Visualization Principles in 3D Cadastre: A First Assessment of Visual Variables

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Keywords: 3D, cadastre, visualization, visual variables

SUMMARY

This paper proposes to investigate which among visual variables are more appropriate (if they are) for geo-visualization of 3D legal units in a probable 3D cadastre system. Visual variables, as proposed by Bertin (1983), include position, size, shape, value, color, orientation and texture. The appropriateness is evaluated base on whether a visual variable can be selective or not in the context of visualising 3D cadastral features. From a literature review, five requirements are identified and used to carry out the assessment. Namely they are represent bounded and partial bounded 3D legal units, represent the relationship between 3D legal units and 2D land parcels, represent the relationship of 3D legal units with corresponding physical object, represent spatial relationships among 3D legal units and label with official measurements. The results clearly show that changing the position of the visual variable for selectivity purpose is not an adequate strategy, except to distinguish bounded and unbounded 3D legal units. A change in size of point and line or in color is fully suitable no matter is the requirement. If there is light source and shading effect in 3D cadastre visualization, value is not a promising choice. However, in a self-illuminating situation, in which there is no light source and shading effect, value could be used to represent all situations. Labeling with official measurements is the requirement the least fulfil.

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1. INTRODUCTION

Facing the growing density of land use in urban context, and consequently increasing situations of vertical demarcation between real estate properties, 3D cadastre is attracting many researchers and institutions through the world in order to better register and spatially represent the overlapping situation. For instance, various pilot systems of 3D cadastre have been tested in different countries like the Netherlands (Stoter et al., 2011), Australia (Karki et al., 2011), China (Guo et al., 2011), Korea (Jeong et al., 2011), and Russia (Vandysheva et al., 2011).

3D cadastre refers to a cadastre system that represents the legal status of properties not only a on 2D cadastral parcel but also as a 3D legal unit with unique and homogeneous rights, responsibility and restrictions (van Oosterom et al., 2011; Stoter, 2004). Visualization of 3D cadastres, as stated in 1st and 2nd international cadastral workshops by Fendel (2001) and Pouliot (2011), has been recognized as a very important question since it allows graphical means to better communicate and spatially comprehend the complexity of overlapping situations. Current visualization methods, that are most often in the form of cadastre map or plan, do not fully depict the 3D situation. For example, Stoter & Salzmann (2003) indicated the deficiency of the cadastre in the Netherlands, that even professional users could not identify the 3D situation. In their opinion, a solution that could make the 3D situation better identifiable and the registration of the 3D situation better accessible could greatly warrant the legal security of the real estate. Another example are the complementary plans (PC) used in the province of Quebec (Canada) that reveal horizontal plans of the ground parcel and each floor of the condominium. Even though they currently respond to the demand of notaries and land surveyors to represent the property right of the condominium units, they are loosely coupled with the cadastral system, and restrict users interactions and queries (Pouliot et al., 2011). A new visualization system based on 3D geometric modelling of cadastre has the potential to provide a better insight into the 3D situation (the Z aspect), to facilitate the information extraction when complex perception and interpretation append (e.g. distinguish the boundary between two properties that partially overlap in X, Y, Z), and consequently to improve processes such as properties' registration or taxing.

Considering the importance of 3D visualization for cadastral system, many researches were undertaken to experiment and enhance the visualization of 3D cadastres. For example, De Vries and Zlatanova (2004) achieved a high interoperability platform which has the ability to retrieve data from a WFS (Web Feature Service) and using the X3D plug-in to handle the visualization and interaction of cadastral data. In Spain, Miguel et al. (2011) provided two special pre-rendered WMS services retrieved from high light with shadow and Z offset by number of floor. They also built a Google Earth visualization system that offers the capabilities of viewing each spatial unit in a condominium by extrusion. In Indonesia, Aditya et al. (2011) tried to build a 3D hybrid cadastre web map with a combination of formats and technologies (e.g. KML, X3D, PostgreSQL/PostGIS database).

