3D Cadastres Best Practices, Chapter 5: Visualization and New Opportunities

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Key words: 3D Cadastral Visualization, Users, User Requirements, Usability, Modelling, Presenting Information, 3D Environments, Interaction

SUMMARY

This paper proposes a discussion on opportunities offered by 3D visualization to improve the understanding and the analysis of cadastre data. It first introduce the rationale of having 3D visualization functionalities in the context of cadastre applications. Second the publication outline some basic concepts in 3D visualization. This section specially addresses the visualization pipeline as a driven classification schema to understand the steps leading to 3D visualization. In this section is also presented a brief review of current 3D standards and technologies. Next is proposed a summary of progress made in the last years in 3D cadastral visualization. For instance, user's requirement, data and semiotics, and platforms are highlighted as main actions performed in the development of 3D cadastre visualization. This review could be perceived as an attempt to structure and emphasise the best practices in the domain of 3D cadastre visualization and as an inventory of issues that still need to be tackled. Finally, by providing a review on advances and trends in 3D visualization, the paper initiates a discussion and a critical analysis on the benefit of applying these new developments to cadastre domain. This final section discusses about enhancing 3D techniques as dynamic transparency and cutaway, 3D generalization, 3D visibility model, 3D annotation, 3D data and web platform, augmented reality, immersive virtual environment, 3D gaming, interaction techniques and time.

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1. INTRODUCTION

In general, 3D cadastre is perceived as helpful for overlapping situations when property units vertically stretch over or cover one part of the land parcel as condominium with co-ownership, infrastructure above and below the ground as utilities network like cables and pipes or tunnels and metro. Visualization is a fundamental component of any cadastral system, providing instant clarity about the boundary of the land or any kind of property unit, such as a co-ownership right, mining right or marine right that cannot be achieved via a textual description (Lemmens 2010; Williamson et al. 2010). A particular benefit of 3D cadastral systems is that they offer better visualization support for complex multi-level properties.

Traditionally, cadastral visualization refers to the visualization of ownership boundaries on 2D maps and/or to descriptive data such as official measurements (length, azimuth, area, and owner's name) or legal documents such as title, deed or mortgage. For example, figure 1 illustrates Quebec cadastre plan with an example of 2D plan and a vertical profile to represent the overlapping situation of condominium units. While interaction with a 2D map may be possible (via geo-technology), the vertical or other profiles are mainly fixed, pre-defined when the cadastral system is created, and can only partially represent the increasingly complex 3D ownership and rights situations that are arising from increasing urbanisation. Adding an interactive 3D visualization system, which enables the visualization of the third geometric dimension in a flexible manner, allows users to explore the complexity of the 3D situation and gives the sensation of depth may certainly overcome some of the issues of 2D techniques or fixed vertical profiles.

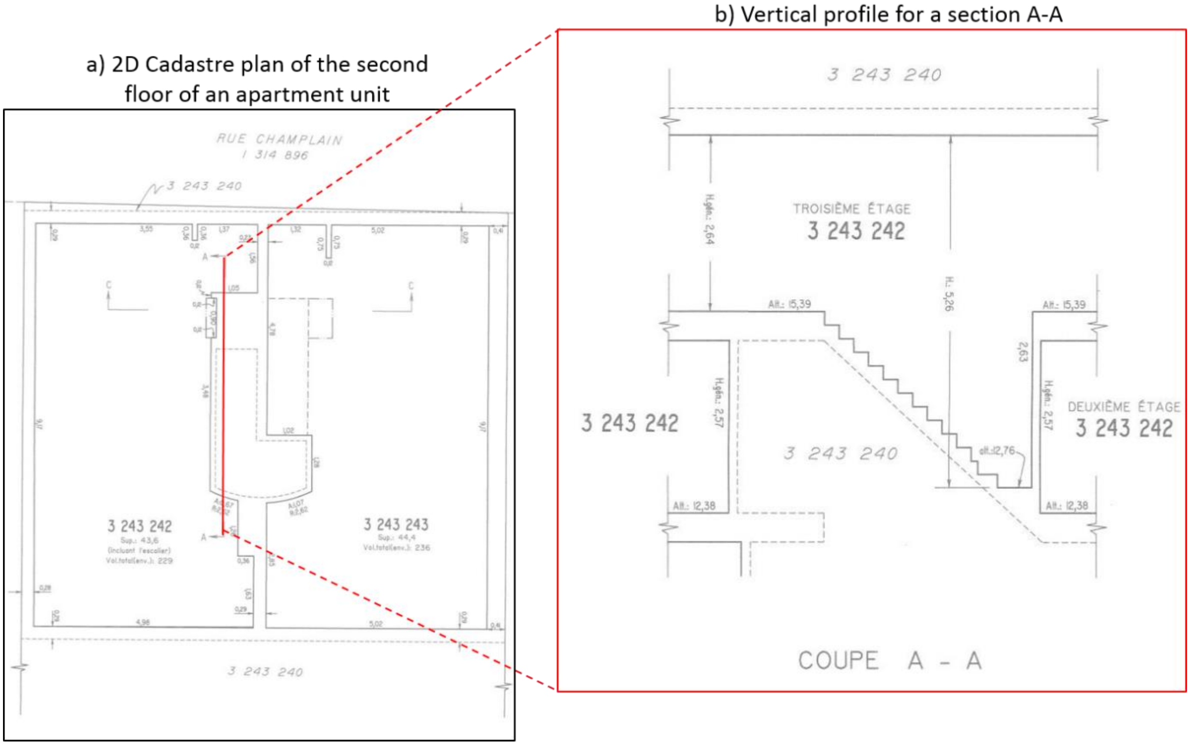


Figure 1. Example of vertical profile (Section A-A) used to represent the vertical dimension in the Quebec cadastre system (extracted from Infolot-MERN[1])

Accordingly, having 3D cadastre visualization brings new opportunities including (Paasch et al. 2016; Rajabifard et al. 2014; Stoter 2004; Stoter and van Oosterom 2006):

- Improve understanding in 3D situations (3D spatial relationships, overlapping, conflict)
- Allow the visualization of an integrated 3D space of property units (above and below the ground)
- Increase information for the user, as additional data variables (height, Z, depth)
- Allow having access to 3D measures and slicing planes
- Provide a familiar view of the world (more realistic) and thus reduce misinterpretation
- Increase the level of interaction

Meanwhile, the third dimension for cadastral visualization results in new challenges as well (Shojaei 2014; van Oosterom 2013; Wang 2015):

- It may requires the user to have certain proficiencies of using 3D visualization interface in order to carry out cadastre related work properly.
- The usual and well known mapping rules applied in 2D (e.g. selecting colour schema or symbols to represent the cadastre unit) may not perform the same as in 3D visualization.

[1] Infolot is the online system for Land register and Cadastre plan managed by MERN (Quebec Minister of Energy and Natural resources).

- The occlusion (inability to see 'behind') in 3D visualization may be an obstacle for user perception of property units in a complex building. Some options:
  - Pre-select some 3D parcels for further exploration (using different levels of transparency), and others to provide context (making these more transparent, or even using wireframe display to distinguish them from the selected parcels),
  - Use exploding-views around selected parcels to allow users to examine in-details,
  - Allow the user to temporarily move objects to other locations (slide out a complete floor of building, and look inside), or
  - Slicing (horizontal, vertical, diagonal).
- Adding some reference topographic objects (buildings, roads, pipelines) and especially the earth surface, further complicates the visualization. Note that topographic objects can be in vector representation (polyhedral surfaces) or smart point clouds, and the same is true for the earth surface.
- From a static 3D image it may not clear if a 3D parcel (related to legal space of pipeline or building) is above or below the earth surface (and how deep or how high). Interaction may help, but also good to include other visualization clues; e.g. connect via vertical sticks to earth surface.
- In regards of scale variation (perspective effect in 3D), the traditional visual interactions or usages with the cadastre data may be more complex to perform as locating a specific unit, taking 3D measurement or applying spatial operators as calculating the distance between two property units Also in case of non-regular (grid-like) objects, it may be difficult to estimate actual size and distances (compared to 2D map with homogenous scale).
- Displaying partly unbounded objects (open at bottom or top side), with their infinite boundary faces is impossible, but users should somehow get right impression.
- Visualizing 3D parcels and their temporal dimension (via animations or other techniques): either slowly changing parcels (continuously boundaries, e.g. near cost or river) or fast/ discrete changes (split of 3D parcel).
- Visually distinguish the legal objects with the physical objects in 3D, especially under overlapping scenarios.
- Availability of 3D cadastral data, and related data processing suitable for 3D visualization.

The purpose of this publication is to promote opportunities offered by 3D cadastres, with a specific focus on the role of 3D visualization as a routine communication tool. This publication may also be perceived as a road map to conduct research and development in 3D cadastre visualization. This manuscript is an extended version of the paper published at the 5th International FIG 3D Cadastre Workshop (Pouliot et al. 2016). It first proposes an introduction to theories and concepts in 3D visualization. Second, a summary of progress made in the last years in 3D cadastral visualization is highlighted. Finally, by providing a review on advances and trends in 3D visualization, the paper initiates a discussion and a critical analysis on the benefit of applying these new developments to cadastre domain.

2. 3D VISUALIZATION

This section of the document provides some background theory in order to supply further detail about the challenges arising from 3D visualization. In particular, the illustration of the visualization pipeline highlights the number of stages through which data must be processed before appearing on screen. This can in turn result in slower performance should the datasets to be processed be large or the hardware on which the visualization is taking place be lower in specification. How the data is stored - i.e. its representation on disk - is also important as format conversion may be required before the data can be passed into the visualization pipeline.

2.1 Theory and concepts

The main aim of visualization - whether 2D or 3D - is to take representations of the real world and display them to a user, most frequently on a 2D screen (laptop, desktop computer, tablet). Visualization will refer to geovisualization when geographic phenomena is under study as it is for cadastral information (ICA 2015; MacEachren and Kraak 2001). Geovisualization presents a number of fundamental challenges - firstly, the real world coordinates stored within the data (i.e. its coordinate reference system, which refers to an origin on the surface of the earth) need to be translated to screen coordinates, where the origin is at the top left of the screen. Similarly, the real world distances - miles, meters - need to be scaled down to screen distances. Additionally, the real 3D world needs to be transformed into a 2D representation on the screen - even if the data is 3D, the screen itself is most of the time 2D.

3D visualization brings the z dimension[2] in the visual field as perception of depth (Dykes et al. 2005; Kraak 1988). There exist many approaches to produce depth perception as physiological cues like eyes convergence, binocular disparity or motion parallax and psychological cues like retinal image size, perspective or shadows and technologies take advantage of them (Okoshi 1976). Formalizing the challenges outlined in the previous paragraph, the 3D visualization pipeline, as shown in figure 2, can be used to better understand the general processes that lead to 3D visualization (Chi 2000; Haber and McNabb 1990; Voigt and Polowinski, 2011; Wang 2015; Ware 2012). To illustrate these categories of product, figure 3 shows simple example of each step applied for representing the same building in 3D.

As can be seen in figure 2, the first stage of the process is data acquisition, which follows traditional routes in Geomatics including LiDAR, laser scanning or photogrammetry. Modelling, a part of the data acquisition process, consists in selecting which objects from the reality or data will be included in the model and in designing geometric and semantic (attribute) features and data structures to be used in order to store the model; in other words the mathematical representation (Marsh 2004; Requicha 1980; Turner 1992). Filtering and data manipulation to enhance or adapt the data as interpolation may also be required in the process of modelling. Mapping indicates the selection and interaction of visual variables and symbols to be applied to the 3D model in order to produce suitable 3D Map.It relies on semiotics; the study of signs and symbols as part of meaningful communication (Ware 2012). Some key foundations in mapping are those proposed by cartographers (Bertin 1983; MacEachren 1995),

[2] Note that in this case the z dimension is distance away from the eyes.

the principles of Gestalt or Tufte (Koffka 1999; Tufte 1992) or the information visualization (Ware 2012). The exact list of visual variables may vary from one author to another but it usually includes colour (hue and saturation), size, shape, orientation, value, texture.

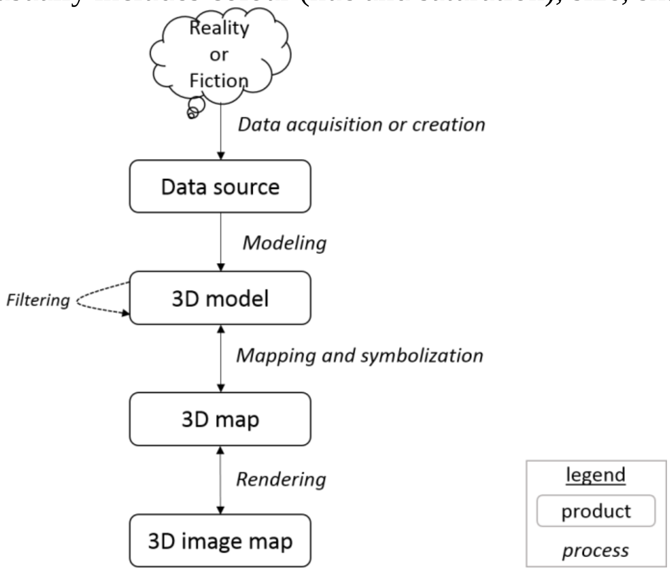


Figure 2. Visualization pipeline (adapted from Häberling et al. 2008; Semo et al. 2015; Terribilini 1999)

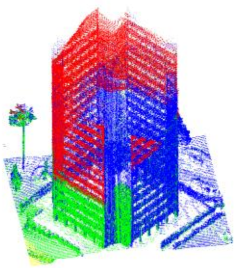
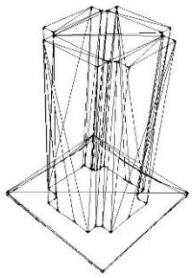
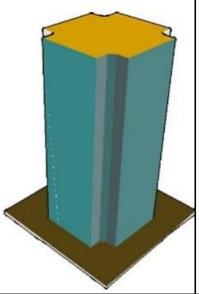
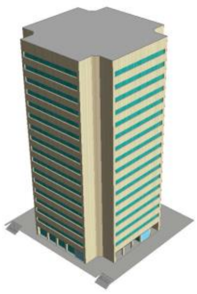
Image of reality	Lidar data source (coloured point cloud)	3D model (wireframe)	3D map (with colour code)	3D image map (with material)
				

Figure 3. Example of outputs corresponding to each stage of the visualization pipeline in figure 2 (the model represents one campus building at Université Laval, Canada)

After mapping comes the operation of graphic rendering. Rendering is the process of generating images from the geometric models and data and it involves many processes as how light is applied (direction, shading, reflection), rasterization, varying the viewpoint, applying texture and transparency, adding effects as atmospheric condition, seasonal variance (Marsh 2004). Rendering may be non-photorealistic rendering or photorealistic which consequently enable more realistic views. Rendering techniques also allow the production of animated images, and thus create the notion of moving objects.
Figure 4 shows one floor of an apartment unit with stairs in the middle (no ceiling or floor are represented) for which rending and mapping parameters are modified to illustrate the impact on

the 3D visualization schema. As it can be seen, modifying mapping and rendering parameters may greatly affect our capacity to see, select or distinguish objects and thus taking decision based on it. Research into 3D visualization may occur in any of the phases of the visualization pipeline but typically advances in visualization target the aspects of mapping and rendering. This paper does not address various aspects of the acquisition and modelling phases.

