3D Cadastre Visualization: Recent Progress and Future Directions

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SUMMARY

The 3D Cadastre has been investigated from many viewpoints (including legal, organizational and technical). However, to date little research has focused specifically on visualization-related aspects despite the value-added of the third dimension. The paper first proposes an overview of progress made in the last five years in 3D cadastral visualization. The authors then summarize discussions at the 2014 3D Cadastre workshop regarding future research and development on the topic. This synthesis is complemented by a broad review of the most recent advances in 3D visualization beyond the 3D cadastral domain, with the goal of providing a number of important directions for further work, allowing researchers, developers and users to consolidate their respective activities, and encouraging collaboration.

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1. INTRODUCTION

Integrating the third dimension (3D) in cadastral systems has already been recognized by a number of players in the scientific and professional communities as being valuable to improve current practices in land tenure, urban planning and real estate transaction (see the 3D Cadastre workshops led by van Oosterom et al, 2001; 2011; 2012; 2014). As part of this wider research portfolio, 3D cadastral systems give rise to novel questions on the topic of visualization of related data and information. This is particularly important since 2D maps and plans are in many cases inadequate to represent the geographic phenomena and support decision-making associated with land and property. A key question, however, is whether 3D visualization systems can be adapted to the 3D Cadastre. At a first glance, we may be tempted to answer yes. In reality, however, the answer is complex since it requires deeper investigation into features specific to cadastral systems. These include the data model to be used (2D, 2.5D or 3D), user needs and behaviour when making legal decisions related to 3D space, how users interact with 3D systems, additional analysis functionality and the level of acceptability of the systems.

In this paper, the authors present a review of current and future research in 3D cadastral visualization to assist researchers, developers and users in planning and structuring research and development, and to promote collaboration among groups. After a short summary of the outcomes of previous 3D cadastral system workshops, we present a review of current research into 3D cadastral systems that focuses on aspects of visualization and interaction. Based on discussions at the 2014 3D Cadastre workshop, and an additional, extensive literature review on 3D visualization, we then highlight potential research and application trends, drawing on both core 3D cadastral research and work in related disciplines. This paper is the third position paper on 3D Cadastral visualization (Pouliot, 2011; Pouliot and Wang, 2014).

2. PREVIOUS WORKSHOPS ON 3D CADASTRE

The series of 3D Cadastre workshops is organized by FIG Commission 3 (Spatial Information Management), and Commission 7 (Cadastre and Land Management) and is now in its fifth edition (2001, 2011, 2012, 2014, 2016). These workshops have been excellent opportunities for researchers and practitioners to share experiences and knowledge. While this paper focuses on most recent developments and issues, many considerations identified in previous workshops are still relevant. A short summary of key topics is given here, and further details can be found in Fendel (2002), Pouliot (2011), Banut (2011), and Pouliot and Ellul (2014).

During the workshops, there was ongoing discussion relating to *user needs*, with an increasing understanding of their importance, with emerging research into user needs in recent years, in particular the relevance of 3D Cadastre to support informed decision-making. The type of users was initially restricted to specialists, but the scope broadened to the general public in 2011, with an additional focus given to training in 2014.

Discussions on what to represent in the 3D system, *how to model and present data* were also featured throughout. The need for full 3D geometry representation has been considered at every workshop: are 2D maps sufficient? In 2001, 3D was considered important in cities in particular, although technical issues related to 3D visualization made this challenging. A similar understanding was expressed in 2011, although user needs were included in this debate. In both 2011 and 2014, the debate also included a core focus on the importance of representing not only physical but also legal objects, and, in 2014, the need to distinguish between private and publicly owned land and model spatial relationships along with the potential to link additional information, e.g. PDF documents, to the 3D geometry was recognized.

Technology and implementation is a third theme for discussion. Emerging web-based technology was a focus in both 2011 and 2014, e.g., websites and web services, with a need for a focus on user interaction also being identified in 2014. Open-source solutions were identified as having potential relevance in 2011; technological trends identified as relevant in 2014 also included 3D printing and augmented reality. Finally, in both 2011 and 2014, reflecting trends in geospatial information, the relevance of crowdsourcing was also considered.

3. CURRENT RESEARCH IN 3D CADASTRE VISUALIZATION

Of the more than 100 papers found in the 3D Cadastre literature since 2011, fewer than 15 publications have a focus on visualization. Interestingly, however, although the 3D cadastral workshops focus on all aspects of cadastre, and not only visualization, similar core themes emerge in the visualization literature: the importance of users, how to model and present information and current and future technical options for implementation.

3.1 Users, user requirements and usability

As noted above, researchers show an increasing understanding that users must be part of development and research activities for cadastral 3D visualization (Shojaei et al, 2013; Pouliot et al, 2014; Stoter et al, 2013; Wang et al, 2016). Two research teams, one in Canada (under the supervision of Pouliot) and the other in Australia (under the supervision of Rajabifard) have specifically investigated user requirements for 3D Cadastral systems. End-users targeted by the two research groups were managers in government and municipal authorities responsible for the maintenance of the land administration system, as well as lawyers and notaries, land surveyors, architects, corporate owners (building managers). 3D visualization of cadastre data mainly facilitates the understanding of ownership boundaries (e.g., locating a specific 3D lot, understanding the spatial relationship with neighbouring lots, and distinguishing the private and common parts in co-ownership apartment buildings. Research also shows that users are eager to learn about the exact advantages of using 3D visualization (Boubehrezh, 2014).

3.2 Modelling and presenting information

Any research into 3D cadastral visualization needs to take into account both the spatial (2D or 3D) and the non-spatial (attribute or semantic) data, along with topological relationships. Geometry may be raster or vector and will include both real geometry and information about RRR (Rights, Restrictions and Responsibilities). Additionally, data used in 2D cadastre should still be valid for 3D Visualization. The Land Administration Domain Model (ISO-TC 19152-LADM, 2011) provides a more exhaustive list of cadastre data.

