

Visualization/dissemination of 3D Cadastre

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SUMMARY

More and more countries in the world are developing 3D Cadastre. To make cadastral information available to the potential users, both cadastral sector professionals and normal citizens, the Web can be used as dissemination platform. However, visualization of 3D cadastral information is still a challenge.

Some of the main issues are: occlusion, distortion, unbounded volumes, perception of position, size and shape of an object. For orientation purposes, it is important to include reference objects to help us understand the location of the parcels in the real world. Although, the resulting higher number of objects makes the clear visualization even more challenging.

We therefore first investigate the requirements to obtain a proper, clear and not misleading visualisation of 3D cadastral parcels through a geo-web viewer. We explore how to handle the above-mentioned issues such as occlusion, distortion and ambiguous perception (in terms of position, size and shape) of objects while interacting with 3D cadastre. Also, techniques for combining the visualization of legal boundaries (cadastral parcels) and real-world objects (topography) are analysed.

The overall technical architecture of a system for the dissemination 3D Cadastral parcels is presented, starting with the storage of the data at the backend server (DBMS and webserver) and the possible encodings for data transfer (such as XML, JSON, glTF) to the client. WebGL based solutions at client side are preferred as these do not require the download of a plugin in the web browser, while still offering many well performing visualization and interaction options.

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1. MOTIVATION

In recent years, many countries have or are considering to extend their cadastral registration systems into the third dimension. The reason of this choice is given by three main factors: the increase in private property values, the higher density and raising complexity of buildings over the last 50 years (i.e. buildings above roads/railways, buildings leaning on top of each other, etc.) and the growing 3D approach in other fields which made 3D cadastre technologically feasible (van Oosterom & Stoter, 3D Cadastre in an International Context - Legal, organizational and technological aspects , 2006).

The aim of cadastre is to make information available to everyone, thus sharing and visualising it on the web would help to fulfil this purpose. An interactive 3D visualization system representing the third geometric dimension in a flexible way would give the user the possibility to explore the complexity of the 3D world and overcome most of the issues of 2D techniques (Pouliot, et al., 2017).

The advantages of a 3D representation of cadastral data over a 2D representation are summarized in Figure 1. The left image shows the difficulty to associate different owners to a unique 2D parcel, while the problem can be easily solved with a 3D representation. The central image presents a complex situation in which a road passes under a building and therefore there is an interference in the land rights that can be solved with a 3D representation showing the situation in more detail. Finally, the right image represents a building and an underground infrastructure, in 2D the underground objects would be hidden by the earth surface, while in 3D they can be easily visualised.

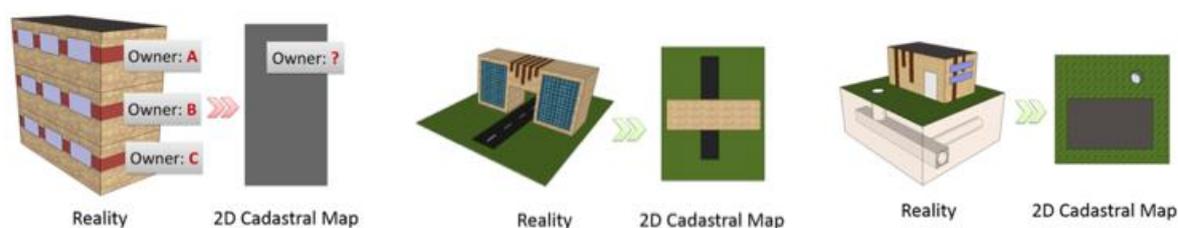


Figure 1 - Limitations of 2D cadastre (Zare Zardiny & Hakimpour, 2015)

Nevertheless, the creation of a proper 3D visualisation of cadastral data presents several challenges. The typical issues of 3D visualization such as occlusion, distortion and difficulties in the perception of position, size and shape of objects are combined with the issues related to 3D cadastre like unbounded volumes representing certain parcels (i.e. no upper height level

defined). In addition, combining topography (i.e. earth surface and reference objects) and legal boundaries (i.e. cadastral parcels) contributes to create a more familiar view of the world. Although, this makes the visualization more challenging due to the growing number of objects in the viewer.

The scope of this research is to implement a prototype for the visualization and dissemination of 3D cadastre through a web-based viewer. The focus will be mainly on visualization, in particular, on how to solve the visualization issues of 3D parcels.

The research will be carried out as follows. First the requirements for 3D web visualization will be analysed (Section 2). Next we explore the possible web-based platforms supporting 3D visualization as basis to develop the 3D Cadastre viewer (Section 3). In Section 4 our first results are presented. Finally, conclusion and future work are described in Section 5.