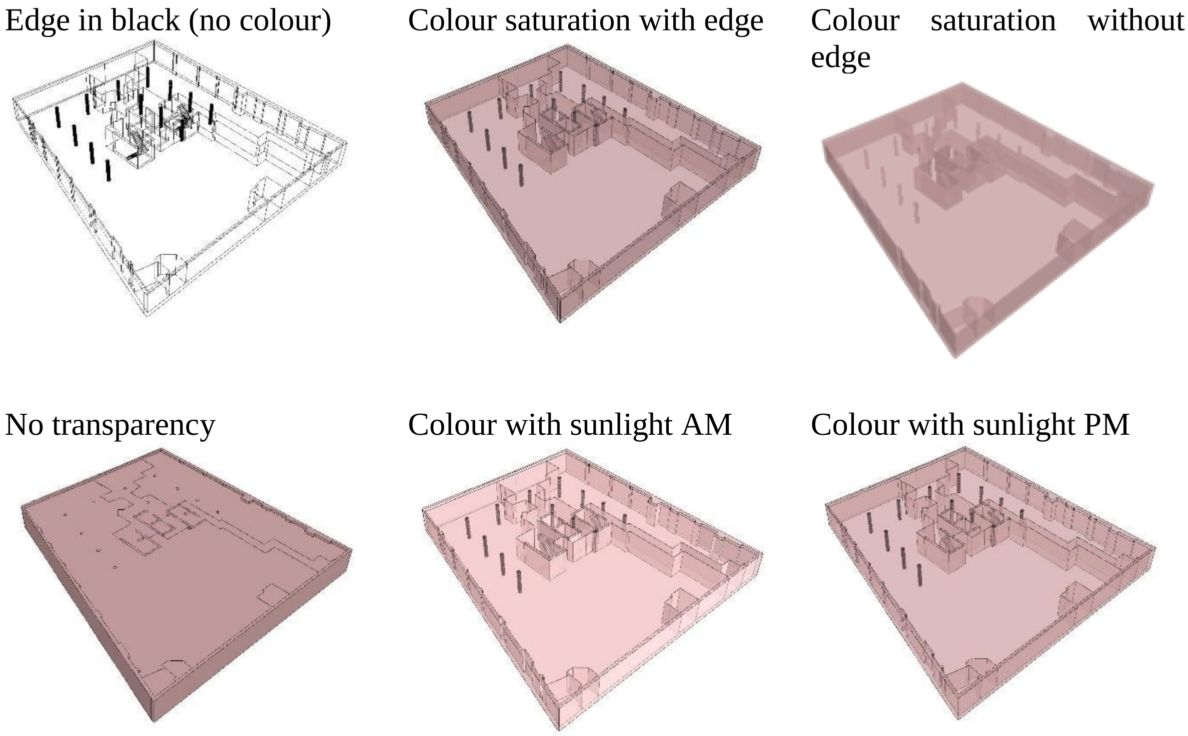


Figure 4. Examples of visual impact when modifying rendering and mapping parameters for 3D visualization (original 3D model built by group VRSB, Quebec City)

In addition to the concepts presented in figure 2, interaction, the dialogue between a human and a map mediated through a computing device (Roth 2011) also happens in the visualization process. Interaction may occur in changing the rendering parameters, focusing, arranging the symbols, etc. 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). The same applies to human related phenomena as perception (psychological and physiological facets), memories in vision, cognitive science since they all may impact the designing and the usage of visualization system (Miller 1956; Popelka and Dolez 2015; Ware and Plumlee 2005).

2.2 Representations and Standards for Storage and Data Exchange

In order to be used for visualization, the data captured at the start of the above pipeline must be stored in a format appropriate for downstream use. In this chapter, the term "D" refers to the geometric dimension and any 3D visualization will require having 3D geometric information, either as a Z coordinate, height or depth information attached to the geometric objects like vector geometry as point, line, surface or solid or volume element (voxel). It should be noted that while this Z information is required for any 3D visualization, solid objects or voxels are not a necessity. For example, a 3D model may be produced from the assembling of surfaces, often called boundary representation (Requicha, 1980). To illustrate this aspect, figure 5 presents 3D visualization of various categories of 3D data in the context of geological modelling (Bédard 2006).

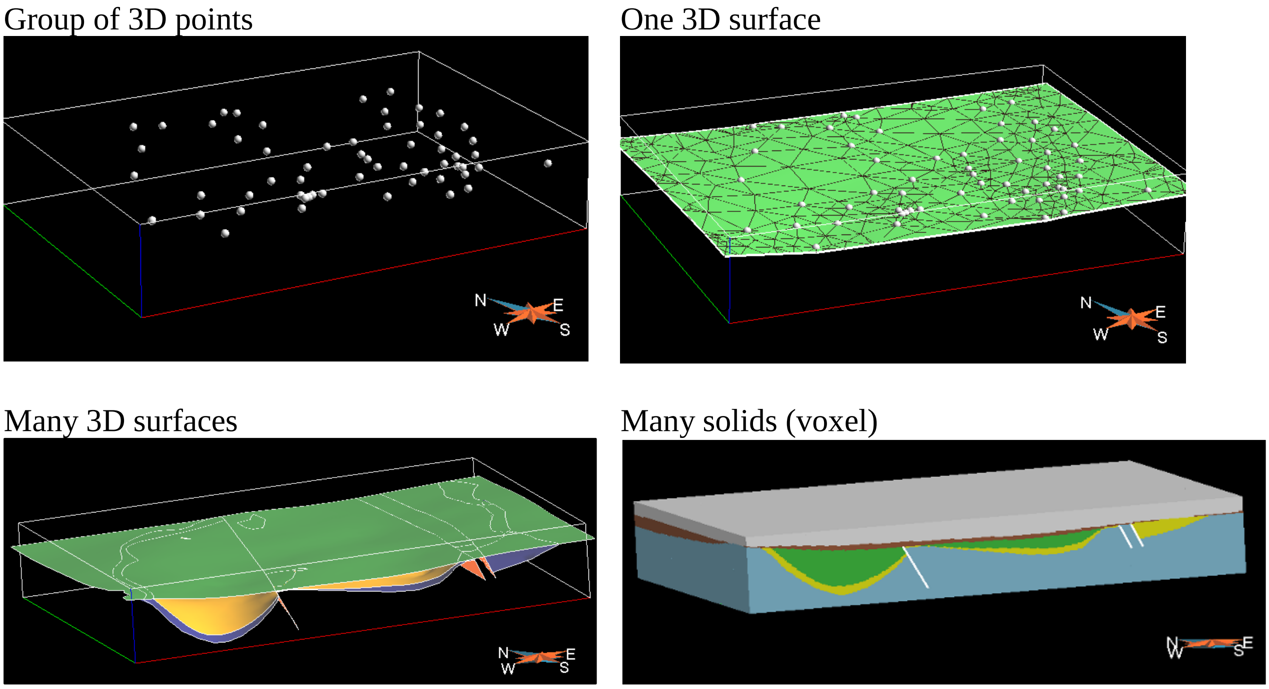


Figure 5 3D visualization of 3D data representing geological features (3D models built by Bédard 2006 with Gocad)

Pertinent standards in 3D visualization relate both to data format and grammar, and are implemented as programming interfaces (API) and Web Feature Services. Many of them are proposed by ISO, OGC and W3C. For instance, CityGML act as an open standardised GML[3] data model for 3D city models and it proposes formalization for the model appearance (Gröger and Plümer 2012; Kolbe et al, 2009; OGC 2012) as well as its content (i.e. what features are modelled and to what accuracy). The Industry Foundation Classes (IFC) is a standard largely in used in the context of Building-information modelling (BIM) and adopted by ISO-16739. BIM-based approach provides significant benefits for visual communication of properties, particularly in complex urban built environments, with both IFC and CityGML focusing on 'intelligent' visualization – i.e. geometry with associated attributes (Atazadeh et al., 2017a,b).

[3] Geography Markup Language.

Other 3D formats that focus purely on geometry without specifying content include X3D, OBJ or KMZ produced by Google Earth. COLLADA (COLLAborative Design Activity) offers an interchange file format. WebGL is a Javascript API for 3D graphics on the web that provides an 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). Finally, OGC is also working on 3D Portrayal Services that enable visualization (OGC 3D Portrayal 2012).

2.3 Generic Technology and Software

Two categories of 3D visualization device can commonly be identified - monoscopic 2D display screen and stereoscopic 3D devices that mimic the human vision thanks to 3D glasses or stereoscopes (sometime called True 3D visualization). On 2D screens, to reproduce the third dimension and give the illusion of depth, we usually apply projection techniques (Marsh 2004; Foley et al. 2003). The projected image could be calculated based on plane, sphere or cylinder form. Planimetric projection is the most common technique in use and two categories are typically found in computer software: perspective and parallel projections, with the perspective view dominating. Increasingly stereoscopic 3D visualization systems can be supplied on local platform, on Web or mobile devices. 3D visualization can also be performed with room-size immersive visualization (virtual reality) environment such as that provided by a 3D CAVE (Philips et al. 2015).

Software tools offering 3D visualization capabilities are abundant and can broadly be divided into graphics and game tools (e.g. *Blender*, *Google Sketchup, Unity3D)*, computer assisted design (e.g. *Bentley Microstation*, *Autodesk Autocad*), geographic information systems (e.g. *ESRI ArcGIS* or *CityEngine, QGis*) or 3D Viewers (e.g. *Adobe 3D PDF*, *Google Earth, ParaView*). An additional categorisation divides the group of tools into those that offer data handling and modelling capabilities or 3D viewers, which are dedicated to 3D visualization (without editing options). An example of the latter is the well-known Adobe Acrobat format, which also proposes an option for 3D PDF file handling, which offers minimal options to modify colour, transparency, projection and navigation. Google also proposes a 3D globe (Google Earth) which includes the visualization of 3D buildings for some cities in the world.

2.4 Comparing 2D and 3D Visualization

As it can be seen, addressing 3D visualization requires knowledge and expertise from various disciplines and is a double edged sword: it opens new possibilities, but also brings in new issues. Bleisch and Dykes (2015), Savage et al. (2004) or St-John et al. (2001) have presented comparative analysis in 2D and 3D visualization on how effectively and efficiently spatial data can be visually analysed in relation to specific tasks. While best practice for efficient mapping in 3D should be the same as it is in 2D, this is not the case - 3D visualization brings additional challenges when compared to 2D including: (Elmqvist and Tsigas 2008; Hardisty 2003; Jobst and Döllner 2008; Shepherd 2008; Todd 2004; Tory et al, 2006) :

- Occlusion and shadow management
- Orientation and position perception
- User interaction and experiences

- Photo Realistic option (more realistic views)
- Scale variation (perspective effect) and orientation dependency when measuring
- Depth perception

3. CADASTRAL SYSTEMS AND 3D VISUALIZATION

Although it is still an emerging field, some literature on 3D cadastre visualization exists and the topic was specifically addressed during the five 3D cadastre workshops (Fendel 2002; Pouliot 2011; Banut 2011; Pouliot and Wang 2014; Pouliot and Ellul 2014). On a total of 137 papers published during these workshops, and although many of them propose 3D pictures of cadastre, less than 15 papers focused on the 3D visualization aspects of cadastral data. The group discussion and material published during these 3D cadastre workshops and complementary literature review in scientific journals underpin this analysis. Three sections are proposed to synthesis the current activities in 3D cadastre visualization: user needs, data and semiotics/rendering aspects and visualization platforms.

3.1 Users and User Requirements

During the workshops, there were a number of discussions relating to users and their needs and researchers show an increasing understanding that users must be part of development and research activities for cadastral 3D visualization (Pouliot et al. 2014; Shojaei et al. 2013; Shojaei 2014; Stoter et al. 2013; Wang et al. 2016). A number of studies in this area are reviewed here, and overall the review shows that users are still eager to learn about the exact advantages of using 3D visualization.