Given the wide variety of geometric and semantic objects in a 3D cadastral system, it is no surprise that a number of different groupings of the data exist. While Isikdag et al (2015), only distinguish between physical and virtual objects, Aien et al (2013), Shojaei et al (2013, 2014), Pouliot (2011), Wang et al (2012), and Wang (2015) suggest that three types of spatial objects are necessary for cadastral 3D visualization: the boundaries of a physical object, the boundaries of a legal object and the boundaries of the zones inside planning schemas and other official urban planning documents. Adding to this, Döner et al (2011), Guerrero et al (2013), Guo (2013), Jeong et al (2012), Pouliot et al (2015), Shojaei et al (2013) and Vandysheva et al (2012) propose the visualization of underground (legal) objects.

Taking a different approach, Thompson et al (2015) used the concept of spatial units proposed by LADM for modelling and visualization. Groupings include 1) the level of geometric encoding (text-based, geometry-based [point, line, polygon or solid] and topology-based), 2) real-world spatial unit types (open or closed volumes, horizontal or vertical faces, faces related to physical construction or not, 3D spatial unit within a single surface parcel or crossing many surface parcels [legal space for pipelines]) and 3) geometric representation (2-manifold boundaries or not, volumes with contiguous or non-contiguous interiors, boundaries described by planar or curved primitives, the presence or absence of caves).

Finally, some authors argue that, to manage and consequently visualize in a cadastral system, time should be part of the explicit data (Döner and Biyik, 2013; Siejka et al, 2013; van Oosterom and Stoter, 2010).

The variety of data also influences research into visualization and communication of 3D cadastral information. Considering 3D Cadastre visualization as an applied domain of geovisualization presents the possibility of applying the epistemology and knowledge of that discipline. For example, the pipeline model (Haber and McNabb, 1990) subdivides the visualization process into data retrieval, visual mapping and the rendering process; Voigt and Polowinski (2011) categorized the most recent papers found in the literature on 3D Cadastre visualization around these three steps.

To date, very few researchers have addressed symbolization from a point of view of the semiotics of graphics; however Pouliot et al (2014), and Wang et al (2012), analyze the performance of visual variables and revisit cartographic foundations to respond to the requirements of 3D visualization of legal units. More recently, Wang et al (2015), explored transparency in 3D cadastral visualization, demonstrating that this is useful to help users delimit property units (administrative boundaries) by using their physical counterparts (e.g., walls).

3.3 Technical solutions – 3D environments and interaction

Currently, research into 3D cadastral technology can be subdivided into two aspects: building 3D cadastral prototype and interaction research.

3.3.1 3D Cadastral System Prototypes

Cadastral system prototypes include web-based and desktop systems, with both focusing on enhancements to software that already supports 3D visualization. In the context of web-based systems, Shojaei et al (2014), established a web-based 3D cadastral visualization system with a comprehensive review of functional visualization requirements and the applicability of 3D visualization platforms. Aditya et al (2011), developed two 3D Cadastre web map prototypes based on KML with Google Earth and X3D with ArcGIS online, respectively. Additional visualizations are based on a desktop version of Google Earth. For instance, Shojaei et al (2012) developed a 3D visualization system based on Google Earth for 3D ePlan/LandXML data to be used in overlapping property situations. Oliveres Garcia et al (2011) explained how to use KML and Google Earth to visualize a volumetric representation of property units in condominiums. Ribeiro et al (2014), tested CityEngine (a desktop tool) for use in 3D Cadastre visualization.

3.3.2 Interaction – Object selection and other functionality

The ability to select, and therefore interact with, objects in a 3D environment is fundamental to the success of any 3D system (Bowman et al, 2012) and this has been explored by Shojaei (2014), who demonstrated the use of a red rectangle to highlight the selected object. In a Russian prototype (Vandysheva et al, 2012), users can drag out the 3D model of a floor together with the 2D plan of the entire building in order to overcome issues related to occlusion.

Additionally, some visualization prototypes enable user navigation, object search and attribute query (i.e. a step beyond selection); these prototypes include one from Korea (Jeong, et al, 2011) and a visualization prototype built on CityEngine (Ribeiro et al, 2014). Going one step further, Navratil and Fogliaroni (2014) proposed a new model for 3D visibility analysis that integrates 3D Cadastre data in the context of urban planning.

3.4 Summary of current research

As can be seen from both the reports of the workshops and the review presented here, progress has been made in recent years regarding 3D cadastral visualization. For example, in terms of what to model, all groups agree on the importance of including not only physical objects but also legal boundaries and auxiliary data for 3D Cadastre visualization purposes.

Despite the early identification of this challenge, the problem of mapping 2D or 3D legal boundaries that do not physically exist has not yet been overcome and, to our knowledge, no innovative solution has emerged from the research. Visualizing invisible or virtual objects like legal boundaries may be examined from the same research standpoint of underground objects, the visualization of which was, in turn, identified as a shortcoming of existing systems by Shojaei et al (2014).

While advanced systems such as CityEngine do exist, Ribeiro et al (2014) note the steepness of the learning curve required to operate them, making them perhaps unsuitable for many of the user groups identified during the various workshops, both technical experts and members of the public.

Thus, key questions concerning user requirements, usefulness, modelling and technical implementation of 3D Cadastre visualization have yet to be answered and the real value gained from applying 3D visualization for 3D Cadastre has not yet been fully met. The next section explores a number of research directions that may help 3D cadastral systems achieve their full potential.

4. FUTURE DIRECTIONS

3D visualization is not only used in the context of cadastral applications; extensive literature from other disciplines relating to 3D visualization and 3D geovisualization exists (Dykes et al, 2005; ICA, 2015). Related research areas also include information visualization (Ware, 2012), cognitive science (Ware and Plumlee, 2005; see ICSC 2015 proceedings), human-computer interaction (Popelka and Dolez, 2015) and 3D Gaming.

Using the discussions that occurred at the 2014 3D Cadastre workshop as a starting point, and following the core themes that emerged both from the workshops and the review of the current 3D cadastral visualization literature summarized above, the authors have conducted an extensive literature review on these topics, identifying emerging research trends that would also benefit 3D cadastral visualization.

4.1 Users, user requirements and usability

Inspired by ISO, IEC and IEEE standardization on quality assessment, three related topics are covered under this heading: feasibility, usefulness/usability and acceptability. Feasibility issues refer to technical execution conditions (technical, time, budget). Usefulness/Usability issues cover solutions which intended users can understand and find useful for decision-making. Acceptability issues comprise collective and legal factors of acceptance, for example if the solution conforms to common practice, approved standards or laws.