These applications demonstrate the feasibility and the advantages of using 3D geo-visualization software for cadastre data. However, these developments are mainly focused on technical issues. They make experimentations1 with different platforms, data types or framework designs. In an era of rapid development of computer science, internet and spatial database, technical advancement effectively plays a critical role but we do estimate that theoretical and conceptual analysis must be undertaken in order to better evaluate what makes cadastral visualization specific compares to any other application domain. To investigate this question, we decided to examine one of the foundations of cartographic (visualization) systems, the visual variables. Visual variables, as proposed by Bertin (1983), include position, size, shape, value, color, orientation and texture.

Consequently, this paper proposes to investigate which among visual variables are more appropriate (if they are) for geo-visualization of 3D legal units in 3D cadastres. The appropriateness is evaluated based on whether a visual variable can be selective or not in the context of visualising 3D cadastral features. Attracting audience to selective symbols may reduce user’s cost for identification and interpretation from massive context information both mentally and temporally. The further question (not directly addressed in this paper) would be how to design the symbols composing the 3D model with a certain combination of visual variables in order to facilitate user perception and interpretation of underlying cadastral data.

For this preliminary experiment, no specific attention was paid to which users or which usages potential 3D cadastral systems may serve. We concentrate our assessment on the suitability of the visual variables to meet some requirements devoted to 3D visualization of cadastral data. To establish this list of requirements, we did a literature review and we selected those criteria specific to cadastral data and of prime importance. Although stereo 3D devices, which sometimes be termed true-3D, are applicable nowadays, 2D display devices like LCD and CRT are still the mainstream. Thus in this paper, 3D visualization mainly refers to the technology that simulate 3D perspective views in 2D displays. In this context, 3D cadastre visualization refers to a cartographic three-dimensional model (CM) which is defined as a 3D model with symbols that are abstracts of real world objects or thematic information (Haeberling, 2005; Terribilini, 1999). A CM is not always static, and could change according to user demand. This interactive visual-system could handle user input and calculate the 2D display based on perspective projection, camera position, lighting, shading and atmospheric effects. For this first experiment and because of time constraint, we did not take into consideration the interaction aspects like motion that may be also categorised as a visual variable.

The paper is organised as follows. After the introduction, Section 2 presents the visual variables. Section 3 describes the list of requirements for 3D cadastre visualization. Section 4 proposes the assessment of the visual variables based on the predefined requirements. Section 5 concludes and explains the next tasks to be accomplished.

2. REVIEW OF VISUAL VARIABLES

When creating a map or a 3D model, a systematic transformation, that may be called cartographic design process (Garlandini & Fabrikant, 2009), is necessary in order to convert the data into symbols. In this process, visual symbols with their visual variables like size or color are the basic graphic components which the human perception system could handle. In this paper, we will not address the large field of semiology of graphics (a research by itself), but remind the importance of representational mappings when producing 3D models. Bertin (Bertin, 1983), a pioneer in semiology of graphics, has identified five kinds of symbols in the creation of cartographic representations such point, line, area, surface (same as area except it exists in 3D space and has no theoretical thickness) and volume. Based on a static 2D map estimation and a perceptual level of organisation, he listed and defined seven visual variables[1] (i.e. a variable that affects the meaningful representation):

- **Position**: Corresponds to a change in spacing between symbols. For example, we may arbitrarily increase the distance between two symbols.
- **Size**: Corresponds to a change in symbol size. For example, we may increase or decrease the line thickness.
- **Shape**: Corresponds to a change in symbol style. For example, we may use an arrow instead of a square to represent a point.
- **Value**: Changing a symbol's value is achieved by changes in darkness or lightness of the symbol.
- **Color**: Changing a symbol's colour involves changes in hue without changes in value. Transparency and saturation also belong to color.
- **Texture**: Texture is the pattern, grain or material that is applied to the symbol.
- **Orientation**: Changing a symbol's orientation can be achieved by changing its general direction. Orientation is sometimes treated together with texture since it usually modifies the orientation of the pattern. For example, we can change the orientation of the lines included in the pattern.