2. REQUIREMENTS

In this section we discuss the requirements for visualization and dissemination of 3D cadastral data. We identified two main types of requirements: 1. Directly related to 3D visualization challenges, 2. Related to the web-based viewer as visualization platform. The requirements are obtained from the history of 3D Cadastral R&D, as described in the forthcoming FIG publication ‘3D Cadastres Best Practices’.

2.1 Requirements related to 3D visualization challenges

In order to define what is the best way to visualize 3D cadastral data it is important to analyse the existing literature and define a list of requirements. Both the issues related to 3D visualization and 3D cadastre will be taken into account. In this section, the requirements regarding 3D visualization of cadastre will be listed and described with examples taken from existing prototypes and related work in the field.

2.1.1 Navigation tools and view controls

One of the main requirements for a proper 3D visualization of cadastral data is interaction by means of navigation tools and view controls. Among them we can list traditional functionalities of 3D viewers: zoom in and out, pan, rotate, tilt and tooltip. These features help the user to better understand the 3D environment by interacting with it. Specifically, the tooltip functionality, which shows the attribute data attached to an object, could be useful in cadastral applications. Administrative information about legal objects is usually in the form of text, so it can be efficiently shown using a tooltip (Shojaei, Kalantari, Bishop, Rajabifard, & Aien, 2013). The figure below presents an example of tooltip to display attribute data (**Error! Reference source not found.**).

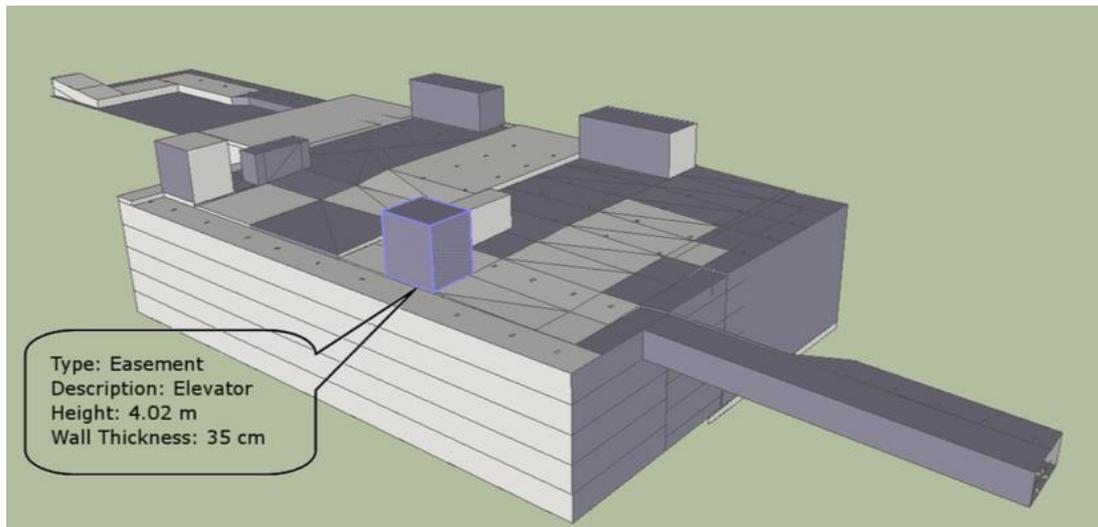


Figure 2 - Example of tooltip functionality (Shojaei, Kalantari, Bishop, Rajabifard, & Aien, 2013)

2.1.2 Integrating topography and reference objects

Visualizing legal boundaries without reference objects, buildings and ground surface would result in an abstract representation; this could lead to misunderstandings in the perception of the actual boundaries. Physical objects give reference to interpret legal objects in terms of location and size (Kalogianni, 2016), therefore it is good practice to combine them together in cadastral representations. Nevertheless, there is the danger that the visualization will result further complicated (Pouliot, et al., 2017). Among these reference objects or surfaces we can list digital terrain models (DTMs), 3D building models, urban utility networks, road networks, railways and rivers.

DTMs represent the different elevations of the earth surface (i.e. topography). In 3D cadastre, parcels can be placed above, below or on the ground surface, therefore the presence of a DTM helps defining a reference for the correct visualization of parcels. It is very common to combine a DTM with satellite and aerial images to have a more detailed view. The accuracy of the DTM and of the parcel vertices must be checked to make sure that parcels are not flying above the ground (when they should not) or intersecting it.

A 3D building model is a representation of the structure of a building, together with associated components. For 3D cadastral purposes, both the external and internal geometry are required to represent the ownership of parcels. Urban utility networks include pipelines, cables, sewage systems, storm-water drainage and so on. They are important from a legal point of view to facilitate the understanding of ownership boundaries and from a physical point of view for the maintenance of infrastructures (Shojaei, 2014).