4.1.1 Usefulness and usability issues

In this context, usability refers to the technical aspects of a visualization (Bleisch, 2012; Landauer, 1995), whereas usefulness addresses whether it does what the user needs. The usability of a solution may not guarantee its usefulness, and there are possibilities that a usable visualization tool would be totally useless in real life (Greenberg & Buxton, 2008).

A starting point to understand the usefulness of 3D visualization may be appraised from the geovisualization cube of MacEachren & Kraak (2001). They proposed three axes to assess geovisualization: 1) user or audience (public to expert), 2) interaction (low to high) and 3) information content (unknown to known). From the point of view of the cadastre, usefulness may also be matched with the concepts of multipurpose cadastre such as discussed by several authors like Dale and McLaughlin, (1999) and Williamson et al (2008); or with suitability for the purpose (Enemark et al, 2014). Adding to these basic requirements, capturing user requirements for on-demand mapping, dealing with different communities of users and establishing various user profiles are also required (Gould and Chaudhry, 2012).

Usability studies (part of research into human-computer interaction), such as heuristic evaluation, cognitive walk-through (Neilsen, 1995) and studies using User Testing and Co-operative Evaluation (Jacobsen, 1999), are also fundamental.

4.1.2 Acceptability

Acceptability comprises collective, political and legal factors of acceptance: does the solution conform to common practice, approved standards or laws. Applying user-centred design (which places the user at the focal point of any design process) in 3D Cadastre visualization research will help the designer understand user requirements. Additionally, it prepares the user for the new visualization solutions from the very first stage of the work, and provides the benefit that working closely with the users will give developers of 3D cadastral systems an immediate understanding of the feasibility of their suggested approaches. For example, a desktop-based system may pose technical issues in an organization with limited IT expertise.

4.2 Modelling and presenting information

The challenges under this heading represent a key conflict in 3D cadastral visualization. As noted above, there is a need to model a wide range of complex real-world and virtual objects in any 3D Cadastral system. This contrasts sharply with the need to present a simple, understandable visualization to the end-users of any system. A number of research areas in Geographical Information Science and beyond can assist with this challenge.

4.2.1 Enhancing the 3D environment – Generalization, multiple representations, occlusion management

Research into 3D generalization has been carried out by several authors, including Meng and Forberg (2007), Fan et al (2009), Glander and Döllner (2009), and Mao et al (2011). As with

2D generalization, a key purpose here is to provide a visualization that meets the specific needs of the user, emphasizing key features and removing or aggregating others (Robinson et al, 1995). The question of level of detail (LoD) as proposed by CityGML (Kolbe 2009), and formalization of LoD (Biljecki et al, 2014) is also important. There is a need for a LoD concept that goes beyond 3D building visualization and integrates visualization of non-visible objects or boundaries, or their corresponding RRR. The work of Gruber et al. (2014), applying LoD for the German Cadastre, is a first step in this direction.

3D generalization and LoD are generally static, i.e., the process is run once. However, having multiple representations of the same object can also be adapted to overcome occlusion issues in a 3D environment, i.e., objects that prevent a user from visualizing or selecting an object of interest. Enhancement techniques such as altering the viewing direction, and depth clues may increase the spatial awareness of the viewer; Elmqvist and Tsigas (2008) present a review of 50 techniques in this area, including multiple viewports and virtual X-ray tools. Related to this, Zhang et al (2016) apply some generalization methods (including building displacement) to ensure the visualization of features of interest like a road without occlusion. Fogliaroni and Clementini (2014), and Billen and Clementini (2006) apply the multiple viewport technique by splitting the 3D space in order to model the visibility between 3D objects.

4.2.2 Geo isualization, visual analytics and big data

As noted above, geovisualization research can provide useful insights into visualization in 3D cadastral systems, since this area of research involves an in-depth understanding of how users understand spatial data, along with related issues such as colour and symbol choice. This research has recently been given additional focus by the need to improve the visualization of a huge volume of data (“Big Data”). Of direct relevance to 3D cadastral systems is the work by Olshannikova et al (2015), examining the potential of integrating Big Data in different augmented and virtual environments. Li et al (2015) also present a 3D globe able to display multiple types of data from Shenzhen city.

In addition to this, an investigation into other visual enhancement techniques in the 3D cadastral environment should be realized in order to advantage of work by Métral et al (2012) and Shojaei et al (2013) on using text for annotation, work by Trapp et al (2011), who added a new arrow symbol above an original symbol to attract the viewer’s attention, and work by Turkay et al (2014), who present the concept of an attribute signature to help the visual analysis of geographic datasets. Finally, adapting interfaces and interactions to the context of usage according to user profiles, their environment (physical or social) and platform (hardware or software), as proposed in the field called plasticity of user interfaces, may also be of interest for cadastre applications (Lacoche et al, 2015).

4.3 Technical solutions – 3D environments and interaction

The two topics covered in this section are in fact closely related, since the choice of environment, web-based, virtual reality, augmented reality or full immersion, will in turn impact the ways in which the user can interact with the environment and objects within it. 3D cadastral research in both of these topics can also be expanded to include research in the broader field of computer science and, in particular, 3D gaming.

4.3.1 Displaying 3D data

Approaches here range from those available on a standard desktop computer or mobile device such as a tablet (no immersion in the environment) through augmented reality (partial immersion) to those requiring very specialized hardware (full immersion), which can in turn be very expensive.

Web-Based 3D Visualization

In addition to the 3D-cadastral prototypes mentioned in Section 2, other researchers are also experimenting with WebGL, which is a standard for 3D graphics on the web that provides a JavaScript interface to the 3D graphics hardware on a machine (Parisi, 2012). It has emerged as the programming language for 3D graphics on the web, allowing a fully customized 3D software package to be developed (Evans et al 2014).