Looking in more detail, the review indicates that cadastres' **users** are mainly the user groups who would also make use of 2D cadastral systems - i.e. managers in government and municipal authorities responsible for the maintenance of the land administration system, as well as lawyers and notaries, land surveyors. The third dimension in cadastre system also appears to contribute of having (or increase) opportunities for new users of cadastre data, including architects, engineers, developers, real estate agents (Atazadeh et al. 2017). Architects and engineering for example already use 3D models for their own obligations and thus may be used to interacting with data in this manner; having 3D cadastre integrated or available is perceived as valuable. Another example to mention is marine areas, 3D visualization is offering many advantages and cadastre information (property/tenure) is part of it (Athanasiou et al. 2016).

Additionally, a questionnaire addressed to Quebec municipalities compared user's expectation regarding cadastre data in 2D and in 3D and showed that overall, the cadastre related tasks are mainly the same in 2D and 3D (Boubehrezh 2014). In brief, interacting with a 3D visualization of cadastre data is helpful to (Boubehrezh 2014; Pouliot and Boubehrezh 2013; Pouliot et al. 2014; Shojaei 2014; Shojaei et al. 2013; Wang 2015):

- Identify and understand the 3D geometric boundary of the property units.
- Locate a specific 3D property unit.
- Look inside and outside the boundary of the 3D property unit.
- Find adjacent objects of a 3D legal object, both vertically and horizontally to identify affected RRRs (Right, Responsibility, and Restriction).

- Distinguish the boundaries of the 3D property units and the associated building parts.
- Distinguish the private and common parts in 3D co-ownership apartment buildings.
- Merge and subdivide volumes to facilitate the registration processes.
- Trace utility networks and infrastructures (e.g. tunnel and bridges) and control the proximity with ownerships boundaries and detect collisions.
- Visually check the spatial validity and data quality, e.g. volume is closed, no overlap between neighboring volumes, and no unwanted 3D gaps.
- Examine the property units in the context of their 3D surrounding environment.
- Associate public and building elements with 2D land parcels and compare their 3D geometry and spatial relationships.
- Perform 3D measurements such as calculating the surface area or volume of the property.
- Perform 3D geometric analysis such as 3D buffering, e.g. in the case of easement applications.
- Perform 3D spatial relationships such as 3D overlapping analysis to identify RRR conflicts.
- Support other management systems including land taxation, construction permits, urban planning, and land use regulation.

To those 3D cadastre requirements, we may also add the traditional functionalities available in 3D visualization system, as zoom in-out, pan, having tooltip, or mapping and rendering controls (as changing the colour, the type of symbol, the level of transparency, the shadow effect, etc). In terms of **usability**, while advanced systems such as *ESRI CityEngine* do exist to facilitate 3D visualization enabling, the steepness of the learning curve required to operate them perhaps makes them unsuitable for many of the user groups identified during the various workshops, both technical experts and members of the public (Ribeiro et al. 2014).
To summarise this section, the table 1 recaps the user types, user requirements and current gaps identified in literature in regards of 3D cadastre system visualization.

Table 1. Users and User Requirements of 3D cadastre system visualization

User types	Requirements	Challenges
- General Public - Land Registry - Local Governments - Land surveyors, Notaries, Land lawyers - Architects, Engineering and Construction - Land and urban planners - Property development - Building Management	- Identify 3D property - Understand the 3D geometry - Locate and compare - Measure - Control accuracy - Query geometry and attributes - Interact with	- Steep learning curve - Presenting a solid value proposition - Barriers to legal and institutional adoption - 3D visualization for other applications - Multipurpose cadastral systems

- Real Estate	- Integrate with other applications	

3.2 Information to Visualize and Semiotic/Rendering Aspects

Discussions on what to represent (information) and how (semiotic and rendering aspects, i.e. the best way to communicate information) in 3D visualization were also featured throughout during the 3D cadastre workshops.

3.2.1 What to Represent

The need for full 3D (solid) representation has been considered at all workshops but as yet most of the current cadastre systems are still proposing 2D plans and limited 3D information, and for backwards compatibility any visualization system would also have to consider these 2D aspects. The Land Administration Domain Model (ISO-TC 19152-LADM, 2011) provides an exhaustive list of cadastral data and modelling aspects to consider. For example, a digital cadastral mapping system in a multipurpose environment may have the following core components (IAAO, 2015):

- geodetic control network based in a mathematical coordinate projection
- cadastral parcel layer delineating the boundaries of real property in the jurisdiction
- other cadastral layers related directly to the parcel layer, such as subdivision, lot and block, tract, and grant boundaries
- unique identifier assigned to each property
- attributes (semantic) to describe the geometry of the property as length, area, volume or to describe the RRR attached to the property as deeds, titles, easements
- computer system that links spatial data and registration system.

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) and Wang (2015) suggest that at least two types of spatial objects are necessary for cadastral 3D visualization as the boundaries of a physical object and the boundaries of a legal object (the term administrative boundary may also be used). Adding to this, Döner et al. (2011), Guerrero et al. (2013), Guo et al. (2013), Jeong et al. (2012), Pouliot et al. (2015), Shojaei et al. (2013) and Vandysheva et al. (2012) propose the visualization of underground objects as part of cadastre systems.

The debate also included a core focus on the importance of representing not only legal but also physical representation of the world, the need to distinguish between private and publicly owned land, the need to formalize the spatial relationships along with the potential to link additional information—e.g., official documents—to the 3D geometry. Mapping legal boundaries that do not physically exist poses a certain number of issues, and some solutions have emerged from research (Aien et al. 2013; Griffith-Charles et al. 2016; Shojaei et al. 2014).

Most of these propose the visualization of orthophotography and legal boundaries draped on a 3D globe. As shown in figure 6 that presents the 3D visualization of bridge and legal boundaries of Shenzhen Bay port, the legal space is enlarged and distinct from the physical space of the construction (Guo et al. 2011). Only through the 3D visualization can we clarify the difference of these spaces.

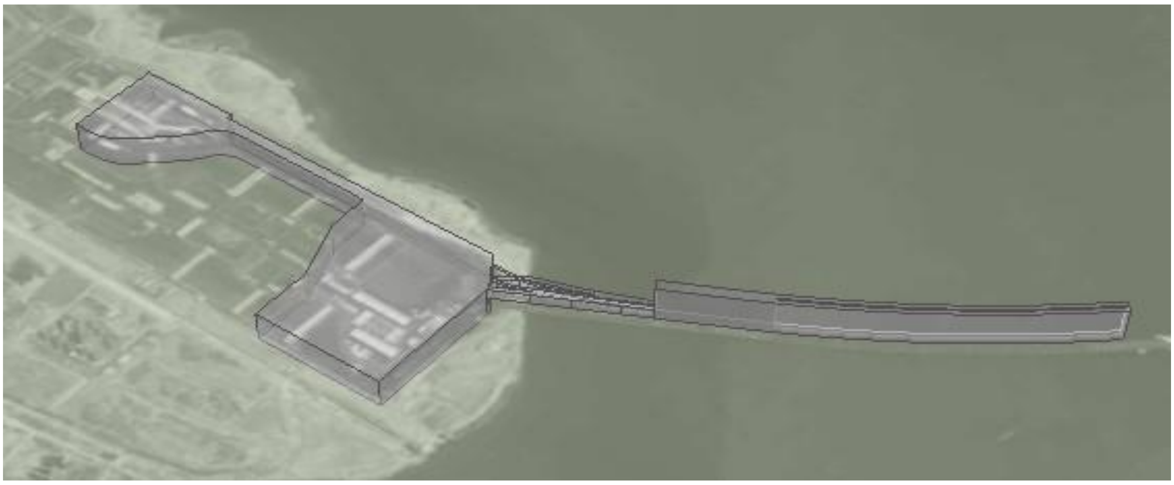


Figure 6. Shenzhen Bay Port 3D visualization of bridge and legal boundaries (source Guo et al. 2011)

Figure 7 shows another example that allows the visualization of inside building (Atazadeh et al. 2017). It was shown that the BIM environment can potentially be utilized to provide a more communicable method of representing a wide range of legal and physical boundaries defined in the state of Victoria in Australia. However, traditional BIM does not yet provide support for defining 3D legal objects (Atazadeh et al. 2017; Shojaei et al. 2014). 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. Figure 8 shows 2D traditional view of superimposed buildings, cadastre parcels and underground networks, while the zoom offers a 3D view of the same objects. Having access, and thus being able to visualize descriptive data as an attribute is also important for cadastral applications. Figure 9 from Atazadeh et al. (2016) shows an example of managing legal information associated with a private property in the 3D digital data environment of BIM.

A legal boundary defined by the interior surface of walls	A legal boundary not defined by the physical structure

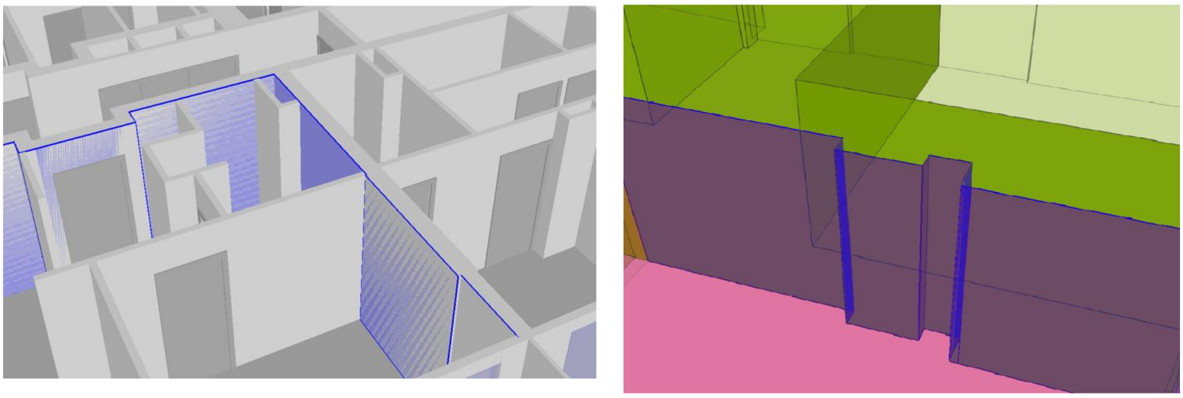


Figure 7. BIM distinction between legal and physical boundaries (built from Atazadeh et al. 2017)

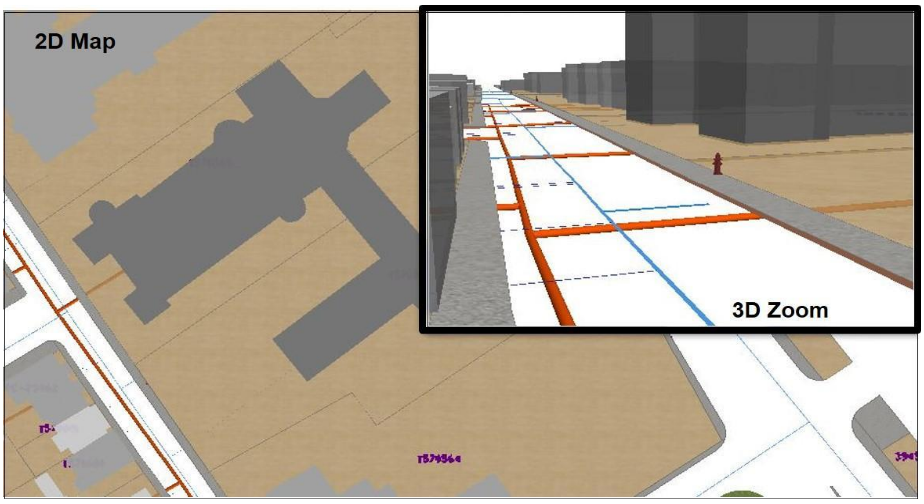


Figure 8. 3D Zoom on overlapping buildings, land parcels and underground networks

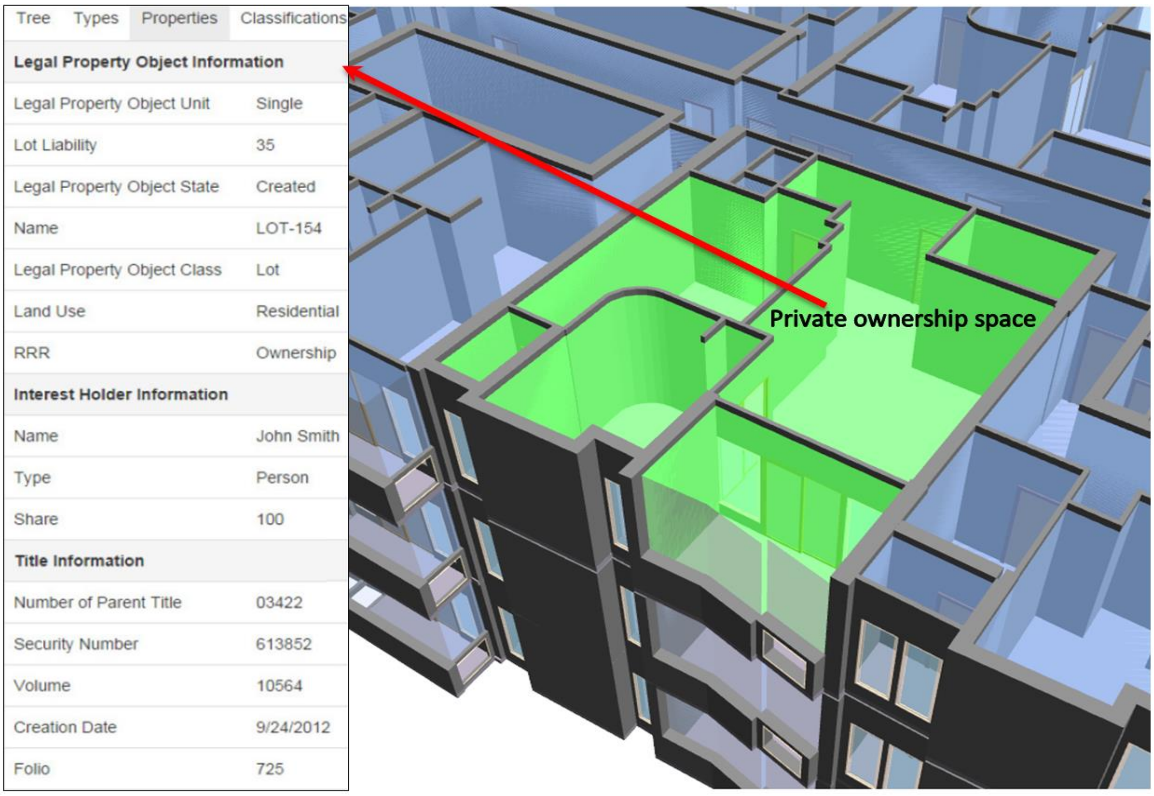
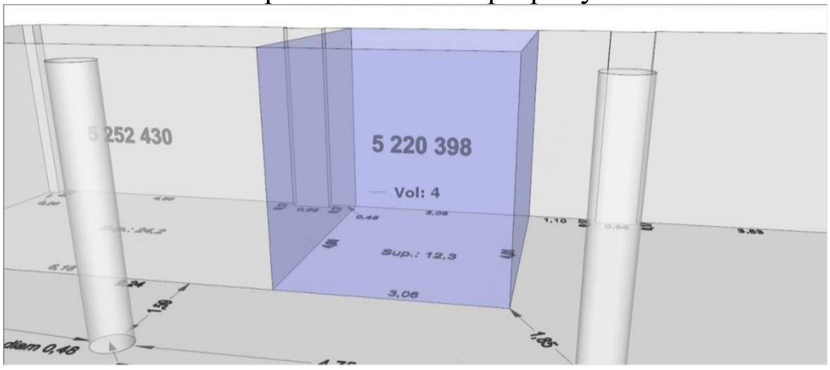