Vandysheva et al. (2012) described the 3D cadastre prototype for the Russian Federation as a combination of 3D cadastral parcels, a DTM, 2D parcels, 2D and 3D reference objects (topographic data) and digital images (Vandysheva, et al., 2012).

2.1.3 Transparency

Another requirement is transparency, which can be interpreted as opacity/transparency at different levels. Transparency can be applied in order to show the interior of a 3D model. This feature is convenient to visualise and distinguish physical and legal objects (Vandysheva, et al., 2012), for example, in Figure 3 two levels of transparency have been used to enhance the difference between legal boundaries and buildings.

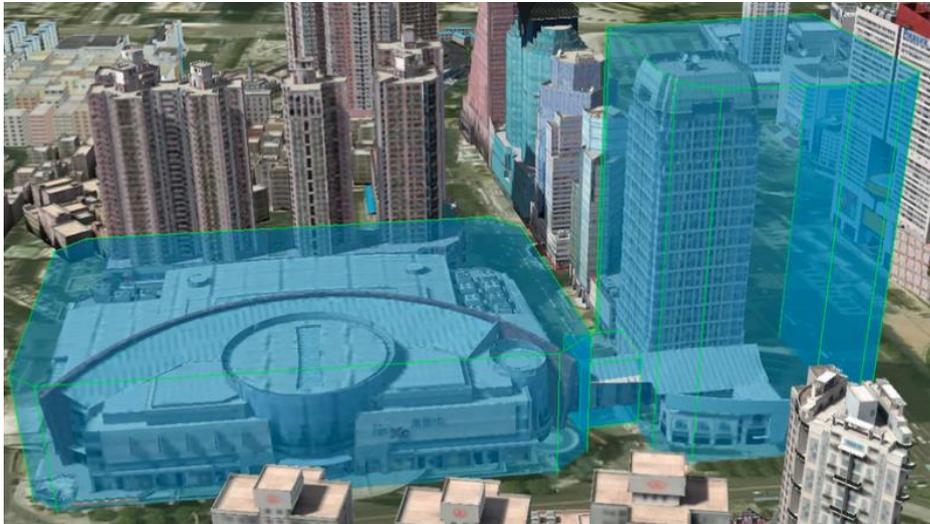


Figure 3 – Use of transparency to enhance the difference between physical and legal objects (Pouliot, et al., 2017)

Similar techniques have also been explored, for instance ‘dynamic’ transparency is able to improve object discovery behind opaque surfaces (Figure 4).

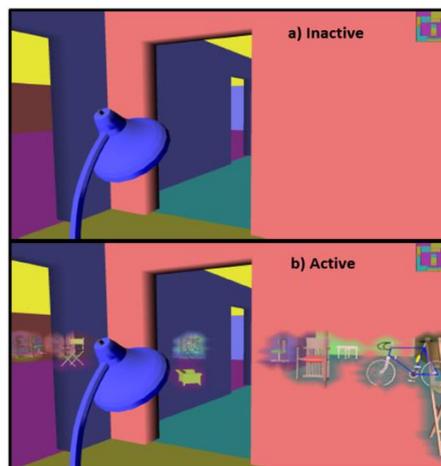


Figure 4 - Example of dynamic transparency feature (Pouliot, et al., 2017)

Additionally, Wang and others (2016) made a research project to assess the usability of transparency in 3D cadastre visualization. They used three different degrees of transparency to

represent three types of boundaries: physical, administrative and linked boundary (both physical and administrative). The result of the research showed that three levels of transparency were enough to demarcate legal parcels and their physical counterparts (Wang, Pouliot, & Hubert, 2016).

2.1.4 Object selection

The selection of objects is a very important interaction technique for the success of any 3D visualization tool (Pouliot, Hubert, Wang, Ellul, & Rajabifard, 2016). Clicking on an object with the mouse or touching the object (if we are using a touch device), is referred to as object selection. Selection can also be performed on administrative data, for example, it is possible to show or select all the parcels owned by the same person. A direct consequence of the selection is the highlighting of the feature, usually by changing its colour to make it better visible (Shojaei, 2014).

An example of selection can be found in the 3D cadastre prototype for the Russian Federation described by Vandysheva et al. (2012). The object selection was used to show the available 3D objects starting from a 2D representation. Therefore, the user must click on the 2D objects marked as having 3D information available in order to visualize them in three dimensions (Vandysheva, et al., 2012).

