The analyses were performed using the Kruskall-Wallis test (Kruskall and Wallis, 1952), and the values are shown in Table 1.

Table 1: Significance by Kruskal-Wallis test (5%) for landmarks drawn on sketch maps from a 3D map in comparison to a conventional 2D topographical map

Test	*Num Land.*	*Topology*	*Orien. Rel**	*NUM+ A+B*	*POS+ A+B*	*NUM+ C+D*	*POS+ C+D*
T 1(FOV)	0,9472	0,0188	0,0054	9,6665e-6	0,0026	2,0268e-8	0,0002
T2.1 (Value)	0,6662	0,0110	4,86e-4	0,0271	0,0008	0,0012	1,58e-4
T2.2 (Size)	0,4602	0,1075	0,4647	1,0453e-4	0,0527	3,4247e-7	0,0267
T2.3 (Shape)	0,2982	0,7179	0,00031	3,5286e-6	0,0705	2,6536e-8	0,0108

A – Instruction level; B – Years in profession; C – Used to walking; D – Used to driving
* Values taken with **a** different number of participants (n=15)

The results indicate that there is no relationship between the number of reference points identified in the 2D and 3D maps, while the appropriate topological position is significant when testing the of FOV and color value. This result suggests that some knowledge of thematic cartography is important for the correct interpretation of the 3D map. To check this assertion, some information from the questionnaires (education in cartography and navigation habits) were crossed with the number of landmarks identified and their topological positions. Critical values in this table were discarded from the analysis.

The frequencies analysis for the educational level and duration of professional activities (A and B) was significant for test 1 ($p < 0, 0026$), and also the number of items identified in the color value test ($p < 0.0271$). In Table 1 illustrates the positive correlation to the position of the landmarks in the tests of shape and size ($p < 0.0267$ and $p < 0.0108$, respectively).

However, the limitations of the 3D view hinder the development of a single map area, so the volunteers needed more time for interaction than a conventional map. The evidence collected in the tests indicates that generally the participants failed to link the four views used in tests 1 and 2 on a single map representing the area. Most participants saw each 3D view as a distinct representation from the others, despite the similarities in the graphical solutions. The exception was a parcel of volunteers, composed of students and professors, who work in map production. This can suggest that the use of this proposition being limited to specific users.

5. Conclusions

It was not possible to provide evidence that the variation of ± 4 ° in FOV can change the perception of participants. However, the paradigm of the conventional topographic map was present when evaluating the presence of the reference grid. This means that in general, users prefer the presence of the coordinate grid near the DTM as a tool for anchoring their spatial decisions. This orientation metaphor has not been tested for models with large variations in height, but the test participants were more secure in estimating relative positions, distances and orientations when the grid was present.

For the 3D maps, symbols constructed with shapes similar to the real object are easier to read, but problems with the perspective limit the spatial exploitation. In the pictures used in this research the fixed point of view did not allow the user to create a 3D internal representation of the objects, but only their outline separated from the background by the contrast. Apparently users not familiar with 3D representations do not perform any processing between views, and symbols are seen next to the primary sketch from Marr‘s theory. It can be assumed that as a result of the exposure time of the test, about 1 minute per image, the participants created a 2.5D image and that the transition from a 2D to 3D view does, in fact, present greater difficulties. Still, the position of features relative to the observer's position was also an important factor, because it identified a greater concentration of landmarks near the line of sight. These signs indicate that selective attention is more intense in the center of the scene.

The sky color had a strong influence on the brightness of landmarks, in particular those symbols furthest from the user. Even when the symbols were located near the line of sight, almost half the participants of the tests did not identify the correct answer when the sky was gray. The problem was repeated with the variables of visual size and shape. When the sky was blue (light tones) the number of correct identifications increased. In this context, the color value has a greater potential for the differentiation of landmarks, while shape achieves the worst results for all tests. Size for this purpose has the drawback of strongly influencing the camera settings, which in turn disturbs the identification of the class hierarchy. This demonstrates the difficulty in using this variable in visual 3D maps.

The statistical correlations found in the results allow the conclusion that, despite the visual variables used to assist visual searching to select specific features such as landmarks, the position of the symbol and its relationship with the rest of the representation may be more important than its appearance.

Finally, through the proposition of symbology and its tests it was possible to prove, though not conclusively for all parameters, that the 3D map project should consider using the concepts of thematic cartography. The result is representations with the power of cartographic communication that resemble the communication made by conventional topographic mapping.

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Corresponding author: Marcio Augusto Reolon Schmidt. Adjunt Professor, Department of Civil Engineer, Universidade Federal de Uberlândia, Uberlândia (MG), Brazil, email <marcioschmidt@feciv.ufu.br>