Figure 9. Representing and managing the legal (land administration) information in the BIM environment. On the left, attributes of the private ownership space are described (built from Atazadeh et al. 2016)

One important outcome of the survey conducted by Pouliot and Boubehrezh (2013) is that from the point of view of users, they required having 3D annotation (official measurements) marked on the 3D model. Wang (2015) and Pouliot et al. (2014) tested in a face-to-face interview with notaries the suitability of having 3D cadastre annotation. They were assessing the 3D position of annotation (inside, outside, next to) for marking the volume of the property unit (figure 10 shows two examples) located in an apartment. Positioning the annotation outside the volume was estimated by the notaries not helpful to achieve task.

Finally, some authors argue that, to manage and consequently visualize in a cadastral system, time (4D) should be part of the explicit data (Döner and Biyik 2013; Siejka et al. 2013; van Oosterom and Stoter 2010). Seifert et al. (2016) for example argue for the development of multidimensional cadastre system that include information related to energy, noise protection, urban planning, disaster management and time-related cadastral information as monitoring the development of cities over time, statistic of changes of land user/land cover or historical archiving. Having a 3D visualization system that allows integrated views of multiple sources of data, including cadastre, and animation scenarios appears as a major challenge.

Annotation "Vol:4" placed inside the property unit



Annotation "Vol:4" placed outside the property unit

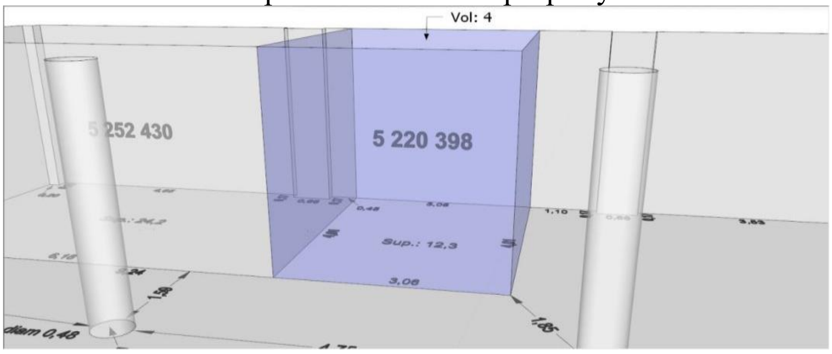


Figure 10 Varying the position of 3D annotation associated to the property unit 5 220 398 (original 3D model built by group VRSB, Quebec City)

3.2.2 Semiotics and Rendering

To date, very few researchers have addressed cadastre symbolization from a point of view of the semiotics of graphics. Wang (2015) and Pouliot et al. (2014) in their experiments with 3D cadastre visualization, have tested the suitability of visual variables (colour hue, colour saturation, position, value, texture and transparency) against six notarial tasks[4]. In their results, with or without transparency, the colour (hue) is among the preferred visual solution compared to value and texture for selection purpose. Colour (saturation) performed well to allow the association of lots into two groups.

Additionally, it is well recognized that transparency is a central technique in 3D visualization system and the same apply to 3D cadastre visualization. Ying et al. (2012) offer a good example in using transparency to depict the boundary difference between cadastral spaces and buildings spaces (figure 11).

[4] 1) See the geometric limits of the 3D lots, 2) Characterize a specific 3D lot according to its official information, 3) Locate a specific 3D lot inside the building, 4) Distinguish the limits of the 3D lot and the associated building, 5) Distinguish the private and common parts of the condo, 6) Understand the neighbouring relationship between 3D lot and its surrounding lots.

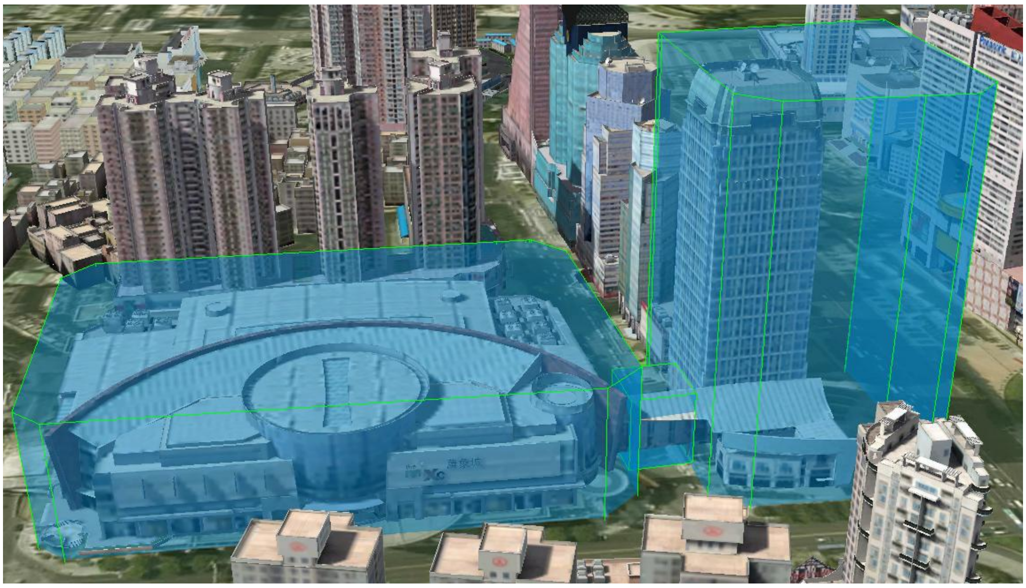


Figure 11. Using transparency to enhance the visualization of 3D cadastre and building spaces (source Ying et al. 2012)

Furthermore, Wang et al. (2016) have 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). Figure 12 illustrates two examples of transparency levels tested during the experiment. They found that, in general, using three different transparency levels is preferable and efficient solution to help users demarcate property units with their physical counterparts. Applying very high transparency to simple legal boundaries as compared to simple physical boundaries improves user certainty in the decision process. Using higher transparency on the physical boundary (wall) is more effective in communicating to users the concept of ownership.

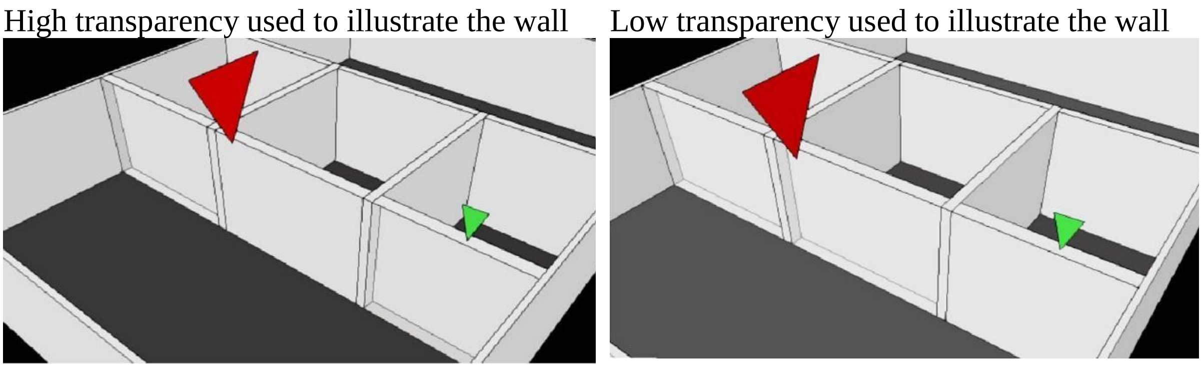


Figure 12. Testing transparency levels for ownership establishment. Participants had to decide whether this wall part belongs to the private property unit or not. The red arrow points to a private property unit and the green arrow points to a wall part (source Wang 2015)

Other researchers tested highlighting techniques like colour rectangle, detaching floors or slicing to improve the communication level (Pouliot et al. 2014; Shojaei 2014; Vandysheva et al 2012). For example, Ying et al. (2016) develop discretization and distortion of the set the property units (identified as coherent set) and depicted their relative spatial locations and spatial relationships (figure 13). An orthogonal function is used to discretize the coherent set of units and then displacement equations are applied while keeping the focus on one specific unit (the red one in figure 13). This distortion transformation and visualization effectively draw the inside property unit that cannot be visible in reality, only with the outer surfaces and appearances. Figure 14 illustrates another example of the use of slicing and detaching floors to get an inside view of the units.

The coherent set | The same set with distortion and focus

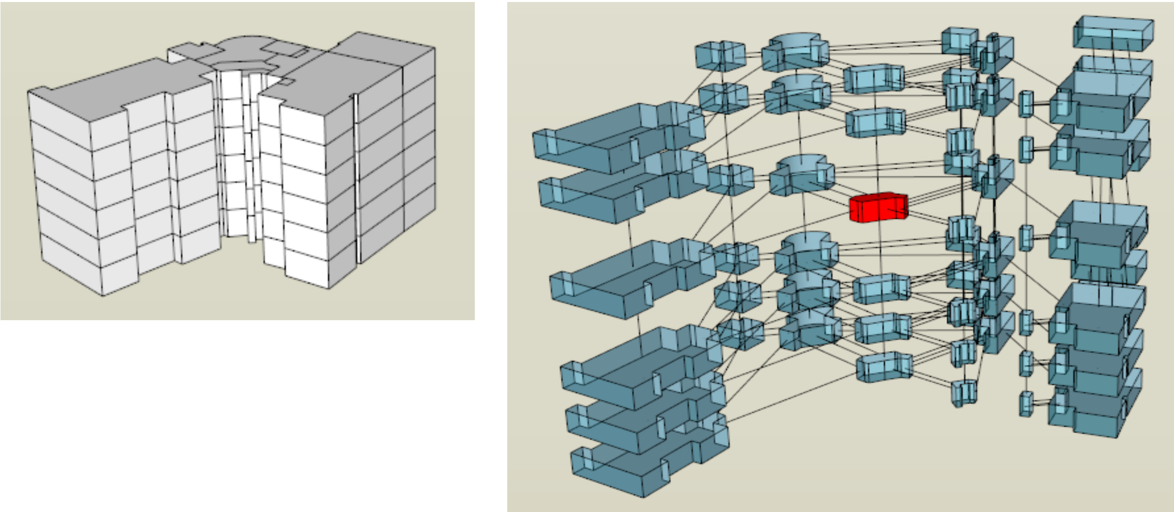


Figure 13. Distortion visualization of 3D property units (source Ying et al. 2016)

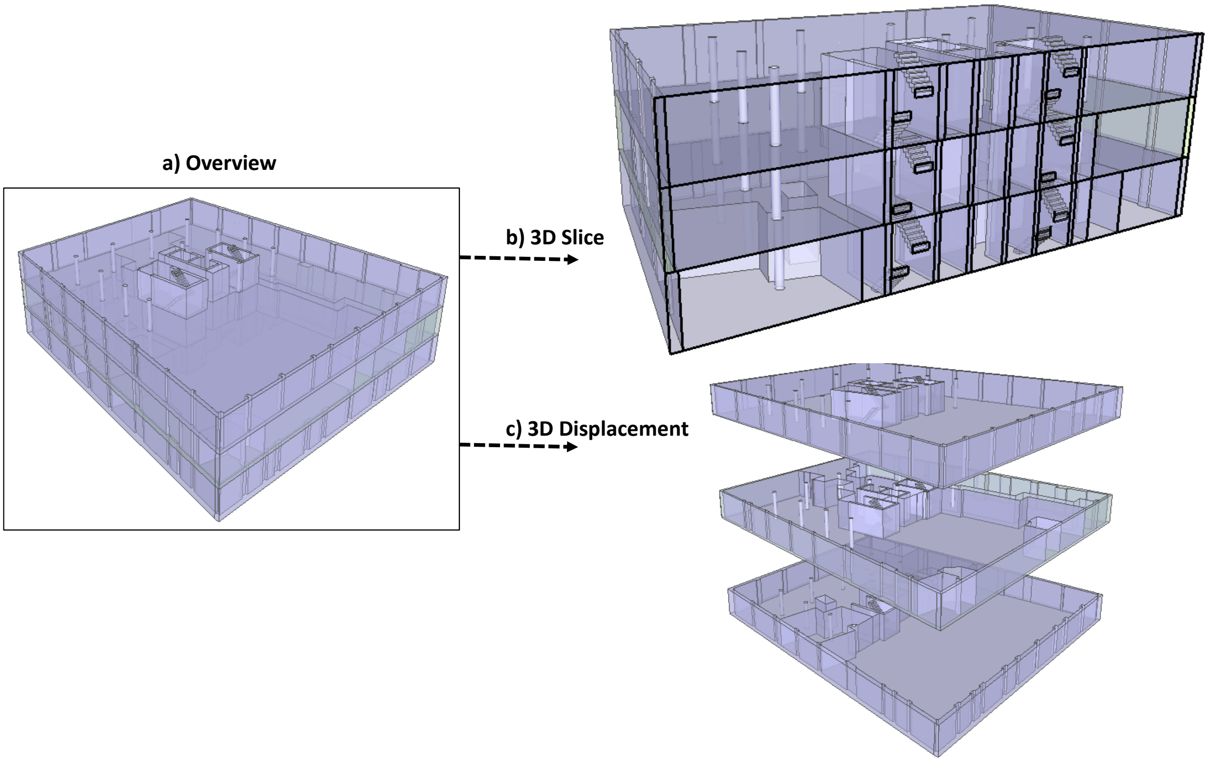


Figure 14. Highlighting techniques applied to the visualization of three floors of an apartment (original 3D model built by group VRSB, Quebec City)

Table 2 summarizes the current trends in 3D cadastre visualization regarding information and semiotic/rendering aspects and current gaps identified.