2.1.5 Object search

A step beyond 'object selection' there is a more advanced functionality, the object search. This search allows the user to find required information in a quick and easy way. It can be carried out both on spatial and non-spatial data, and it can be based on address, name, geocode, coordinates, etc. The user only needs to type the input and the system will zoom to the desired object or location (Shojaei, 2014). A variant of 'object search' is the 'active set search'. The concept of active set refers to a group of objects which has been selected and saved for further processing (van Oosterom, Maessen, & Quak, Spatial, Thematic and Temporal Views, 2000). Thanks to this functionality, a group of parcels with the same characteristics can also be found easily.

2.1.6 Wireframe display

A wireframe view is a representation of a 3D object exclusively by means of its edges. It can be used to enhance the rendering speed when a large amount of data is loaded. In cadastral applications, the wireframe view can also help the user to see through objects and overcome occlusion issues that can obstacle the correct perception of the parcels. Figure 5 below shows an example of wireframe display. In addition, wireframe display can be applied to unselected parcels to provide context and distinguish them from the highlighted ones (Shojaei, 2014).

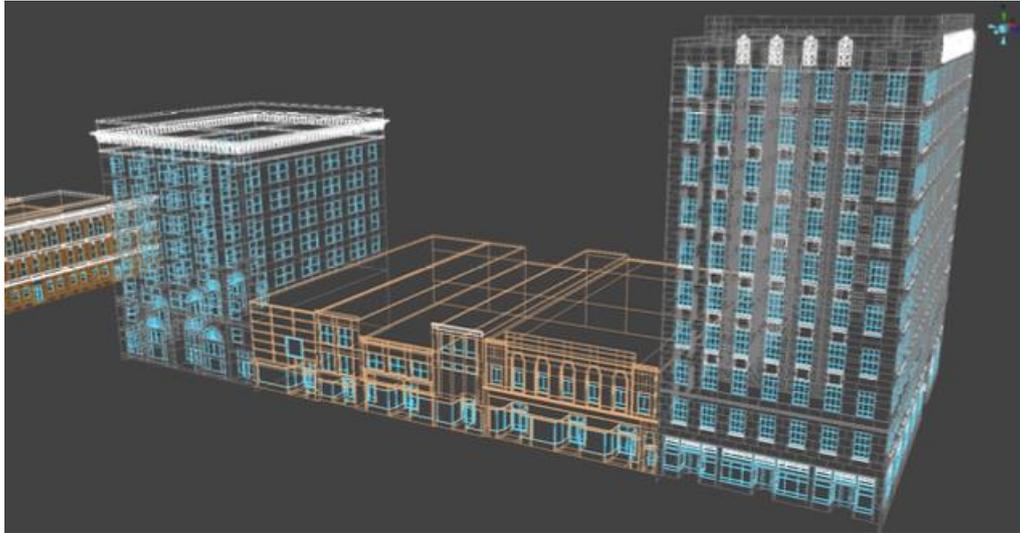


Figure 5 - Example of wireframe display (Shojaei, 2014)

2.1.7 Explode view

Explode view is used in 3D cadastre applications to show the internal components of complex units (for example, apartment buildings). This functionality displaces the components in space separated by a given distance, therefore all the components of an entity are slightly shifted from their original location (Shojaei, 2014). Among others, Ying et al. (2016) explored the explode view functionality; they started from a connected set (left of Figure 6) and using displacement equations they created the exploded view (right of Figure 6) to have a better visualization of the inner unit (Ying, et al., 2016).

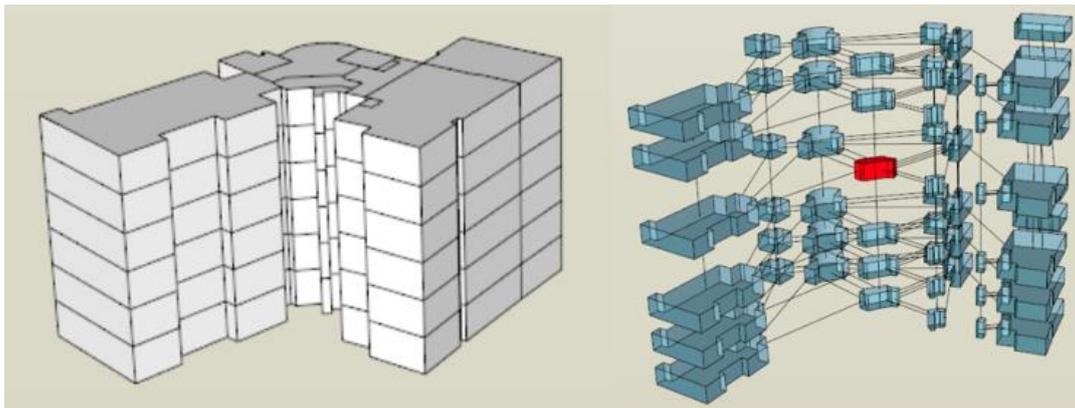


Figure 6 - Explode view example (Ying, et al., 2016)

2.1.8 Sliding

The sliding tool is similar to explode view since it also has the function to better show the internal geometry of a 3D object which is otherwise occluded by the surrounding features. Usually this tool moves an object horizontally in a specified direction, i.e. the floor of an apartment building, to reveal its internal structure. By looking at the interior geometry of the

parcels the user can better understand the subdivision of the space (Shojaei, 2014). This functionality can also be used to slide the floors of a building on top of each other to make comparisons (Figure 7).