An example of this can be found in Milner et al (2014), who present a 3D-enabled web GIS with full selection and editing functionality. Resch et al (2014), used WebGL to build web-based 3D+time visualization application for marine geo-data and Chaturvedi et al (2015) present a web-based virtual globe able to integrate and display very large semantic 3D city models, developed with Cesium, an open-source JavaScript library for 3D globes and maps. Ferraz and Santos (2010) combine Spatial OLAP tools with virtual globes to facilitate the discovery and exploration of multidimensional data (i.e., thematic, temporal and spatial data) on 3D maps.

Augmented Reality

Work on augmented reality in geovisualization by researchers, including Duinat and Daniel (2013), van Krevelen and Poelman (2010), Park et al (2015), Pierdicca et al (2016), Schall et al (2013), Lee et al (2012), and Hugues et al (2011), indicates that it may also be helpful for 3D cadastral systems.

Immersive Virtual Environments

Research here includes enhancing interactive learning about flood risks by using a 3D CAVE (Philips et al 2015) and displaying 3D virtual environments on walls (CAVE2) where a CAVE is a room-size immersive visualization environment.

Other immersive and interactive works concern holographic technologies including Zebra Imaging (www.zebraimaging.com), Musion (http://musion.com), Leia 3D (www.leia3d.com) and Holusion (http://holusion.com/fr). In a geovisualization context, a first holographic map was produced in 2011 by DARPA in the "Urban Photonic Sandtable Display" program in collaboration with Zebra Imaging (www.nextbigfuture.com/2011/03/darpa-has-3d-holographic-display.html). Combining these novel holographic technologies with 3D cadastral objects could be considered as an attractive means for private or public institutions to promote cadastral systems, although the expense means they are beyond the reach of the everyday user.

4.3.2 Interaction – Moving around in the 3D world

Traditionally, interaction with 3D Cadastral Systems takes place via a screen and a mouse. This is in great part due to the wide availability and low cost of these tools (Ortega et al, 2016). These options, however, have the disadvantage of not providing easy access to a full 6 Degrees of Freedom, (3 * rotations and 3* translations (Kub et al, 2016)) required for 3D interaction. A number of tools commonly associated with 3D gaming, as well as emerging interaction options, are perhaps worth considering. These include (from Ortega et al, 2016): keyboards and mice, controllers such as the Nintendo Wii, joysticks, inertial sensing devices (e.g., a combination of gyroscopes and accelerometers on a smart phone) and head-mounted displays – such as the Oculus Rift or Google Glass.

Related usability research may guide the choice of interaction mode for 3D cadastral systems. For example, Farhadi-Niaki et al (2013) compare static and dynamic gesture interaction, as well as haptic options (a haptic mouse) as interfaces to 3D games, concluding that static gestures performed better in terms of time and precision and naturalness of the interaction while the 3D mouse was easier to use, but caused more fatigue. Additionally, there is extensive usability research examining specific tasks that users perform within the 3D environment, including object selection, retrieving information about objects, capturing new data and moving around the environment. In a study that is perhaps close to the needs of 3D cadastral users, Cashion et al (2012) looked at object selection in the context of dynamic, dense environments, concluding that a ray-casting approach, such as that provided by the Wii remote, is best for static, low-density environments. For high-density scenes, however, an 'expand' approach, where the user is offered a grid of possible targets once the ray has been cast, is more efficient.

Focusing on the mixed geometry/attribute environment that reflects a 3D cadastral situation, Jankowski and Decker (2012) presented a comparison of two modes of interacting with 3D data on the web, where hypertext and 3D graphics are mixed. They experimented with labelling and annotating 3D interactive illustrations in three settings: annotations attached to objects using translucent shapes, located within the objects' shadows, or with the areas showing the 3D model and text being separated. They conclude that the last method is best for long text, since users can explore the scene without text interrupting the view. The first setting is best for short texts, a result directly transferrable to 3D cadastral interfaces. They also described research into two interaction modes for "travel", movement around a 3D VE, a simple mode, where the user can click on hyperlinks in the 3D view and go to fixed view points; and an advanced mode, where the user is free to explore, concluding that the opportunity to swap between modes as the user requires provides the most efficient interface.

4.4 Beyond 3D visualization – Integrating time

Adapting time-based 2D visualization and interaction could be of interest for suggesting new time-based 3D cadastral data. The space-time cube is a well-known application combining time series as the third dimension with 3D maps (Kwan and Lee, 2004). This 3D environment is also mainly used to visualize and analyze temporal information in the space for movement data (Kraak 2003). Displaying a temporal division of parcels can be easily achieved (van Oosteroom and Stoter 2010) and time-based interactions in such a space-time cube have already been studied by Bach et al (2014). Ringmaps is a method to interact with data in order to visualize time series, and Zhao et al (2008) present different representations of time series in a geovisualization point of view with a specific focus on this approach. Wu et al (2015) also integrate Ringmaps in their analysis of Dutch temperature data. For interactions, temporal navigation methods by direct manipulation are designed for 2D and 3D environments (Kondo and Collins, 2014; Wolter et al, 2009).

5. CONCLUSION

The literature review relating to 3D cadastral visualizations shows that the topics vary from the identification and characterization of cadastre data, to symbolization and realization of visualization. Data to be visualized must be linked not only to physical objects but especially to legal boundaries, which can range from the boundary of the parcels, easements, restrictions, and to the distinction between common and private properties. Visualizing invisible or virtual objects like legal boundaries may be examined from the same research standpoint as an underground object. While many 3D cadastral prototypes, especially web-based, have been developed and the various 3D workshop conferences have contributed to sharing experiences to publish research relating to 3D Cadastre, there is still a need to diversify the research domains considered in order to enlarge the audience and, consequently, disseminate the challenges and innovations of 3D Cadastral visualization.

A first attempt to do this has been presented in this paper, which includes literature from human-computer interaction, usability studies, 3D gaming and similar sources. However, it is also important to note that, in the context of 3D Cadastre, there is a need for specific visualization, usability and interaction research. Key differences from other domains include the fact that users of 3D Cadastre may not be using the software on its own, but instead would be using it in conjunction with, for example, the production of a report. This contrasts with the standard gaming contexts assumed in the interaction approaches and research described above, which assume that the user will be playing the game in isolation from other tasks. Thus, for example, many gaming consoles which must be held with both hands would not be very useful for interacting with a 3D Cadastral system while writing a report. Much of the research is also carried out in VE with a small number of objects rather than the thousands of buildings and other complex data that may be displayed within a 3D cadastral system. Within 3D Cadastre, there is a need for extensive text-based information (semantics) to be viewed in association with any 3D geometry (i.e., the semantics, links to other documents). Additionally, and again in contrast with many other 3D projects, maps (and associated cartographic principles) have been around for a thousand of years, and 2D maps and vertical profiles are still perceived as valuable solutions, and must not be excluded from any research.