Table 2 Cadastral information and semiotic/rendering aspects of 3D cadastre visualization

Cadastral information to visualize	Semiotics and Rendering	Challenges
- Physical, legal and virtual objects/ spaces/boundaries as: • Annotations and attributes • Descriptive or legal documentation • Private and common parts • Private and publicly owned land	- Altering and suitability of visual variables - Applying texture and transparency - Colour rectangle - Slicing, cross-sections - Discretization and distortion	- Legal boundary not visible - Embedding within the legal decision making process - Availability of 3D cadastre data - Geometric complexity of apartment - Temporal data visualization

- Spatial relationships - Time and "chain" of property right		

3.3 Visualization Platforms

Alongside the generic platforms identified in *Section 2.3* above, emerging web-based technology as websites and web services was a clear focus in the review, which identified many prototypes built specifically for 3D cadastral systems that include web-based and desktop systems for which. Open-source solutions were identified as having particular relevance.

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. They also developed a 3D visualization system based on Google Earth for 3D ePlan/LandXML data to be used in overlapping property situations (Shojaei et al. 2012). Figure 15 shows some examples of the interface proposed by the prototype of 3D ePlan developed by Land Use Victorian Government. It is used to illustrate how the legal and physical objects of a building subdivision plan can be stored, visualised and queried in a 3D digital system (Olfat et al. 2016).

Aditya et al. (2011), for the jurisdiction of Indonesia, developed two 3D cadastre web map prototypes based on KML with Google Earth and X3D with ArcGIS online, respectively. Stoter et al. (2013) explained how in Netherlands 3D cadastre maybe applicable and in 2016 (Stoter et al. 2016) they presented a first attempts to accomplish 3D cadastral registration within the existing cadastral and legal framework.

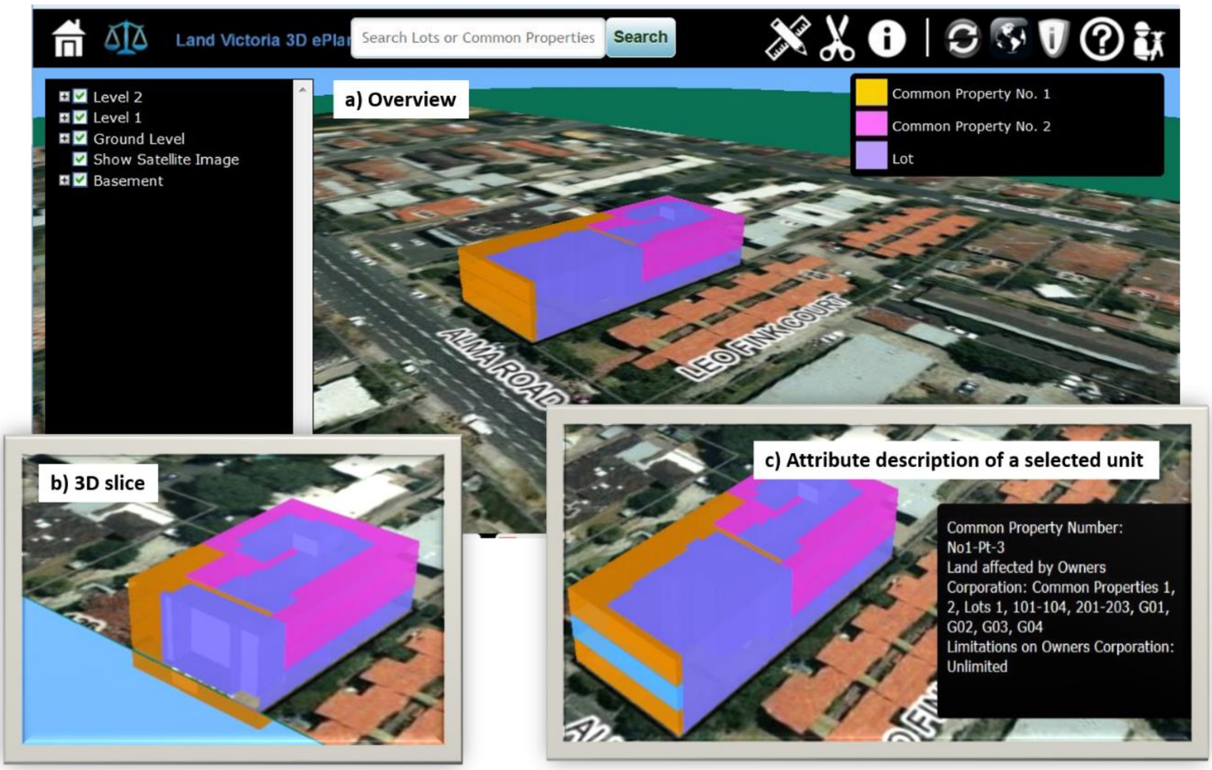


Figure 15. Land use Victoria prototype for online 3D ePlan (extracted from https://www.spear.land.vic.gov.au/spear/pages/eplan/3d-digital-cadastre/land-victoria-3d-eplan-prototype.shtml)

Additional visualizations are based on a **desktop** version of Google Earth. In China, Guo et al (2013) developed a 3D cadastre for the administration of urban land use for the city of Shenzhen. In Korea, Jeong et al. (2011) explored the future settle of 3D cadastre. Vandysheva et al. (2012) presented a 3D cadastre prototype applicable in the Russian Federation. Vucic et al. (2016) assessed the possibility for upgrading Croatian cadastre to 3D. In the context of Spain, Oliveres Garcia et al. (2011) explained how to use KML and Google Earth to visualize a volumetric representation of property units in condominiums. As illustrated in figure 16, Ribeiro et al. (2014) tested ESRI CityEngine for use in Portugal 3D Cadastre visualization.
On the other hand, Shojaei (2014) exploited a stereo approach using 3D anaglyph glasses to present ownership rights. In this technique, two different images are presented into right and left eyes to give 3D perception (figure 17).

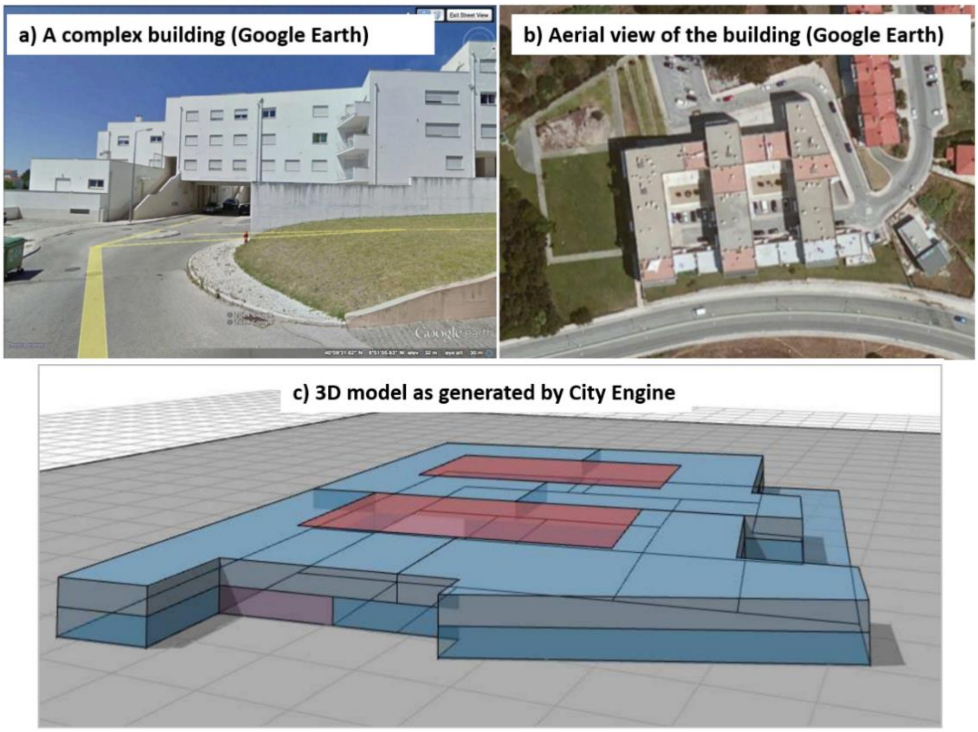
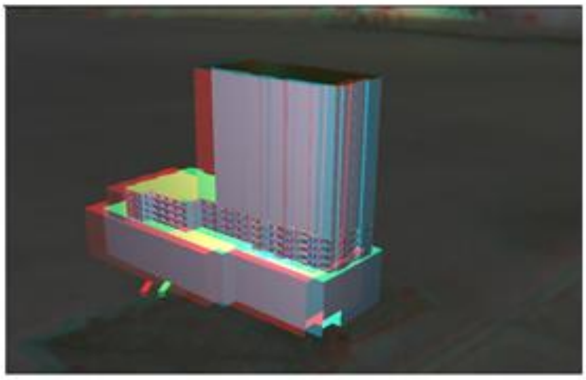


Figure 16. Generating 3D Cadastral Data using ESRI City Engine (source Ribeiro et al 2014)

A stereo representation of ownership rights



Presenting the prototype to the industry

Figure 17. A stereo representation of ownership rights based on anaglyph approach (source Shojaei 2014)

As noted in *Section 3.1*, 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). Visual highlighting techniques previously discussed is helpful to perform such interaction with the 3D model. 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. In order to look inside a building, it is also possible that user interaction is applied to temporary drag a floor with 3D parcels outside the building (figure 18). The benefit of interaction is that user is controlling this temporary distortion and therefore gets no wrong mental picture (and human intelligence is used to find nice location when dragging a floor outside the building).

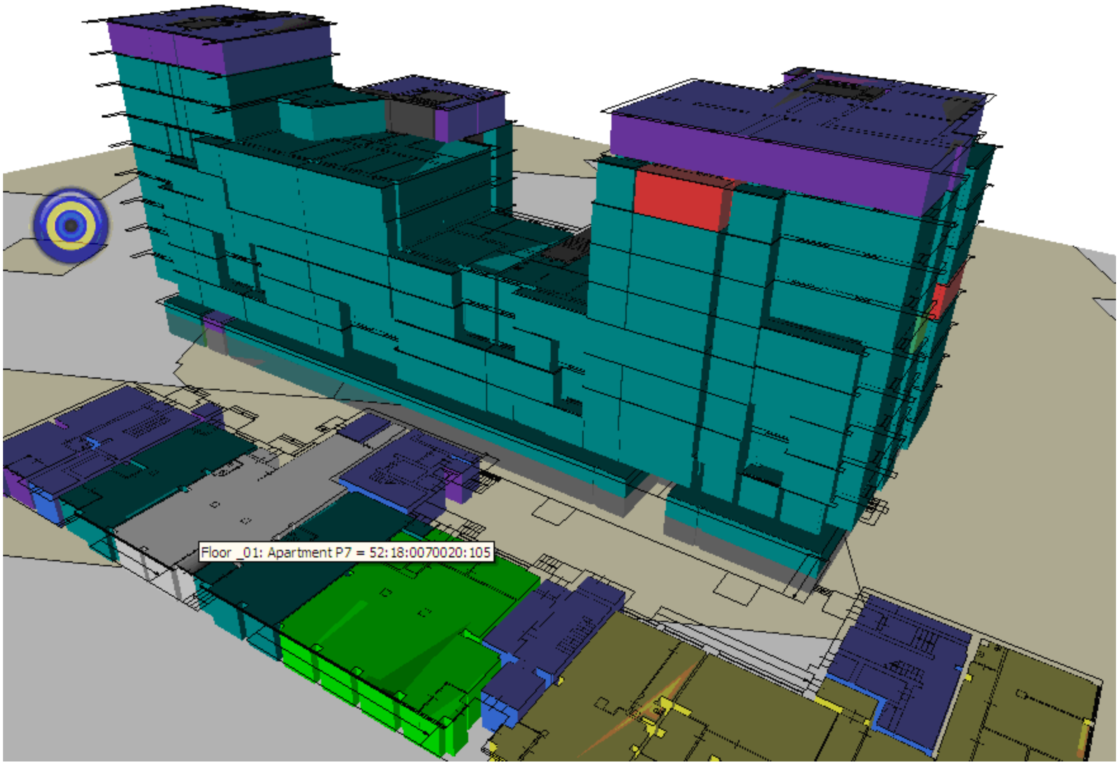


Figure 18 Floor_01 dragged outside the building. Note the tooltip which contains the identifier of the object during move-over (apartment P7). Source: (Vandysheva et al. 2012)

User interaction can also be used to switch on or off certain visualization clues. In a static image, it might be quite difficult to estimate the relative depth or height of objects. Toggling on/off vertical height/depth cue stick may help the user to get proper impression (in addition to moving, rotating, etc.); see figure 19.