For example, the sliding tool is one of the essential functionalities of the 3D cadastre prototype of the Russian Federation (2012). By selecting the 'move-floor-mode', floors can be dragged out of high rise buildings, revealing the parcels subdivision in each floor (Vandysheva, et al., 2012) as shown in Figure 8.

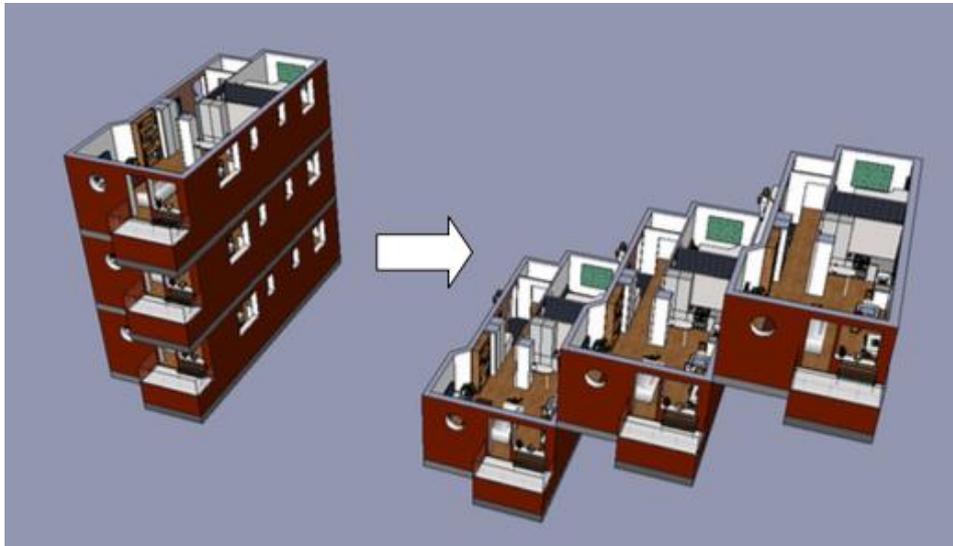


Figure 7 - Sliding tool used to compare floor plans (Shojaei, 2014)

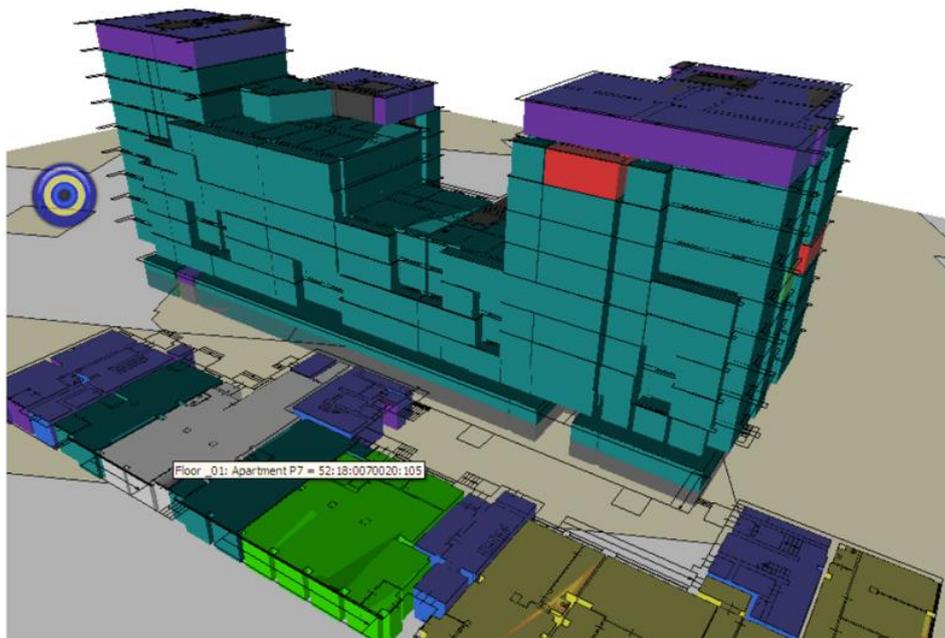


Figure 8 - Sliding tool in the 3D cadastral prototype of the Russian Federation (Vandysheva, et al., 2012)