Thus, while 3D visualization systems are mature, research and development activities related to usability and acceptability are missing in the context of cadastre users. To understand the specific needs of 3D Cadastre users, researchers need to meet and engage the professional end-users and be part of their day-to-day activities. This is fundamental to ensure that any proposed systems are successful not only in terms of usability but also in terms of acceptability and feasibility. The participation of a wider spectrum of cadastral users, e.g., urban planners or the general public, is necessary. Thus, we need to promote 3D Cadastre in a very understandable manner (e.g., via videos, games). For example, we could produce showcases that demonstrate the value-added (for professionals, the general public, government authorities). We should also better establish what to call the "3D product", since in many ways the term 3D Cadastre is too broad, whereas a term such as a "3D Certificate of localization" is something tangible that is easily understood. Integrating the visualization system into a legal document such as a deed or title, which is well known to cadastre experts, would certainly help by lessening the cognitive leap required to understand the purpose of the 3D system. We also need to participate in educational programs to help practitioners adapt to new realities and technologies, and in particular to ensure that undergraduate students are involved as part of their professional development. This new generation of citizens and professionals is much more aware of technologies and the acceptability level of new solutions is probably higher. Promoting quality assessment, improving confidence in the 3D product and making limitations known are also important aspects of visualization. We need to understand how to do this while at the same time not over-complicating the visual interface and software system. Being involved in committees to adapt laws and regulations is probably a must. We, as specialists in spatial data processing and visualizing, have to be part of this step.

Have we made any progress since 2011 regarding 3D Cadastre visualization? It is clear that we have found more literature related to the production of 3D Cadastre models when compared to 2D representation. But, are 3D models implemented, visualized, and integrated in the everyday duties of land administration players? Our analysis indicates that this is not yet the case, even though greater efforts have been made to increase users' participation. Changing habits is a long process and must be addressed step by step. This is particularly the case in a domain such as cadastre application, which involves a legal framework applied to properties/possession/rights, and thus human values. Despite these issues, reality is three-dimensional, as is any decision-making associated with it, so it is important that visualization migrates to 3D. The concept of a "spatially enabled society" as presented by Steudler and Rajabifard (2012) is certainly an interesting framework to consider in order to progress in this direction.

REFERENCES

Aditya, T., Iswanto, F., Wirawan, A. and Laksono, D.P. (2011). 3D Cadastre Web Map : Prospects and Developments. In Proceedings of the 2nd International Workshop on 3D Cadastres, 16-18 November 2011, Delft, the Netherlands, pp.189–208.

Aien, A., Kalantari, M., Rajabifard, A., Williamson, I. and Wallace, J. (2013). Towards Integration of 3D Legal and Physical Objects in Cadastral Data Models. Land Use Policy, 35, pp.140–154.

Bach, B., Dragicevic, P., Archambault, D., Hurter, C. and Carpendale, S. (2014). A Review of Temporal Data Visualizations Based on Space-Time Cube Operations. In Eurographics Conference on Visualization.

Banut, R. (2011). Report on Results of Working Sessions, 2nd International Workshop on 3D Cadastres, 2011, Delft, 10 pages.

Biljecki, F., Ledoux, H., Stoter, J. and Zhao, J. (2014). Formalisation of the Level of Detail in 3D City Modelling. Computers, Environment and Urban Systems, 48, pp.1–15.

Billen R. and Clementini, R. (2006). Projective Relations in a 3D Environment. In Geographic Information Science, Springer, p.18-32.

Bleisch, S. (2012). 3D Geovisualization – Definition and Structures for the Assessment of Usefulness, ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume I-2, 2012 XXII ISPRS Congress, 25 August – 01 September 2012, Melbourne, Australia (September), pp. 129–134.

Boubehrezh, A. (2014). Usages et pertinence d'une représentation volumique (3D) cadastrale dans un contexte de gestion municipale Québécoise. Mémoire de maîtrise, Université Laval.
Bowman, D.A., McMahan, R.P. and Ragan, E.D., 2012. Questioning naturalism in 3D user interfaces. Communications of the ACM, 55(9), pp. 78-88.

Cashion, J., Wingrave, C. and LaViola Jr, J.J. (2012). Dense and dynamic 3D selection for game-based virtual environments. IEEE transactions on visualization and computer graphics, 18(4), pp. 634-642.

Chaturvedi K., Yao, Z. and Kolbe, T.H. (2015). Web-based Exploration of Interaction with Large and Deeply Structured Semantic 3D City Models using HTML5 and WebGL. In Wissenschaftlich-Technische Jahrestagung der DGPF und Workshop on Laser Scanning Applications (Vol. 3).

Dale, P.F. and McLaughlin, J.D. (1999). Land Administration. Oxford, Oxford University Press.

Döner, F., Thompson, R., Stoter, J., Lemmen, C., Ploeger, H., van Oosterom, P. and Zlatanova, S. (2011). Solutions for 4D Cadastre–With a Case Study on Utility Networks. International Journal of Geographical Information Science, 25(7), pp. 1173–1189.

Döner, F. and Biyik, C. (2013). Conformity of LADM for Modeling 3D/4D Cadastre Situations in Turkey. 5th Land Administration Domain Model Workshop, 24-25 Sept., Kuala Lumpur, Malaysia: pp. 433-446.

Duinat, B. and Daniel, S. (2013). Urban Situated Simulation Interface: Design & Development of a Tablet-based Solution. ASPRS Annual Conference, 2013-03-24, Massachusetts, USA.

Dykes, J., MacEachren, A.M and Kraak, M.-J. (2005). Exploring Geovisualization. International Cartographic Association, Elsevier.