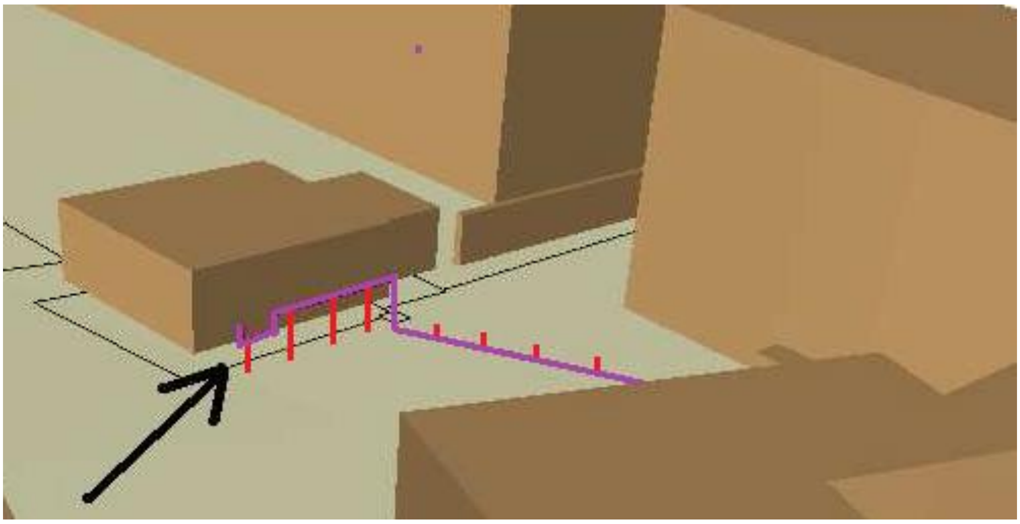


Figure 19. The pipeline (the purple line, starts above ground near arrow and is partly below ground). The black lines on the surface are the normal 2D parcel boundaries. The virtual 'red sticks' show vertical distance to surface, this is a clue for above/below the surface and the actual depth/height, and can be switched on/off. Source background: (Vandysheva et al. 2012)

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) propose a new model for 3D visibility analysis that integrates 3D Cadastre data in the context of urban planning.
To summarise this section, table 3 recapitulates the platforms, their functions and current gaps identified in literature.

Table 3. 3D cadastre platforms and their functions in the context of cadastre visualization

Platforms	Functions	Challenges
- Web/desktop - Open/proprietary - Fully functional (editing) or basic visualization only - Virtual and augmented reality - Gaming platforms	- Zoom in/out - Pan - Changing the colour, the type of symbol, the level of transparency, the shadow effect, etc - Spatial analysis - Navigation - Spatial Search - Attribute query - Stereo presentation	- Legal and institutional adoption - Interoperability of software - Absence of mobile devices - Interface for field surveys (not 3D) - Gap between 3D developers/users (e.g. gaming) and cadastral system developers/users

4. EMERGING TRENDS IN 3D VISUALIZATION

This section identifies a number of emerging research or trends in 3D visualization that may benefit 3D cadastral visualization. To facilitate the comparison, the topics are presented with the same groups as section 3.

4.1 Users and User Requirements

As noted in section 3.1, current research in 3D cadastre visualization proposes limited user analysis and those assessments are not really initiated by standardized concepts and terminologies. To this end, ISO, IEC and IEEE standardization on data quality assessment would have to be examined in more detail. For instance, the terminology of usefulness, usability and acceptability would be required to conduct reliable investigations that integrate end-users. Usefulness/usability issues cover solutions which intended users can understand and find useful for decision-making. 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 and Buxton, 2008). Usability studies (part of research into human-computer interaction)—such as heuristic evaluation, cognitive walk-through (Neilsen 1993) and studies using user testing and co-operative evaluation (Jacobsen 1999)—are also fundamental.

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 be considered along the concept of multipurpose cadastre (Dale and McLaughlin 1999; Williamson et al. 2008) or along suitability for the purpose (Enemark et al. 2014). Integrating the third dimension in cadastre is a possible opportunity to involve new users or develop new markets as it forces current users and practitioners to re-examine their own mission or professional practice. Climate change, sustainable development, urban planning are important societal preoccupations which now integrate 3D models of the Earth; land information is - should- be part of it. Capturing user requirements for on-demand mapping, dealing with different communities of users and establishing various user profiles would be benefit (Gould and Chaudhry 2012). Personalising visualization of the content of maps (2D/3D) according to the profile and location of final users would be useful in a cadastral context (Mac Aoidh et al. 2009). For a notary, an expert or a citizen, a same object (a building for example) could be represented differently following a simplified/complex geometry, other graphics (visual variables), and/or semantic information.

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 to 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.

As mentioned, an additional important factor to consider is the learning curve for users moving into a 3D environment. Preliminary tests have been done (Lu et al. 2016) comparing interaction in 2D and 3D GIS using ESRI's ArcMap and ArcScene for 7 users (Nielson 2000 notes that 5 users are sufficient for usability tests). Their results show that while all 7 users were able to find a given location and measure a distance, they struggled with more complex tasks in 3D. In particular, only 1 of the users managed to fly through a route, and only 5 managed to measure the height of a building. Similar experiments are required for cadastre users.

Semantics-driven visualization is another possible direction to explore to guide users through 3D visualization parametrization since it would result in adding formalized knowledge of a certain domain, user's experience, interaction and learning aspects to support visual task (Nazemi et al. 2015). Semantics-driven visualization would allow adding formalized knowledge of a certain domain, user's experience, interaction and learning aspects to support visual task (Klima et al. 2004; Mitrovic et al. 2005; Posada-Velásque 2006). Attributes and information from data, users and resources can then enrich visualization applications to decide how to represent data effectively according to defined rules. Smart applications can think and choose appropriate methods of visualization for a specific user for specific tasks. For example, if the user profile specifies the type of user and tasks (semantic information), needs and resources (e.g. device, internet bandwidth, and processor speed) might be specified for the application. Ideally, the application can automatically provide a customised visualization for the specified user according to semantic information acquired from users (Shojaei, 2014). For example, Neuville et al. (2017) is proposing a decision support tool that facilitates the production of an efficient 3D visualization. They propose a set of predicates and truth conditions between two collections of entities: on one hand the static retinal variables (hue, size, shape…) and 3D environment parameters (directional lighting, shadow, haze…) and on the other hand their effect(s) in achieving a specific visual task. Their approach could be interestingly applied to cadastre context.

Ethical issues may also be discussed when 3D visualization systems are exploited since the visualization pattern may benefit to promote (or not) one aspect or hide another. Monmonier demonstrated long time ago (1996) how it is easy to lie with maps and in 3D visualization, this issue is even more prevailing. 3D model visualization appears sometime so similar to the reality, that user may be confused; this is especially true when photorealistic rendering is applied. Ethical code was the basis of the 3D Charter proposed by various practitioners (Pouliot et al. 2010) or the Statement of Values for the Geomatics professional community (Pouliot et al. 2013). Sheppard conducted several studies in this topic in promoting for having a code of ethics for 3D landscape visualization (Sheppard 2000; Sheppard and Cizek 2009). This issue of 3D ethics in the context of 3D cadastre application has not been examined yet.

4.2 Information to Visualize and Semiotic/Rendering Aspects

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 GIS and beyond can assist with this challenge.

4.2.1 Enhancing techniques

Although this publication does not address the topic of data modelling, how data are organised and modelled may influence the visualization design. Some mapping and modelling practices like data generalization, multiple representations or occlusion management are techniques that may be investigated to improve data communication and thus visualization, and provide the additional benefit of a more nuanced understanding of user needs for 3D cadastral visualization, recognizing that a 'one size fits all' approach may not be appropriate.

Research into 3D generalization has been carried out by several authors, including Fan et al. (2009), Glander and Döllner (2009), Mao et al. (2011) and Meng and Forberg (2007). As with 2D generalization, a key purpose here is to provide a visualization that suit visual tasks for a specific 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 an interesting concept to examine. In current cadastre system, legal objects are most of the time visualized individually and are displayed as small as necessary to represent RRRs (van Oosterom et al. 2011). Unlike physical objects, legal objects cannot be generalised in cadastres. For example, at a city level, it would be misleading to generalise and merge legal objects (e.g. lots in a high rise) and visualise them in a single volume. Therefore, the traditional concept of LoD is not applicable to legal concepts (Shojaei, 2014), unless it is used to go beyond 3D building visualization and integrates legal, non-visible objects or boundaries, or their corresponding RRR as a specific LoD. The work of Gruber et al. (2014), applying LoD for the German Cadastre, is a first step in this direction. A similar argument might apply to traditional approaches to generalisation - for example, can RRR be aggregated conceptually in a similar way to individual buildings being aggregated into a single block.

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 (Zhang et al. 2016). Elmqvist and Tsigas (2008) presented an interesting and detailed review of 50 techniques in this area, including multiple viewports and virtual X-ray tools. For example they proposed an occlusion management called dynamic transparency which improve object discovery, and they applied it for 3D games, see figure 20.

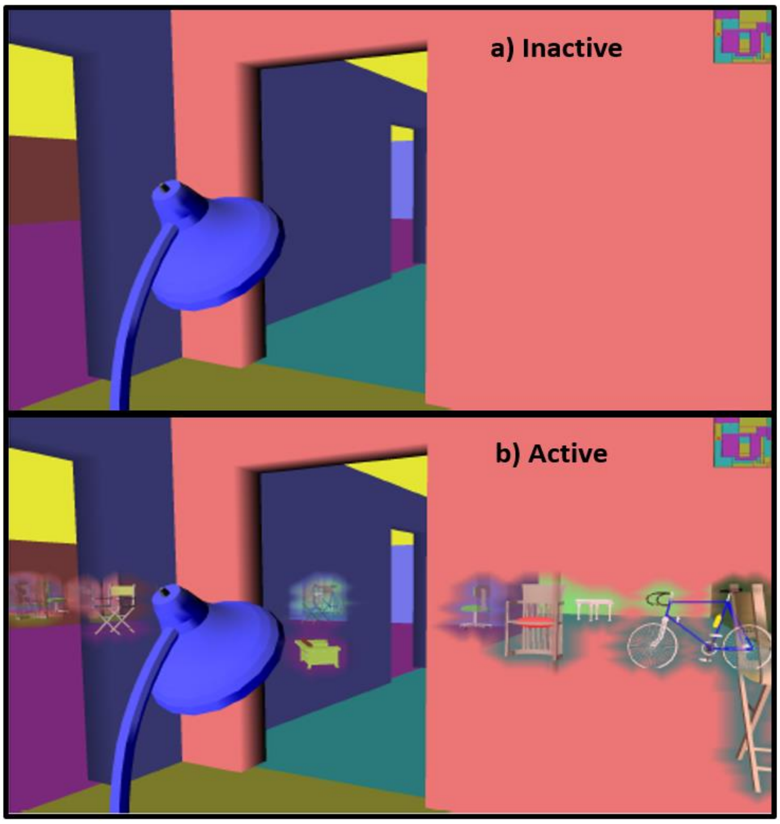


Figure 20. First-person view of the application of dynamic transparency (source Elmqvist 2006)

Cutaways and cross-sections (which are traditionally used in 2D cadastral mapping) also provide a direct technique to remove visual occlusion. Nevertheless, cross-section or cutaway illustrations are challenging to compute in keeping consistent material and surface textures in a vector boundary modelling. Li, Duan et al. (2015) explored semantic volume texture (SVT) model to overcome some of these computational challenges. They proposed an approach that rasterize the 3D model, while embedding pre-extracted semantic hierarchy and volume texture and rendering. Figure 21 illustrates one of their results. Voxel modelling and successive visualization have not yet been explored in cadastre application.
Fogliaroni and Clementini (2014) and Billen and Clementini (2006) applied the multiple viewport technique by splitting the 3D space in order to model the visibility between 3D objects. They proposed a new 3D visibility reference framework based on qualitative spatial representation, more reliable to human visual perception. Figure 22 shows an example of this framework. This technique may be suitability applied in the context of modelling and then revealing servitude of view while the concept of qualitative positioning (on left, above, etc.) better correspond to the user perception of how restrictions affect its own land usage.