2.1.9 Cross-section view

The slicing or cross section view is a useful functionality in 3D cadastral visualization because it allows the user to see the internal geometry of the building or parcel (Shojaei, 2014). The cross sections are views revealed by slicing an object at a plane that it is usually vertical, but can also be oriented in a different way (Shojaei, Kalantari, Bishop, Rajabifard, & Aien, 2013). The cross-section tool is currently used in Australia in building subdivision plans to represent the relative position of cadastral objects. In particular, this visualization tool is useful in complex buildings to facilitate understanding ownership information (Shojaei, Kalantari, Bishop, Rajabifard, & Aien, 2013). In Figure 9 we can see an example of a cross-section view.

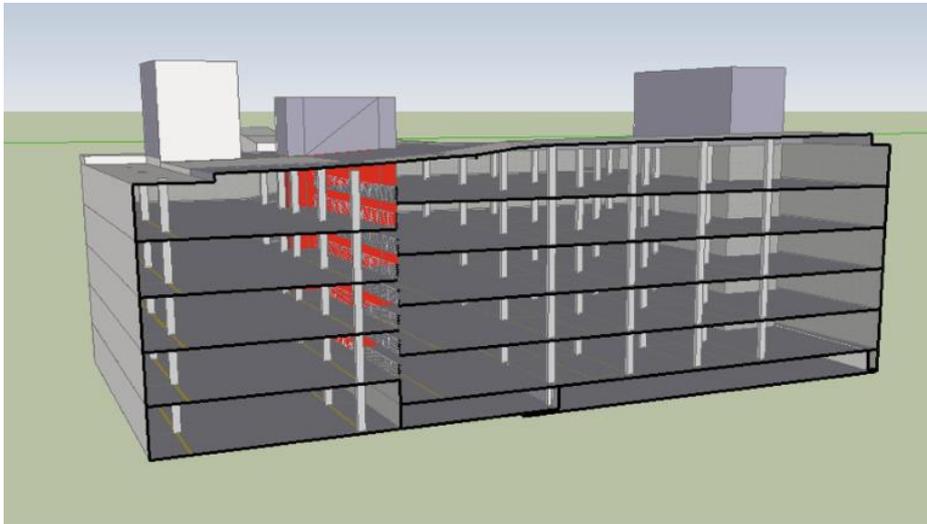


Figure 9 - Cross section view (Shojaei, Kalantari, Bishop, Rajabifard, & Aien, 2013)

Other researchers combined 3D displacement (i.e. ‘explode view’ described above) and cross-section to have an internal view of the building/parcel (Pouliot, et al., 2017) as shown in Figure 10.

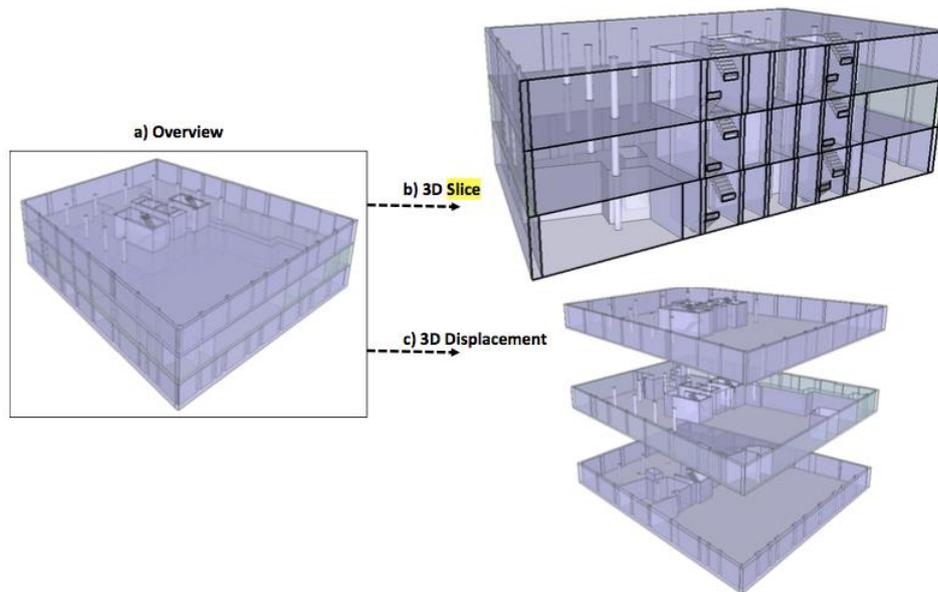


Figure 10 - Combination of 'explode view' and 'cross-section functionalities' (Pouliot, et al., 2017)

2.1.10 Visualization cues

Switching on and off visualization cues can help the user to estimate the relative position of an object. Figure 11 shows a pipeline (coloured in purple) which is partly above and partly below ground; to better represent this, vertical red 'sticks' have been added to the canvas to show the position and distance between the pipeline and the earth surface (Pouliot, et al., 2017).