It is good to mention that some authors also talk about highlighting techniques to indirectly refer to visual variables. Highlighting techniques are the transient visual effect on certain objects that improves the salience of the objects in order to support the pre-attentive cognition (MacEachren & Kraak, 2001; Robinson, 2009; Trapp et al., 2011). Thus, highlighting technique is not only a technology that enables feedback of user selection in a CM but could be a promising enhancing method, attracting user's attention to a subset of objects.

Bertin also defined five visual interpretation tasks associated to the visual variables. He called them the characteristics of visual variables.

- **Selective**: A visual variable could be said to be selective if users may easily distinguish the isolation between two groups of symbols only by their difference in this visual variable. The main question to be asked is: Does change in the visual variable allow users to select one object from a group of objects?

[1] Some references are talking about six visual variables since the position is considered as an intrinsic component of the feature. For this analysis, we considered the position as a visual variable.

- **Associative**: A visual variable is said to be associative if users could easily distinguish the association between two groups of symbol only by this visual variable. The main question to be asked is: Does change in the visual variable allow users to identify a number of objects as a group?
- **Quantitative**: A visual variable is said to be quantitative if numerical relationship could be perceived by users from the differing of this visual variable. The main question to be asked is: Does change in the visual variable allow users to quantify the change?
- **Order**: A visual variable is defined as ordering the difference in this visual variable could indicate an order. The main question to be asked is: Does change in the visual variable allow users to observe a difference in the order?
- **Length:** Length is slightly different from the previous one since it addresses the question of how many changes in a particular visual variable can be used effectively. The question to be asked is: After how many changes in the visual variables the user can still distinguish the symbols?

3. REQUIREMENTS FOR 3D CADASTRE VISUALIZATION

The next step in the assessment of the seven visual variables is to estimate how they perform by considering their characteristics to achieve specific requirements. From literature review and based on our experience, we have identified five requirements specific for the visualization of 3D cadastral data (of no matter is the category of usages, cadastre types, or rights). We immediately admit that this list is not exhaustive and the methodology used maybe not robust. Nevertheless, and for this preliminary experiment, we estimate this list to be good enough to initiate the assessment of the ability of visual variables to be selective in the process of 3D cadastral model interpretation, and consequently decision making.

The literature review took advantage of the papers published at the first and the second international workshops on 3D cadastres[2], the inventory made by van Oosterom about the status of 3D cadastres (van Oosterom et al., 2011), oral presentations done at a special session about 3D cadastre during the FIG Working Week 2012 (Rome, Italy) and finally an unpublished survey done last summer about the usages of 3D cadastres for urban management (Boubehrezh & Pouliot 2012). The five requirements for 3D cadastre visualization that hold for this preliminary assessment are:

- **Represent bounded and partial bounded 3D legal units:** The limits of a 3D legal unit could be bounded when it has a well-defined volume and partially bounded when those limits cannot define a finite volume. There could be many possibilities of partial bounded 3D legal unit including the restriction under a certain depth tolerance, that the right of easement. These partial bounded 3D legal units should be represented in a way that people can recognize their bounded and unbounded parts.
- **Represent the relationship between 3D legal units and 2D land parcels**: Since almost all cadastral systems are still parcel-based, the correspondence between the legal unit and the land parcel is obvious. For instance, current cadastral systems that

[2] http://3dcadastres2011.nl/

allow registration of 3D legal units require to locate the 2D land parcel and its association with the legal units. It is also common to identify the terrain (the relief), that could be perceived as a must feature.