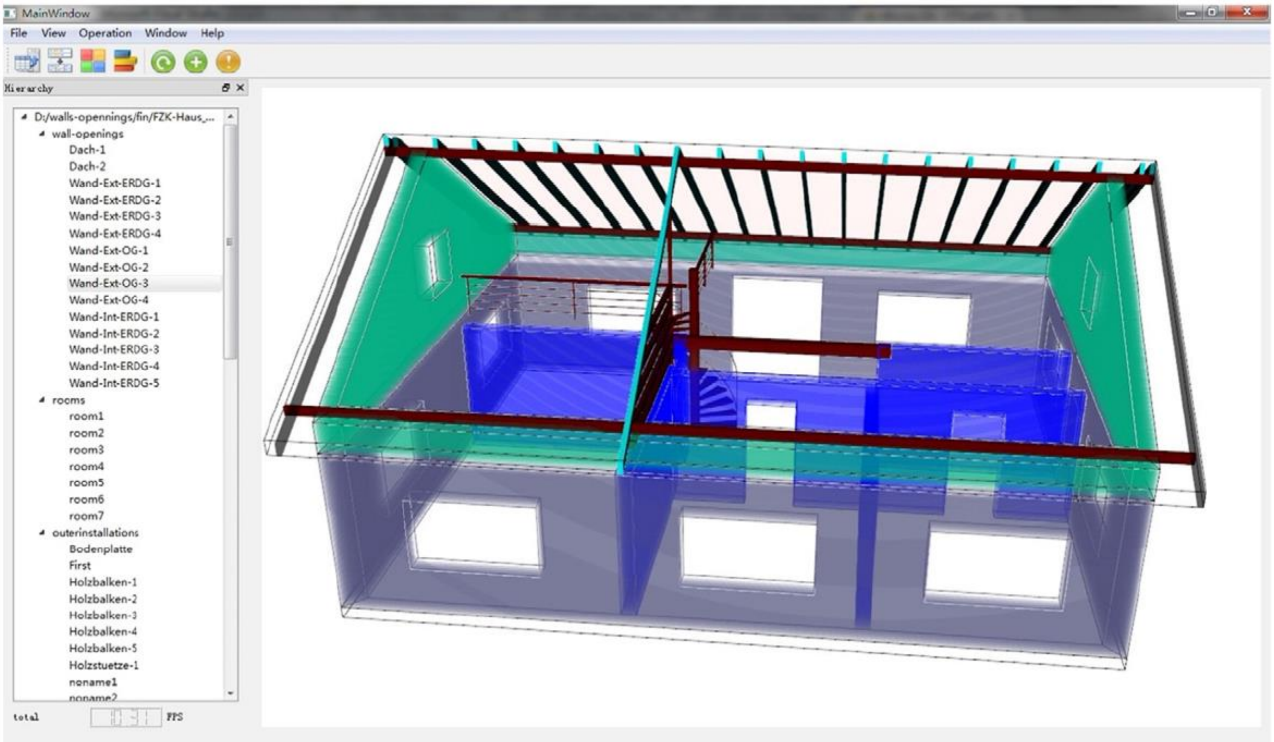


Figure 21. Example of semantic volume texture (source Li, Duan, et al. 2015)

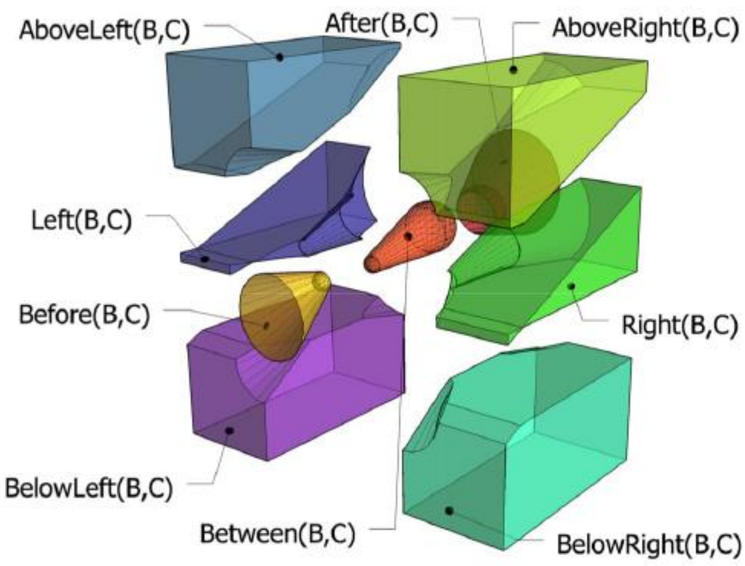
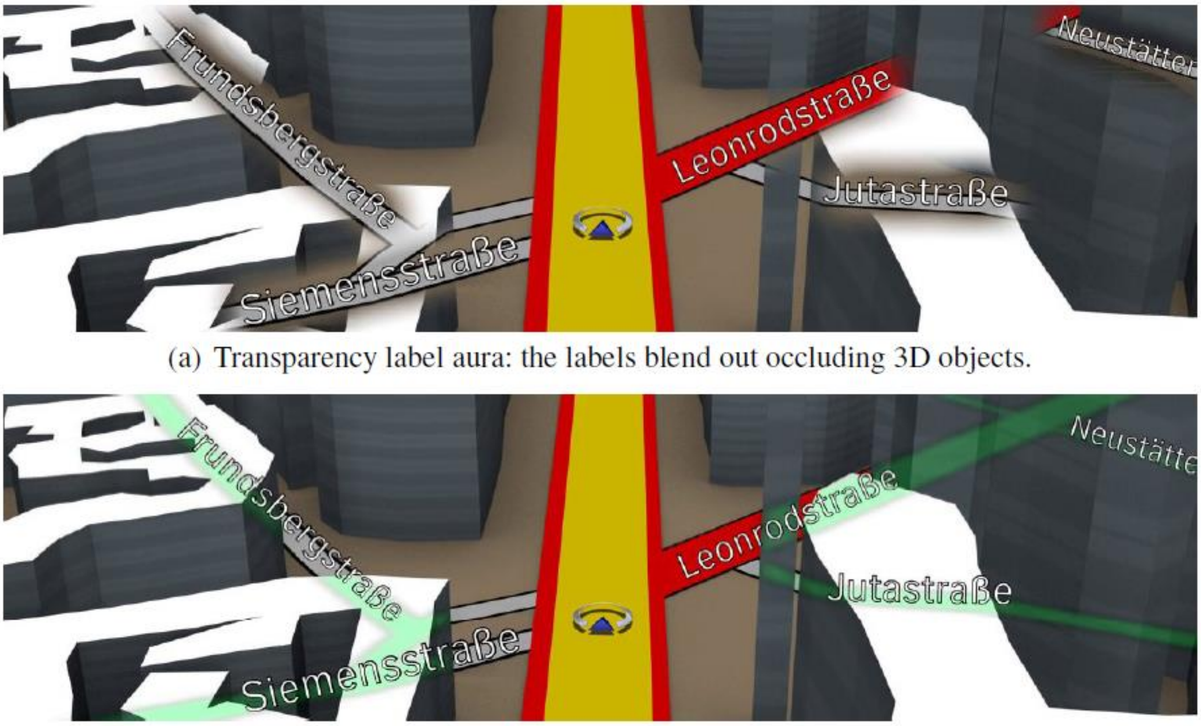


Figure 22. Visibility model in 3D space (source Fogliaroni and Clementini 2014)

Correspondingly, metadata and data cataloguing also need to be refined in the context of 3D model (Zamyadi et al. 2014). 3D annotation, as previous noted as of main importance for cadastre users, needs to be taken in consideration in the visualization process since it is a critical issue for spatial orientation in 3D model. For example, Vaaraniemi et al. (2012) propose to enhance the visibility of annotation (labels) in 3D navigation maps and they tested various techniques with users. Figure 23 shows two examples of approaches used to preserve the visibility of textual labels. Their approach looks much appropriate for cadastre application.



(a) Transparency label aura: the labels blend out occluding 3D objects.

(b) Glowing roads: the roads shine through occluding 3D objects.

Figure 23. Example of how to enhance the visibility of annotation (source Vaaraniemi et al. 2012)

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 (see figure 24). 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.

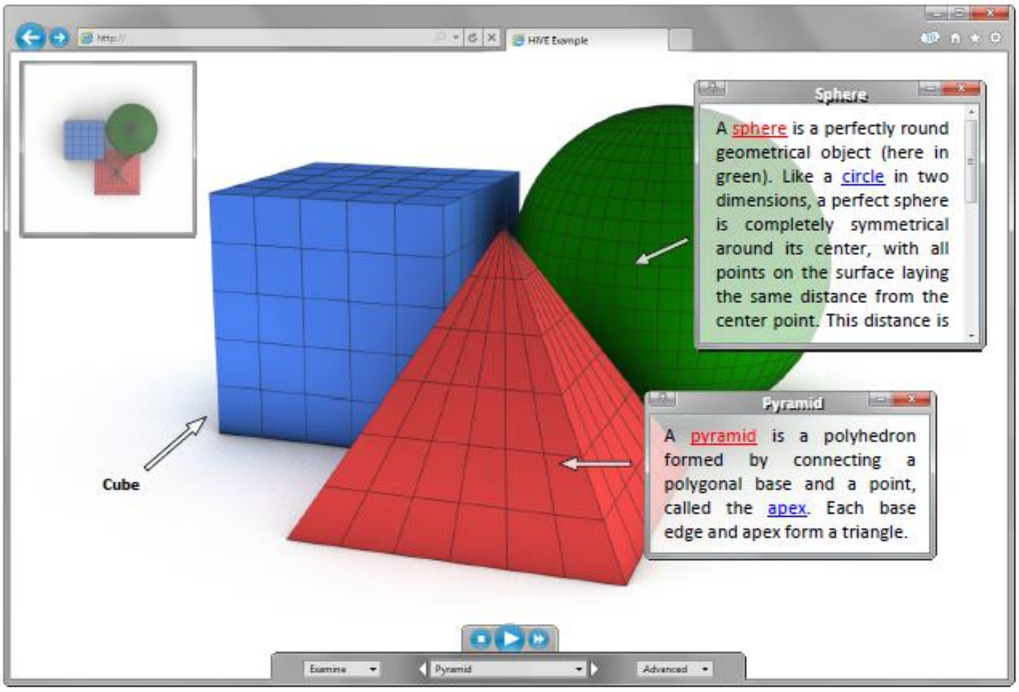


Figure 24. Illustration of the combination of hypertext and 3D graphics (source Jankowski and Decker 2012)

In addition to this, an investigation into other visual enhancement techniques in the 3D cadastral environment should be realized in order to take advantage of work done by Métral et al. (2012) and Shojaei et al. (2013) on using text for annotation, work done by Trapp et al. (2011) who added a new arrow symbol above an original symbol to attract the viewer's attention, and work done 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 3D cadastre applications, with the work on 3D plasticity by Lacoche et al. (2015). An extensive review was first published in *3D User Interfaces: Theory and Practice (*Bowman et al. 2004), and more recently in Ortega et al. (2016).

4.3 Visualization Platforms

The use of 3D environments and interaction topics mentioned in *Section 2.2* above—web-based, mobile-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, and 3D cadastral research should 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 experimenting with WebGL or OGC Portayal. An example of this can be found in Milner et al. (2014), who presented 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) presented a web-based virtual globe able to integrate and display very large semantic 3D city models, developed with Cesium JS, an open-source JavaScript library for 3D globes and maps. For cultural heritage dissemination purpose, Koeva et al. (2017) proposed a web-based portal that use spherical panoramas, videos and sounds. Ferraz and Santos (2010) combined Spatial OLAP[5] tools with virtual globes to facilitate the discovery and exploration of multidimensional data (i.e., thematic, temporal and spatial data) on 3D maps. Devaux et al. (2012) conceived a web framework, named iTowns[6], to visualize 3D geospatial data, Lidar data and street view images. iTowns is based on WebGL and offers also tools for 3D precise measurements.

Augmented Reality

Rooted in the concepts of spatially enable and smart city (Coleman et al. 2016), augmented reality (AR) is certainly one promising field to explore for cadastre application (Hugues et al. 2011). Figure 25 illustrates a number of possible applications of AR devices to land management purposes. Exploiting AR also results in new challenges to be considered (van Krevelen and Poelman (2010). For example, Duinat and Daniel (2013) and Schall et al. (2013) explored the applicability of AR devices for interactive visualization of underground infrastructure. Pierdicca et al. (2016) tested AR devices in the context of natural resource maintenance while Lee et al. (2012) used it for city visualization. Figure 26 shows the example of AR system applied to the 4D visualization of data uncertainties (olde Scholtenhuis et al. 2017). In this last example, the level of uncertainties, categorised into three classes (standard, estimated, surveyed location), is used to generate variable cylinder shapes. Integrating the visualization of uncertainties information also looks appealing in the context of cadastre application.

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[5] OnLine Analytical Processing.
[6] http://www.itowns-project.org/

Check apartment subdivision

Source Dyer 2015

Confirm easement location

Source
http://geospatial.blogs.com/geospatial/augmented-reality/

Locate underground networks

Source Rajabifard 2015 and Grant 2012

Inform about occupancy

Source
https://petitinvention.wordpress.com/2009/09/04/red-dot-design-concept-award-2009/

Figure 25. Examples of possible application of augmented reality devices to land management purposes

Figure 26 Augmented reality and fuzzy concepts to enable the 3D-representation and visualization of uncertainties for underground utility data (olde Scholtenhuis et al. 2017)

Immersive Virtual Environments

Geovisualization laboratories are emerging and they give access to a variety of tools and instruments dedicated to interactive viewing of geospatial data. Some interactive, physical and virtual environment (VE) could be useful in the context of 3D cadastre learning. Some research have emerged in the past ten years: displaying 3D virtual environments on walls (CAVE2) and interacting by using the CAVE2 wand controller, the prototype CAVE Sphere device or tablet devices (Febretti et al. 2013), exploiting BIM data in virtual reality environment for construction and architecture in the Callisto-SARI project (Genty 2015), interacting with the Google Earth virtual globe by using the Microsoft Kinect (Boulos et al. 2011), enhancing interactive learnings with students about flood risks by using a 3D CAVE (Philips et al. 2015). Figure 27 presents the example of Casala Centre (Netwell/CASALA, Dundalk Institute of Technology[7]) to demonstrate the 3D CAVE. It shows a virtual apartment in a complete immersive environment modeled from data collected by 3000 sensors positioned in the real apartment (in using 3D glasses, people can freely interact with the 3D model). There is also a

[7] https://www.dkit.ie/research/research-centres-groups/ict-health-ageing/netwellcasala

dearth of research regarding stereoscopic and immersive virtual reality for visualizing 3D parcels (Buchroithner and Knust 2013).