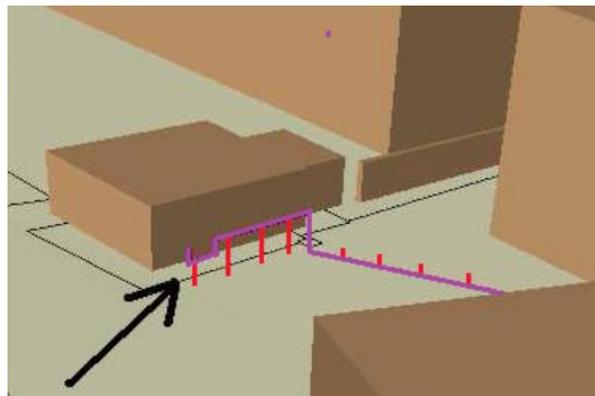


Figure 11 - Adding visualization cues to a pipeline representation can help understanding depth and height of the object with respect to the earth surface (Pouliot, et al., 2017)

2.1.11 3D measurement tools

In cadastral applications, a 3D measurement tool can calculate the area or volume of a parcel to quickly estimate its size. The user must be able to perform measurements according to his needs (Shojaei, 2014). Among the possible calculations there are: areas, volumes, distance between points, view coordinates, etc. Furthermore, to perform these operations, object

snapping should be implemented to allow the user to make accurate measurements (Shojaei, Kalantari, Bishop, Rajabifard, & Aien, 2013).

2.1.12 3D buffer

The 3D buffer functionality creates a buffer around an object. This feature can be suitable for querying and selecting neighbouring objects to a 3D object; for instance, assessment of constraints in a specific area and creation of an ‘active set’ of objects. The 3D buffer functionality must be possible both for cadastral parcels and for physical objects in order to support various analyses. The features within the buffer are then selected for further processing (Shojaei, 2014). In the figure below, a 3D buffer example of a pipeline is shown (Figure 12).

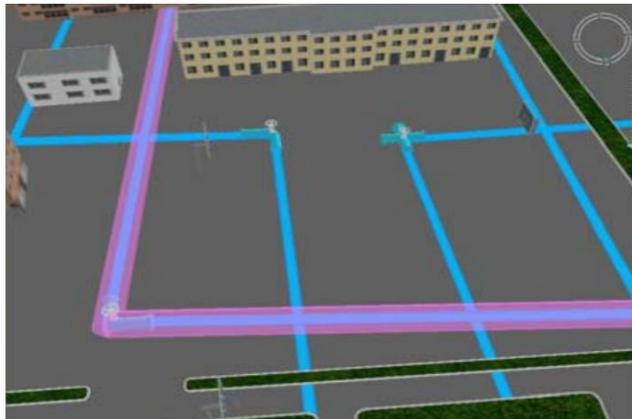


Figure 12 - Example of a 3D buffer of a pipeline (Shojaei, 2014)

2.1.13 Display partly unbounded objects and ‘complex’ geometries

Legal objects can be both bounded and unbounded. Bounded objects have a defined volume, so they are relatively easy to represent. On the other hand, unbounded objects are more challenging for 3D cadastre visualization since their volume is undefined. These unbounded objects are for example parcels that continue infinitely towards the sky or below ground level. A 3D cadastre application should be able to show them in a non-misleading way. Some researchers suggested their representation in two dimensions as the most efficient method (Shojaei, Kalantari, Bishop, Rajabifard, & Aien, 2013). Moreover, 3D bounded objects can also be rather complex to represent; examples are, non-2-manifold geometries and curved boundary surfaces. The support for these complex geometries is crucial to represent the different shapes of buildings in modern cities. Curved surfaces boundaries are difficult to represent; therefore, a solution could be the approximation of the curved surface.

2.2 Requirements related to the web-based viewer as a visualization platform

In addition to the functionalities related to 3D visualization, the web viewer requirements must be considered too. One of the main aims of cadastre is to make information available to everybody and the web is a powerful tool which can make this happen. Consequently, the choice of the most appropriate web platform is crucial. Having a good 3D visualization would be useless if the platform in which the data is visualised is not suitable for that purpose. Choosing

the proper web-based platform for the dissemination of 3D cadastre is not an easy task. Most of the following functionalities should be present.