Elmqvist, N. and Tsigas, P. (2008). A Taxonomy of 3D Occlusion Management for Visualization. IEEE Transactions on Visualization and Computer Graphics, 14(5), pp.1095–1109.

Enemark, S., Cliffort Bell, K., Lemmen, C. and McLaren, R. (2014). For-For-Purpose Land Administration. Joint FIG/World Bank Publication. FIG Publication No.60.

Evans, A., Romeo, M., Bahrehmand, A., Agenjo, J. and Blat, J. (2014). 3D graphics on the web: A survey. Computers & Graphics, 41, p.43-61.

Farhadi-Niaki, F., Gerroir, J., Arya, A., Etemad, S.A., Laganière, R., Payeur, P. and Biddle, R. (2013). Usability study of static/dynamic gestures and haptic input as interfaces to 3D games. In ACHI 2013, The Sixth International Conference on Advances in Computer-Human Interactions, pp. 315-323.

Fan, H., Meng, L. and Jahnke, M. (2009). Generalization of 3D Buildings Modelled by CityGML. In Advances in GIScience, Springer Berlin Heidelberg, pp. 387-405.

Fendel, E., 2002, Report on the Working Sessions, International Workshop on 3D Cadastres, 28-30 November 2001, Delft.
Available at http://www.gdmc.nl/events/3DCadastres2001/Working%20sessions.pdf.

Ferraz, V.R.T., Santos and M.T.P. (2010). GlobeOLAP-Improving the Geospatial Realism in Multidimensional Analysis Environment. In ICEIS (5). pp. 99-107.

Fogliaroni, P. and Clementini, E. (2014). Modelling Visibility in 3D Space: a Qualitative Frame of Reference. In proceedings of the 9th international conference on 3D GeoInformation Science. Lecture Notes in Geoinformation and Cartography, Springer November.

Glander, T. and Döllner, J. (2009). Abstract Representations for Interactive Visualization of Virtual 3D City Models. Computers, Environment and Urban Systems, 33(5), pp. 375–387.

Gould, N and Chaudhry, O. (2012). An Ontological Approach to On-demand Mapping. 15th ICA Generalisation Workshop, Istanbul, Turkey.

Gruber, U., Riecken, J. and Seifert, M. (2014). Germany on the Way to 3D-Cadastre. FIG Congress, Kuala Lumpur, Malaysia, 16-21 June.

Guerrero, J., S. Zlatanova, S. and Meijers, M. (2013). 3D Visualisation of Underground Pipelines: Best Strategy for 3D Scene Creation. ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume II-2/W1, ISPRS 8th 3D GeoInfo Conference & WG II/2 Workshop, 27 – 29 November 2013, Istanbul, Turkey, pp. 139-145.

Guo, R., Li, L., Ying, S., Luo, P., He, B. and Jiang, R. (2013). Developing a 3D Cadastre for the Administration of Urban Land Use: A Case Study of Shenzhen, China. Computers, Environment and Urban Systems, 40, pp. 46–55.

Haber, R. and McNabb, D. (1990). Visualization Idioms: A Conceptual Model for Scientific Visualization Systems. In Visualization in Scientific Computing, IEEE Computer Society Press, pp. 74-93.

Hugues, O., Cieutat, J. M. and Guitton, P. (2011). GIS and Augmented Reality: State of the Art and Issues. In Handbook of Augmented Reality, Springer New York, pp. 721-740.

ICA (2015). International Cartographic Association - Commission on Visual Analytics, http://viz.icaci.org/.

ICSC (2015). Proceedings of the VI International Conference on Spatial Cognition, Cogn Process (2015) 16 (Suppl 1):S1–S113 DOI 10.1007/s10339-015-0732-7.

Isikdag, U., Horhammer, M., Zlatanova, S., Kathmann, R. and van Oosterom, P. (2015). Utilizing 3D Building and 3D Cadastre Geometries for Better Valuation of Existing Real Estate. FIG Working Week 2015, Sofia, Bulgaria, 17-21 May.

ISO-TC 19152-LADM, 2011, Geographic information - Land Administration Domain Model, Draft international standard.
Retrieved from http://www.isotc211.org/protdoc/211n2886/.

Jankowski, J. and Decker, S. (2012, April). A dual-mode user interface for accessing 3D content on the world wide web. In Proceedings of the 21st international conference on World Wide Web, ACM, pp. 1047-1056.

Jeong, D.-H., Jang, B.-B., Lee, J.-Y., Hong, S., van Oosterom P., de Zeeuw, K., Stoter, J., Lemmen, C. and Zevenbergen, J. (2012). Initial Design of an LADM-based 3D Cadastre – Case Study from Korea. In Proceedings of the 3rd International Workshop on 3D Cadastres: Developments and Practices, Shenzhen, China, 25-26 October, pp. 159–184.

Kolbe, T.H. (2009). Representing and Exchanging 3D City Models with CityGML, 3rd International Workshop on 3D Geo-Information, 13.-14. November 2008 in Seoul, South Korea. Published in Lee, Zlatanova (eds.): 3D Geo-Information Sciences, Springer, 2009.

Kondo, B. and Collins, C. (2014). Dimpvis: Exploring Time-Varying Information Visualizations by Direct Manipulation. IEEE transactions on visualization and computer graphics, 20(12), 2003-2012.

Kraak, M.-J. (2003). The Space-Time Cube Revisited from a Geovisualization Perspective. In Proc. 21st International Cartographic Conference, pp. 1988-1996.

Kwan, M. P. and Lee, J. (2004). Geovisualization of Human Activity Patterns using 3D GIS: a Time-Geographic Approach. Spatially integrated social science, 27.

Lacoche, J., Duval, T., Arnaldi, B., Maisel, E. and Royan, J. (2015). Plasticity for 3D User Interfaces: New Models for Devices And Interaction Techniques. In Proceedings of the 7th ACM SIGCHI Symposium on Engineering Interactive Computing Systems (pp. 28-33). ACM.

Landauer, T. (1995). The Trouble with Computers: Usefulness, Usability and Productivity. The MIT Press, Cambridge, Chapter 6, pp. 141-168.