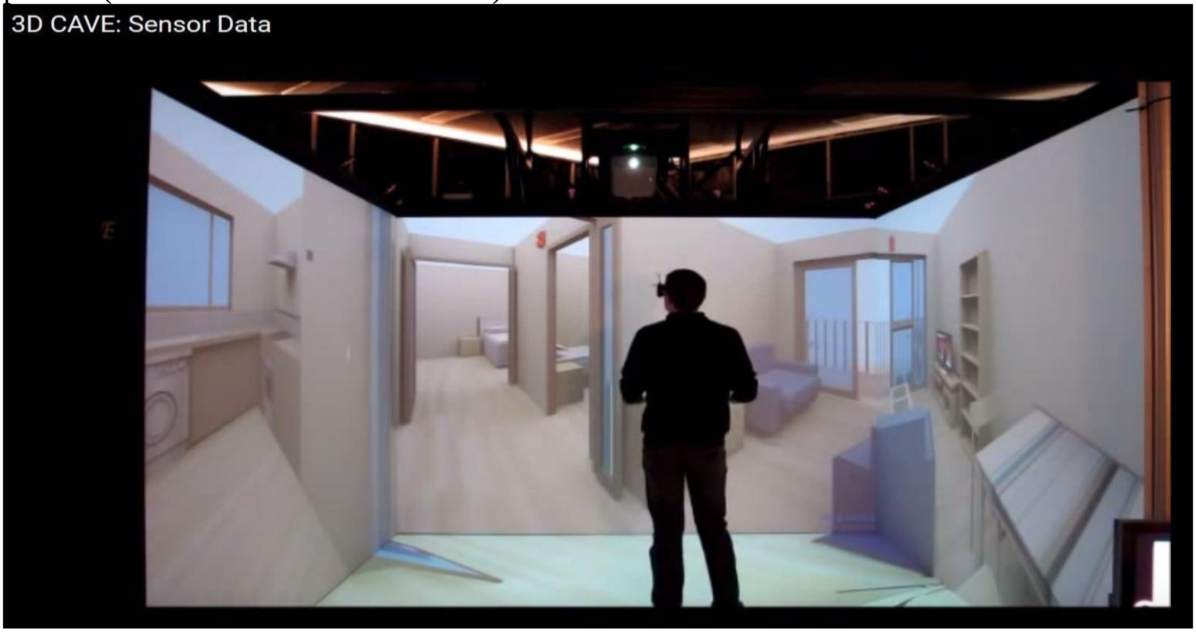

Figure 27. Example of 3D Cave for an apartment (source www.casala.ie)

Other immersive and interactive works concern holographic technologies including Zebra Imaging[8], Musion (http://musion.com), Leia 3D[9] and Holusion[10]. 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[11] (see figure 28). 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. It could accelerate the decision making process in focusing on the message rather the medium.

[8] www.zebraimaging.com
[9] www.leia3d.com
[10] http://holusion.com/fr
[11] www.nextbigfuture.com/2011/03/darpa-has-3d-holographic-display.html

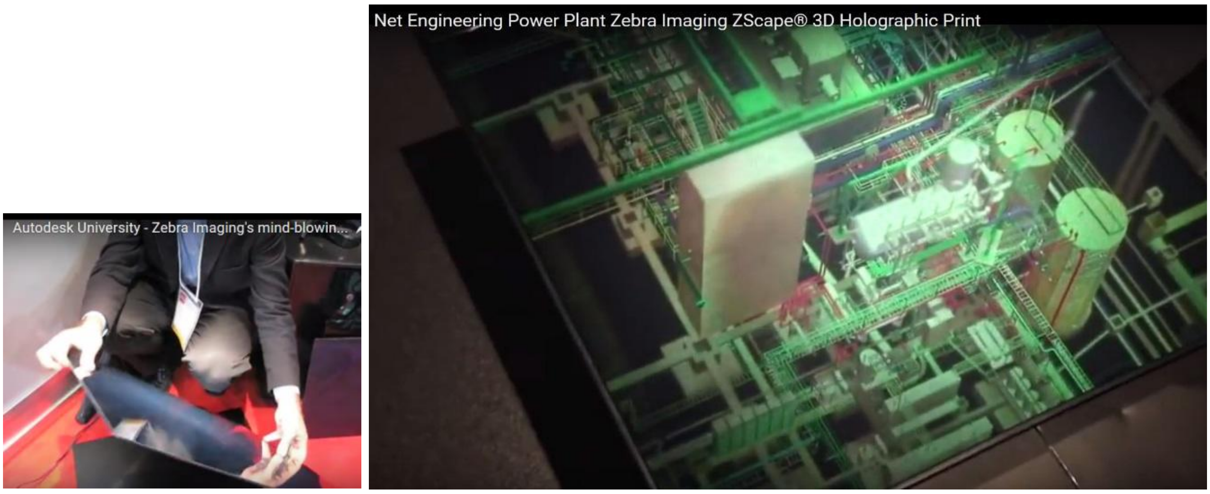

Figure 28 ZScape 3D holographic viewing (source www.zebraimaging.com**)**

3D Gaming

Users of 3D cadastre systems are for the most of them beginner with 3D environment. For this reason research carried out in 3D Gaming may also be beneficial since it may provide additional learning from both technical and user points of view. In particular the concept of Serious Games appears relevant here – defined as which encourage active and critical learning through a game environment, where users enjoy pursuing challenging tasks, and where competition may also be involved (Kosmadoudi et al. 2013). 3D examples include games used to teach users how to use complex CAD systems, how to navigate a fork-lift truck, and research into collaborative engineering design. Minecraft offers to user a new opportunity to build a virtual environment to help students to reproduce and understand some phenomena (Formosa 2014; Short 2012). In the same way, simulated LEGO blocks (as cube forms) could be assembled to build virtual scene from the real world. Yuan and Schneider (2010) built an indoor scene with LEGO cubes in a context of 3D route planning.

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), 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 smartphone) and head-mounted displays – such as the Oculus Rift or Microsoft Hololens. For instance, SketchUp now offers a viewer for Microsoft Hololens that enables mixed-reality visualization as part of collaboration scenarios ("what if" design scenarios).

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 'expanded' approach—where the user is offered a grid of possible targets once the ray has been cast—is more efficient (Teather and Stuerzlinger 2013).

Jankowski and Decker (2012) presented a comparison of two modes of interacting with 3D data on the web. 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 viewpoints; 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.

Interactive lens for visualization is a novel tool allowing to view other visual data through a spherical surface above a basic visualization like a map (Tominski et al. 2014). This interactive tool could be useful in a context of 3D cadastre in order to interact with 3D objects for viewing various representations and more details of these same objects. Magic lenses based on additional physical supports like a paper with a tabletop (Spindler and Dashselt 2009) or with tangibles devices in virtual 3D environment (Brown and Hua 2006) already exists.

4.4 Beyond 3D Visualization

The vast majority of the papers discussed visualization from the point of view of "geo"visualization (geometric representation). To conclude this review, we though interesting to open a short parenthesis on time visualization and visual analytics that may help us to enlarge the typical notion of 3D digital representation of geospatial (cadastre) data.

4.4.1 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 (Hägerstand 1970; Kwan and Lee 2004). This 3D environment is also mainly used to visualize and analyse 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).

Ringmap is another method to explore to interact with data in order to visualize time series. For example, Zhao et al. (2008) present different representations of time series in a geovisualization point of view with a specific focus on ringmaps. Wu et al. (2015) also integrate ringmaps in their analysis of Dutch temperature data. In the context of real estate transaction monitoring or tracking, such representation would be helpful to discover spatio-temporal patterns. For interactions, temporal navigation methods by direct manipulation are designed for 2D and 3D environments (Kondo and Collins 2014; Wolter et al. 2009).

4.4.2 Integrating Visual Analytics and Big Data

Visual analytics offer techniques and tools that synthesize information and derive insight from massive and dynamic data by providing interactive visual interfaces (Keim et al. 2008). It proposes a combination of graphs, dashboards, statistical views, etc. For instance, managing and thus visualize a huge volume of data has recently emerged the research field or "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, Lv et al. (2015) also present a new 3D globe, named WebVRGIS, able to display multiple types of big data from Shenzhen city. Preliminary researches are also started by Drossis et al. (2016) about the visualization of big data in an ambient intelligent environment. All these researches on big data give us an opportunity to explore 3D cadastre from another point of view.
As part of big data and visual analytics, GeoBI (Geospatial Business Intelligence) systems offer motivating opportunities to take into account 3D cadastre model and data. In fact, GeoBI is "an intelligent coupling of GIS tools with Business Intelligence (BI) technologies to suitably exploit, analyse and visualize geo-spatial part of business data (e.g. borders, places, addresses, GPS coordinates, routes, etc.)" (Diallo et al. 2015). Spatial OLAP tools provide GeoBI client interfaces (Rivest et al. 2005). With such clients, combination of Spatial OLAP tools with virtual globes have already be made in order to facilitate the discovery and exploration of multidimensional data (i.e. thematic, temporal and spatial data) on 3D maps (Di Martino et al. 2009; Ferraz and Santos 2010).

5- DISCUSSION AND CONCLUSION

This paper provides a synthesis of current research and development activities in the context of 3D cadastral visualization. It shows that the topics vary from the identification and characterization of cadastral data, to symbolization and realization of visualization. In each case while 3D cadastral visualization can benefit from the work carried out in related fields – gaming, human computer interaction, augmented or virtual reality and so forth – it is important to realise that unlike other domains the data to be visualized in 3D 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. Additionally, we need to recognize that, while closely aligned, cadastral systems are distinct from engineering or urban data – in particular due to the legal aspects, and the challenges of visualizing information that does not have a 1:1 correspondence with physical features and thus could not be visually controlled in the real world (cadastre boundaries are what we called *bona fide boundaries*). This adds an additional level of research to ensure that any solutions are fit for purpose, and highlights the need for interdisciplinary collaboration with those having cadastral expertise and experts from other domains. 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. Challenges to be addressed include the following:

5.1 Understanding User Needs and Functional Requirements

This is perhaps the most fundamental of all the challenges to be addressed, as it is only through this process, and via close collaboration with users, will it be possible to migrate from a 2D to a 3D visualization. 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. Importantly, users do not only include notaries, land lawyers or land surveyors – in fact, the participation of a wider spectrum of cadastral users—e.g. urban planners or the general public—is necessary.

Functional requirements are one aspect of user needs to explore – i.e. what do users expect from the 3D visualization software in terms of performing visualization tasks (cross sections, viewpoints, visualising hidden objects, navigating in a 3D world, providing details about RRR) but also the identification of spatial relationships between features (spatial relationship of touch, cross, overlap). A key difference from other domains is 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. 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.

These requirements are central to allowing users to accomplish their daily tasks. However, integrated 3D visualization tools embedding these are currently missing, with some functionality (e.g. cross sections) being present in CAD/BIM and other elements (e.g. spatial relationships) in GIS. More specifically, to date, much of the 3D cadastral visualization approaches have focussed on ownership boundaries rather than the challenging visualization of right restrictions. While some tools offer editing capabilities (CAD/BIM and GIS tools such as ArcScene), some are restricted to viewing data. As the latter approach reduces the complexity of the software, both approaches may be relevant to different user groups. It remains to be seen whether we will be able to adapt existing tools to user needs or whether there is a role for a custom-built 3D cadastral toolkit.

5.2 Usability of Tools and Training

Moving from a 2D workflow to a 3D workflow involves a major cognitive leap and a steep learning curve, and users have to learn how to manipulate a 3D model, how to interact with the 3D model and also develop an understanding of the new semiotic approaches required for 3D. There is thus a major role to be played through both usability and semiotic research in this domain.

Building on the functionality highlighted above, linking the visualization system with a legal document such as a deed or title, which is well known to cadastre experts, would 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 in 3D systems

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.
As researchers, it is also important to consider alternative approaches - in particular, given the extensive training and cognitive load required to move into 3D, a key question still needs to be highlighted regarding whether a 3D visualization systems is required to implement 3D cadastre (full or hybrid). Is it possible to work with 3D cadastre without having recourse to a 3D digital visualization system (Pouliot et al. 2011; Stoter 2004). This is particularly important to recall since 2D maps and vertical profiles are in many cases adequate to represent the geographic phenomena and support decision-making associated with land and property, and additionally professionals working in this area are accustomed to working with these 2D maps and profiles.

5.3 Organisational, Legal and Ethical Issues

Being involved in committees to adapt laws and regulations is probably a must. We, as specialists in spatial data processing and visualization, should be part of this step, placing the visualization in the context of land information system and requirement at the centre of discussions on the future of the profession and providing insight into legal options regarding registration, modelling and visualization using 3D approaches. As part of this, 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 City Model" or "3D Map of a Road" is something tangible that is easily understood.
Ethical issues are particularly important, and are especially relevant in the context of property information – both from the standpoint of the information held as well as from the importance of understanding how users perceive and understand 3D visualizations. Promoting quality assessment, improving confidence in the 3D product and making limitations known are part of an overall ethical approach to 3D visualization. We need to understand how to do this while at the same time not over-complicating the visual interface and software system. Additionally, metadata analysis, and quality assessment for 3D cadastral visualization is an area where no research has yet been conducted.

5.4 Conclusion

As can be seen from this paper, the third dimension in cadastre may be perceived as an opportunity to enlarge the role of cadastre data and to involve new users or develop new markets. A number of positive steps have been made in this direction - in particular with regard to software to visualize such data - but much remains to be done. To conclude, we ask ourselves whether 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 by addressing the challenges listed above. 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.

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