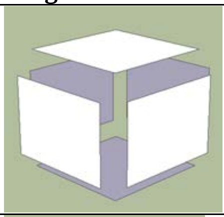
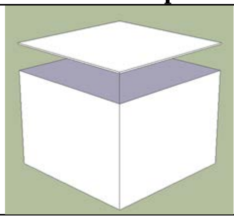
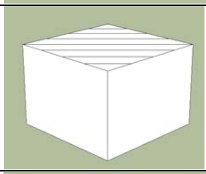
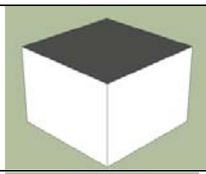
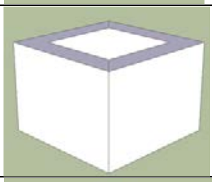
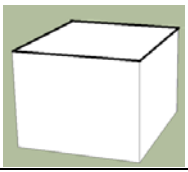
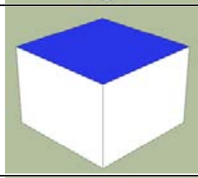
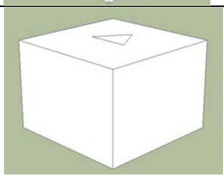
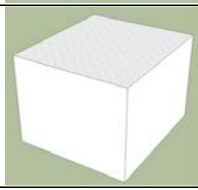
- **Represent the relationship of 3D legal units with corresponding physical objects:** The legal unit does not necessarily correspond to a physical object as building or bridge but usually it has some relationships with it. In some situations, legal demarcation is tightly attached to the physical object like an apartment or underground constructions which makes the co-visualization indispensable. Physical objects thus play an important role in cadastre data visualization, since they act as landmarks, which are easily recognizable by humans. With the presence of physical objects, the location and size of the legal objects would be less ambiguous and easier to understand. The geometry of a physical object (e.g. a bona fide boundary) is easier to measure, to establish, and to compare with the geometry of the legal units (e.g. a fiat boundary) that exist relative to a specific legal interpretation or human demarcation (Smith & Varzi, 2000).
- **Represent spatial relationships among 3D legal units:** The 3D overlapping situations of legal units have to be clearly comprehended. They include topological connexion or adjacency, distance, or orientation relationships. For example in the case of the common parts (e.g. wall, ceiling) of a condominium, they all must touch in order to form one unique unit. Other situations would be 3D easement or mining property that indicates a volume without any physical construction but the spatial link with the surrounding properties is important to understand. In a 2D cadastre map, because of its two-dimensional display, topology, orientation and distance relationships are easy to perceive. However, in 3D cadastre visualization, perspective projection and occlusion make these relationships harder to identify.
- **Label with official measurements:** When considering cadastral data, it usually refers to official measurements of the geometry of the property boundaries. In most cases, this information is known and certified by officers like land-surveyors or notaries. The direct and non-ambiguous access to this information was considered crucial for any cadastral visualization system.

As mentioned, other criteria could be taken into consideration for the establishment of a 3D cadastre visualization system like the level of detail for the geometric representation, the direct access to registration documents, the highlighting of contextual objects, etc. But none of them were considered for this preliminary experiment.

4. ASSESSMENT OF VISUAL VARIABLES CONSIDERING THE REQUIREMENTS OF 3D CADASTRE VISUALIZATION

The proposed assessment of the visual variables only considers the selective characteristic. The test examines for position, orientation, size, shape, value, color and texture if a change in the visual variable allows user to distinguish one object from other objects. We have to note that for some symbols (point, line, area, surface or volume) the visual variable could not be changed since it modifies the meaning of the object itself. In brief, for point, surface and volume symbols, we cannot change the position without modifying the meaning of the object. The color, the value and the texture may be altered for any kind of symbols. The size, the orientation and the shape cannot be changed for area, surface and volume symbols. The size of thickness of surface symbols may nevertheless be altered without modifying the meaning. Based on these restrictions, the following examples will reveal some admissible changes, depending on the kind of symbols used. For each predefined requirement, we took a cube[3], acting as a 3D legal unit, applied every visual variable with various symbols to it and estimated the clarity and the ambiguity in the context of visualising it with others cubes or symbols. The following tables show some of the tests made.

Table 1. Testing changes of the visual variables to represent bounded and partial bounded 3D legal units

position	 		
orientation		value	
size	 	color	
shape		texture	

[3] The cube is the 3D geometric object used for 3D visualization, not the symbol. Readers have to be aware of the difference between the geometric primitive used to represent the feature and the symbol applied in the cartographic design process.