Lee, G. A., Dünser, A., Kim, S. and Billinghurst, M. (2012). CityViewAR: A Mobile Outdoor AR Application for City Visualization. In 2012 IEEE International Symposium on Mixed and Augmented Reality-Arts, Media, and Humanities (ISMAR-AMH), IEEE, pp. 57-64.

Li, X., Lv, Z., Zhang, B., Wang, W., Feng, S. and Hu, J. (2015). Webvrgis Based City Bigdata 3D Visualization and Analysis. arXiv preprint arXiv:1504.01051.

MacEachren, A. and M., Kraak, M.-J. (2001). Research Challenges in Geovisualization. Cartography and Geographic Information Science, 28(1).

Mao, B., Ban, Y. and Harrie, L. (2011). A Multiple Representation Data Structure for Dynamic Visualisation of Generalised 3D City Models. ISPRS Journal of Photogrammetry and Remote Sensing, 66(2), pp. 198-208.

Meng, L. and Forberg, A. (2007). 3D building Generalisation. Challenges in the Portrayal of Geographic Information. Amsterdam: Elsevier Science.

Métral, C., Ghoula, N. and Falquet, G. (2012). Towards an Integrated Visualization of Semantically Enriched 3D City Models: An Ontology of 3D Visualization Techniques. arXiv Preprint arXiv:1202.6609.

Milner, J., Wong, K. and Ellul, C. (2014). "Beyond Visualisation in 3D GIS". Proceedings of the GIS Research UK Conference.

Navratil, G. and Fogliaroni, P. (2014). Visibility Analysis in a 3D Cadastre. 4th International Workshop on 3D Cadastres, 2014, Dubai, pp. 183-196.

Nielsen, J. (1993). Usability Engineering. Academic Press, New-York.

Oliveres Garcia, J.M., Virgós Soriano, L.I. and Velasco Martín-Vares, A. (2011). 3D Modeling and Representation of the Spanish Cadastral Cartography. 2nd International Workshop on 3D Cadastres, 16-18 November 2011, Delft, the Netherlands, pp. 209-222.

Olshannikova, E., Ometov, A., Koucheryavy, Y. and Olsson, T. (2015). Visualizing Big Data with augmented and virtual reality: challenges and research agenda. Journal of Big Data, 2(1), 1.

Ortega F., Abyarjoo F., Barreto A., Rishe N. and Adjouadi M. (2016). Interaction Design for 3D User Interfaces: The World of Modern Input Devices for Research, Applications, and Game Development, CRC Press.

Parisi, T. (2012). WebGL: up and running. "O'Reilly Media, Inc.".Park, C. S., Lee, D. Y., Kwon, O. S., Wang, X., 2013. A Framework for Proactive Construction Defect Management using BIM, Augmented Reality and Ontology-Based Data Collection Template. Automation in Construction, 33, pp. 61-71.

Park, J., An, S. and Woo, W. (2015 September). Light Detecting 3D User Interface-Equipped System for Mixed and Augmented Reality Games. InMixed and Augmented Reality-Media, Art, Social Science, Humanities and Design (ISMAR-MASH'D), 2015 IEEE International Symposium. IEEE, pp. 55-56.

Philips, A., Walz, A., Bergner, A., Graeff, T., Heistermann, M., Kienzler, S. and Zeilinger, G. (2015). Immersive 3D Geovisualization in Higher Education. Journal of Geography in Higher Education, 39(3), pp. 437-449.

Pierdicca, R. Frontoni E., Zingaretti, P., Mancini A., Savina Malinverni E., Nora Tassetti A., Marcheggiani, E. and Galli, A. (2016). Smart maintenance of Riverbanks using a Standard Data Layer and Augmented Reality, Computers and Geosciences, 95, pp. 67-74.

Popelka, S. and Dolez, J. (2015). Non-Photorealistic 3D Visualization in City Maps: An Eye-Tracking Study, pp. 357–367.

Pouliot, J. (2011). Visualization, Distribution and Delivery of 3D Parcels. Position paper for 2nd International Workshop on 3D Cadastres, 16-18 November 2011, Delft, the Netherlands.

Pouliot, J. and Ellul, C. (2014). Workshop on Visualization, Distribution and Delivery of 3D Parcels – Synthesis. 4nd International Workshop on 3D Cadastres, Dubai, United Arab Emirates, 2014-11-09.
Available at http://www.gdmc.nl/3DCadastres/workshop2014/programme/Pres2014_p31.pdf.

Pouliot J. and C. Wang (2014). 3D Visualisation for cadastre applications. Position paper at 4nd International Workshop on 3D Cadastres, Nov. 9 to 11th, Dubai, United Arab Emirates.

Pouliot, J., Wang, C., Hubert, F. and Fuchs, V. (2014). Empirical Assessment of the Suitability of Visual Variables to Achieve Notarial Tasks Established from 3D Condominium Models. In Innovations in 3D Geo-Information Sciences (Series: Lecture Notes in Geoinformation and Cartography, Publisher: Springer Berlin Heidelberg, Ed U. Isikdag, pp.2 67-290.

Pouliot, J., Bordin P. and Cuissard, R. (2015). Cadastral Mapping for Underground Networks: A Preliminary Analysis of User Needs. International Cartographic Conference, Brazil, 2015-08-23.
Resch, B., Wohlfahrt, R. and Wosniok, C. (2014). Web-based 4D visualization Of Marine Geo-Data using WebGL. Cartography and Geographic Information Science, 41(3), pp. 235–247.

Ribeiro, A., Duarte de Almeida, J-P. and Ellul, C. (2014). Exploring CityEngine as a Visualization Tool for 3D Cadastre. 4th International Workshop on 3D Cadastres, Dubai, United Arab Emirates, pp. 197-217.

Robinson, A, Morrison', J. Muehrcke, P. Kimerling, J. and Guptill, A. (1995). Elements of Cartography, Wiley and Sons.

Schall, G., Zollmann, S. and Reitmayr, G. (2013). Smart Vidente: Advances in Mobile Augmented Reality for Interactive Visualization of Underground Infrastructure. Personal and ubiquitous computing, 17(7), pp. 1533-1549.