Table 2. Testing changes of the visual variables to represent the relationship between 3D legal units and 2D land parcels (only building footprint is showed)

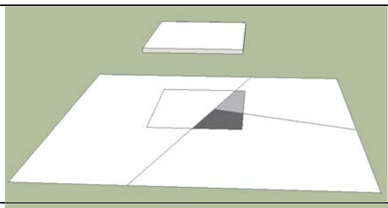
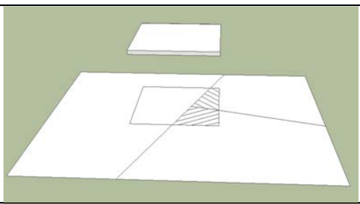
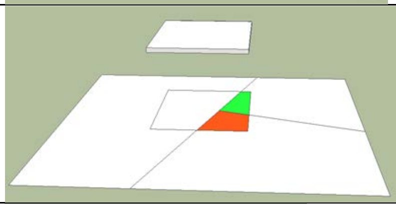
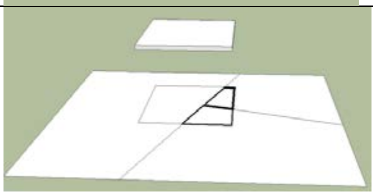
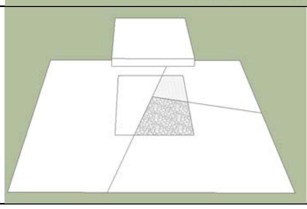
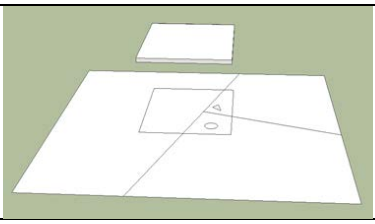
position	Not applicable	value	
orientation		color	
size		texture	
shape			

Table 3. Testing changes of the visual variables to represent the relationship of 3D legal units with a corresponding physical object

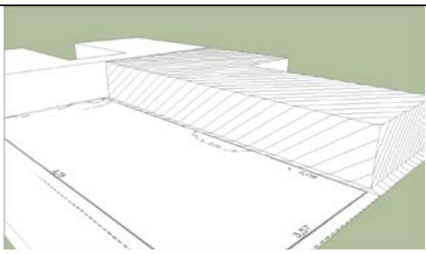
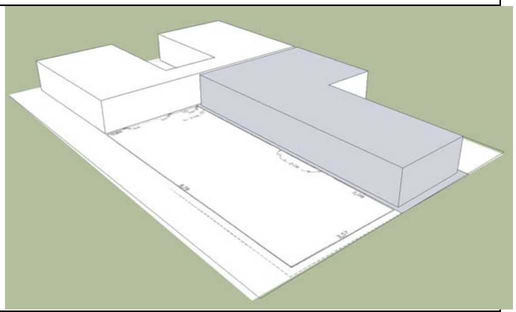
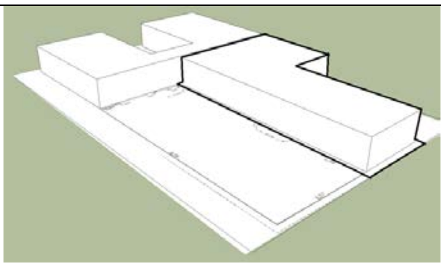
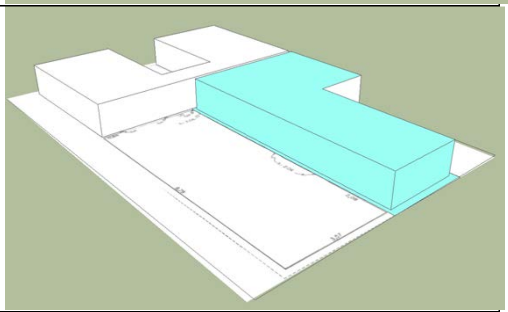
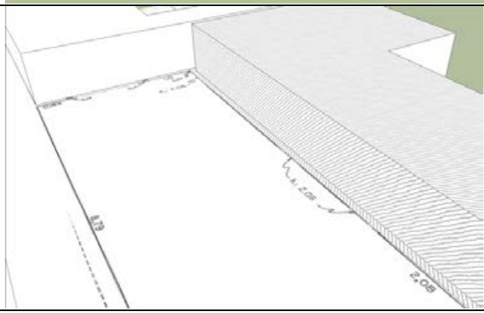
position	Not applicable		
orientation		value	
size		color	
shape	Not applicable	texture	

Table 4. Testing changes of the visual variables to represent spatial relationships among 3D legal units

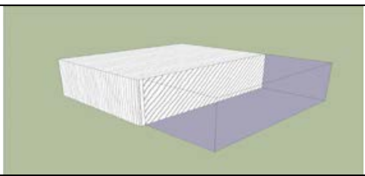
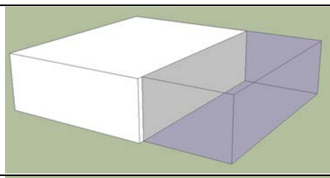
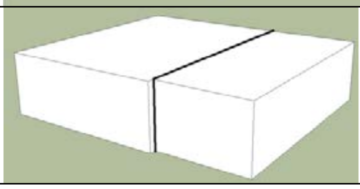
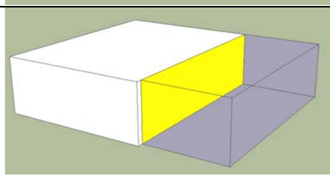
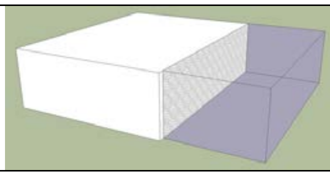
position	Not applicable		
orientation		value	
size		color	
shape	Not applicable	texture	

Table 5. Testing changes of the visual variables for labelling official measurements

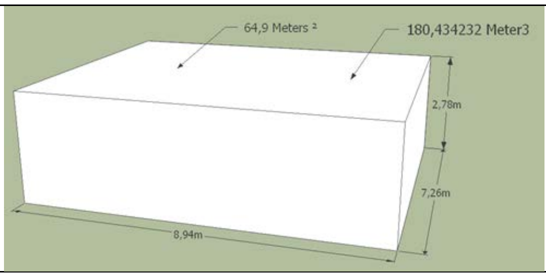
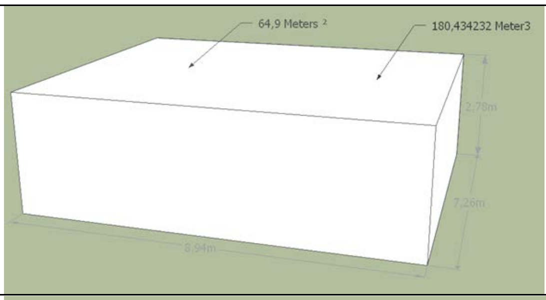
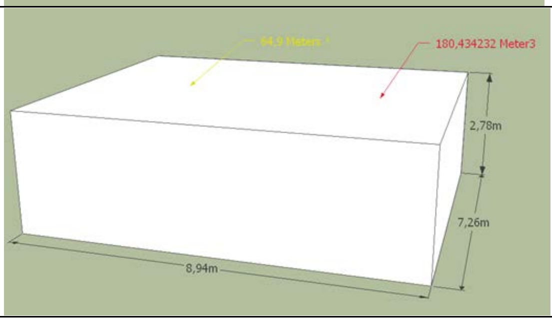
position	Not applicable
orientation	Not applicable
size	
shape	Not applicable
value	
color	
texture	Not applicable

Table 6 proposes an overall view of the results where:

- Yes = The visual variable is evaluated suitable to meet the requirements
- No = The visual variable is evaluated not suitable to meet the requirements
- Maybe = The visual variable may provide a possible solution to meet the requirements but with deficiencies and limitations or needs further evaluations.