Shojaei, D., Rajabifard, A., Kalantari, M. and Bishop, I. D. (2012). Development of a 3D ePlan / LandXML Visualization System in Australia. In Proceedings of the 3rd International Workshop on 3D Cadastres: Developments and Practices, Shenzhen, China, 25-26 October, pp. 273–288.

Shojaei, D., Kalantari, M., Bishop, I. D., Rajabifard, A. and Aien, A. (2013). Visualization Requirements for 3D Cadastral Systems. Computers, Environment and Urban Systems, 41, pp. 39–54.

Shojaei, D. (2014). 3D cadastral visualisation: understanding users' requirements, PhD Thesis, Infrastructure Engineering Department, The University of Melbourne, Australia.

Shojaei, D., Rajabifard, A., Kalantari, M., Bishop, I.D. and Aien, A. (2014). Design and Development of a Web-Based 3D Cadastral Visualization Prototype. International Journal of Digital Earth, September, pp. 1–20.

Siejka, M., Ślusarski, M. and Zygmunt, M. (2013). 3D+time Cadastre, Possibility of Implementation in Poland. Survey Review, 46(335), pp. 79–89.

Steudler, D. and Rajabifard, A. (2012). Spatially Enabled Society. FIG Publication, No. 58.

Stoter, J., Ploeger, H. and van Oosterom, P. (2013). 3D Cadastre in the Netherlands: Developments and International Applicability. Computers, Environment and Urban Systems, 40, pp. 56–67.

Thompson, R., van Oosterom, P., Karki, S. and Cowie, B. (2015). A Taxonomy of Spatial Units in a Mixed 2D and 3D Cadastral Database. FIG Working Week 2015, Sofia, Bulgaria, 17-21 May.

Trapp, M., Beesk, C., Pasewaldt, S. and Döllner, J. (2011). Interactive Rendering Techniques for Highlighting in 3D Geovirtual Environments. Advances in 3D Geo-Information Sciences, XXXVIII, pp. 197–210.

Turkay, C., Slingsby, A., Hauser, H., Wood, J. and Dykes, J. (2014). Attribute Signatures: Dynamic Visual Summaries for Analyzing Multivariate Geographical Data. IEEE Transactions on Visualization and Computer Graphics.

van Krevelen, D.W.F. and Poelman, R. (2010). A Survey of Augmented Reality Technologies, Applications and Limitations. International Journal of Virtual Reality, 9(2), 1.

van Oosterom, P.J.M., Stoter, J. and Fendel, E. (eds) (2001). Registration of Properties in Strata, First international workshop on 3D cadastres, International Federation of Surveyors, Delft, the Netherlands.

van Oosterom, P. and Stoter, J. (2010). 5D Data Modelling: Full Integration of 2D/3D Space, Time and Scale Dimensions. In International Conference on Geographic Information Science, Springer Berlin Heidelberg, pp. 310-324.

van Oosterom, P.J.M., Fendel, E., Stoter, J. and Streilein, A. (eds) (2011). Proceedings 2nd international workshop on 3D Cadastres, November, Delft, the Netherlands.

van Oosterom P.J.M., Guo, R., Li, Ying, S, Angsüsser, S (eds) 2012, Proceedings 3rd international workshop 3D Cadastres: Developments and practices, October, Shenzhen, China, ISBN:978-87-92853-01-1 (published by International Federation of Surveyors).

van Oosterom PJM and Fendel E (eds) (2014). Proceedings 4th international workshop on 3D Cadastres., November, Dubai, United Arab Emirates, ISBN 978-87-92853-20-5 (published by International Federation of Surveyors).

Vandysheva, N., Sapelnikov, S., van Oosterom, P., de Vries, M., Spiering, B. and Wouters, R. (2012), The 3D Cadastre Prototype and Pilot in the Russian Federation. In FIG Working Week 6-10 May, Rome, Italy, pp. 6–10.

Voigt, M. and Polowinski, J. (2011). Towards a Unifying Visualization Ontology. TU Dresden, Institut für Software und Multimediatechnik.

Wang, C., Pouliot, J. and Hubert, F. (2012). Visualization Principles in 3D Cadastre : A First Assessment of Visual Variables. In Proceedings of the 3rd International Workshop on 3D Cadastres: Developments and Practices, Shenzhen, China, 25-26 October, pp. 309–324.

Wang, C. (2015). 3D Visualization of Cadastre : Assessing the Suitability of Visual Variables and Enhancement Techniques in the 3D Model of Condominium Property Units, Ph.D. Thesis, Université Laval, Canada.

Wang, C., Pouliot, J. and Hubert, F. (2015) (accepted)., How Users Perceive Transparency in the 3D Visualization of Cadastre: The Usability Test in an Online Questionnaire. Geoinformatica.

Ware C. and Plumlee, M.D. (2005). 3D Geovisualization and the Structure of Visual Space. Exploring Geovisualization Series, International Cartographic Association, p.567-576.

Ware, C. (2012). Information Visualization: Perception for Design, Elsevier.

Williamson, I., Enemark, S., Wallace, J. and Rajabifard, A. (2008). Understanding Land Administration Systems. Position paper presented at the International Seminar on Land Administration Trends and Issues in Asia and The Pacific Region 19-20 August 2008, Kuala Lumpur, Malaysia.

Wolter, M., Hentschel, B., Tedjo-Palczynski, I. and Kuhlen, T. (2009). A Direct Manipulation Interface for Time Navigation in Scientific Visualizations. In 3D User Interfaces, 2009. 3DUI 2009. IEEE, pp. 11-18

Wu, X., Zurita-Milla, R. and Kraak, M.-J. (2015). Co-clustering Geo-Referenced Time Series: Exploring Spatio-Temporal Patterns in Dutch temperature data. International Journal of Geographical Information Science, 29(4), pp. 624-642.

Zhang, L., Zhang, L. and Xu, X. (2016). Occlusion-Free Visualization of Important Geographic Features in 3D Urban Environments. ISPRS Int. J. Geo-Inf. 2016, 5, 138.

Zhao, J., Forer, P. and Harvey, A S. (2008). Activities, Ringmaps and Geovisualization of Large Human Movement Fields. Information Visualization, 7(3-4), pp. 198-209.

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