Table 6. Assessment of the visual variables to distinguish one object from a group of objects (the selective characteristic)

Visual variables / Requirements for 3D cadastre visualization	Position	Orientation	Size	Shape	Value	Color	Texture
1. Represent bounded and partial bounded 3D legal units	Yes	Maybe, yet perspective view may cause ambiguity	Yes	Yes	Maybe, yet shading effect will cause ambiguity	Yes	Maybe
2. Represent the relationship between 3D legal units and 2D land parcels	no	Maybe	Yes	Yes	Yes	Yes	Maybe
3. Represent the relationship of 3D legal units with a corresponding physical object	No	Maybe, yet perspective view may cause ambiguity	Yes	No	Maybe, yet shading effect will cause ambiguity	Yes	Maybe
4. Represent spatial relationships among 3D legal units	No	Maybe, yet perspective view may cause ambiguity	Yes	No	Maybe, yet shading effect will cause ambiguity	Yes	Maybe
5. Label with official measurements	No	No	Yes	No	No	Yes	No

According to each visual variable, the overall comparison clearly shows that:

- Changing the **position** of the visual variable for selectivity purpose is not an adequate strategy, except to distinguish bounded and unbounded 3D legal units. This diverges from general analysis of visual variables since normally the position could not be changed for the surface since it modifies the meaning of the object (Carpendale, 2003). In our specific case, as we have to manage an unbounded surface, modifying the position remains an acceptable solution.
- A change in **size** is fully suitable which requirement you need to meet. Moreover, we can quickly and easily view the selection for each requirement on a 3D unit. Usually in general analysis of visual variables, size has the most perceptual characteristics and is recognized to be the most efficient visual variable for humans to percept its change. This conclusion is partly true in our analysis since size performs only when line symbols are changed.
- A change in **color** is fully suitable no matter which requirement you need to meet. Like the visual variable size, we can easily identify the selection for the different requirements. Color is also an efficient visual variable for human perception. However, the selection of the best color still remains a challenge which depends on the visualization context and the background color.
- If there is a light source and a shading effect in 3D cadastre visualization, **value** is not a promising choice. However, in a self-illuminating situation, in which there is no light source and shading effect, value could be used to represent all situations. Background color will also have to be taken into account and combining value and transparency is recommended.

- **Orientation** is usually proved to be the least efficient among visual variables (Garlandini & Fabrikant, 2009). In our analysis, orientation performs well for some requirements since they mainly concern the relationships (the line intersection) between objects. But using orientation in perspective display could be problematic, because perspective projection will cause changes in orientation for different symbols. Users may be confused of whether the difference of orientation is caused by the symbol or by perspective projection.
- **Shape** did not really perform adequately in the experiments made. Some confusion is notified and makes the interpretation difficult. The exception is when the object is represented by arbitrary geometry (like unbounded surface), then shape may perform adequately.
- **Texture** is regarded as a possible solution. Texture is complex that contains pattern, grain and material. Our evaluation only covers part of it. Further evaluation should be implemented.

According to the requirements, we can say that labeling with official measurements is the requirement that least fulfills while representing bounded and partial bounded 3D legal units is totally achieved when changing the visual variables.

5. CONCLUSION AND FUTURE WORK

As indicated by Kaufmann in 1998 in the initiatives of Cadastre 2014, the aspiration for a cadastre visualization system “will be to represent information in such a way that it can be communicated easier and in a more comprehensive form”. We proposed in this paper a first step towards a rich assessment of cartographic foundation, like visual variables, to create suitable 3D cadastre models. We tried to isolate visual variables and their abilities for selecting one cadastral object over another. This exercise was tricky and more experiments are required.

We already mentioned some of the limitations we faced that should be addressed in future work. For instance, the list of requirements is not exhaustive, nor validated with users, experiments should be done with true cadastral data and associated with specific usages like supporting land registering, land-use planning, and traffic engineering, the analysis should validate if the results are correlated with the type of cadastre or the type of RRR, motion and interaction aspects were not taken into consideration. We only evaluated the selectivity of the visual variables; the associative, the quantitative, the order and the length characteristics should also be investigated. The ultimate outcome of this experiment may be perceived as design principles for 3D cadastral mapping. The visual principles along with these processes and analysis together have the potential to support visual tool development for future 3D cadastres.

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