2.2.1 Platform and browser independence

A wide variety of platforms is present nowadays, they are either based on computer workstations or on mobile/tablet devices. Among the most popular ones we can list Windows, Mac OS, Linux, Android and iOS. Some applications only work in specific operating systems, but this strongly limits their dissemination to users of a different platform (Shojaei, 2014). For example, if an application is supported only by Windows, Mac users will have difficulties in using the same application or will not be able to use it at all.

Cadastral systems serve a wide variety of users and a platform-independent 3D visualization system is a ‘must’ for achieving a high level of dissemination. In this way, the user does not have to concern about the underlying technology for using the application (Shojaei, Kalantari, Bishop, Rajabifard, & Aien, 2013).

Correspondingly, a wide variety of web browsers are available such as, Internet Explorer, Google Chrome, Mozilla Firefox, and Safari. The web viewer must also be supported by the main web browsers to ensure its dissemination over the World Wide Web. As it will be explained in detail in the next section, WebGL is a web-based solution which does not require plug-ins, it is supported by the most popular web browsers and can work in any platform thanks to the JavaScript API that interacts with the Graphics Processing Unit (GPU) (Khronos Group, 2017).

2.2.2 Handling massive data and caching/tiling between server and client

A 3D cadastral application on the web must be able to handle many users at the same time while maintaining the performance objectives. The amount of data obtained by combining physical and legal objects is huge, therefore the application performance should not be affected while dealing with big data (Shojaei, 2014). In addition, since the client cannot see all the data at the same time, an application supporting tiling and caching can provide a subset of the server data, which makes the visualization faster and smoother.

2.2.3 Layers control

As already mentioned in the previous section, an important requirement for a web-based 3D cadastral viewer is the support for 3D visualization basics. In particular, the possibility to add and remove layers (i.e. layers containing reference objects), switch on and off their visibility and modify their transparency enables the user to make a customised visualization. Moreover, adding layers to the web viewer requires the support of different data sources (Shojaei, 2014).

2.2.4 Database support

A database allows users to have all the information in a unique place and to maintain it up to date. Currently, 2D cadastral data is stored into databases, the so called Digital Cadastral Databases (DCDBs). In the same way, 3D cadastral data should also be stored in DCDBs. Hence, 3D cadastre visualization applications must support and connect to databases to retrieve data and submit to the server the changes made in the front-end (Shojaei, 2014).

2.2.5 Support different models (vector/polyhedral, raster/voxel, point clouds)

As already discussed above, the combination of physical and legal objects further complicates the visualization issues. Reference topographic objects are buildings, pipelines, roads, bridges, railways, waterways, etc. and they can be represented in different ways such as raster or voxel representations, vector or polyhedral surfaces and even smart point clouds (Pouliot, et al., 2017). Therefore, a viewer supporting a wide variety of models allows diverse datasets to coexist in the same environment.

2.2.6 Support of basic topographic visualization

A 3D web viewer should support basic 3D topographic visualization both for the content or information model, and for the encoding, which is the actual exchange format. Many data formats and specifications currently exist to store, deliver and exchange 3D data. The most popular ones are: CityGML, KML, X3D, GeoVRML, GML, DWG, 3DS, shapefile, Collada, 3D PDF, IFC and LandXML. For a more detailed explanation about the formats see Davood Shojaei PhD thesis (Shojaei, 2014).

2.2.7 Support for geo-referencing

A 3D cadastral system contains geo-data. Geo-data is information about a geographic location and it is produced in different coordinate systems. For this reason, a good 3D cadastre visualization platform should support (Stoter , Ploeger, & van Oosterom, 2012) various horizontal and vertical coordinate systems. In addition, real world coordinates (absolute coordinates with an origin on the surface of the earth) need to be translated into screen coordinates (relative coordinates with origin on the top left part of the screen) to be visualised on a computer (Pouliot, et al., 2017).

2.2.8 Ensure spatial validity (3D vector topology)

Integrating topology in 3D cadastral applications can be of great benefit for two main reasons: efficiently render 3D data and carry out various types of analyses. An application lacking topological support may have information redundancy and therefore it will require more resources to render the data. Topological structures enable spatial analyses such as, identify adjacency, intersection, connectivity, containment and disjunction between objects, which can be useful for users of 3D cadastre. Checking spatial validity makes sure that all the parcels are closed and valid both in 2D and 3D. For example, complex 3D cadastral objects, such as apartment buildings, are composed by parcels sharing many faces which should not overlap or intersect, but align with each other to ensure a valid subdivision of the space. On the other hand, in the case of unbounded volumes using vector topology can give invalid results (Shojaei, 2014).

2.2.9 Underground view

Modern cities are growing and becoming more complex, both above and below the earth surface. Many underground developments such as pipelines, shops, parking spaces, tunnels, etc. are now present in urban areas. Lacking underground visualization will lead to a non-

reality-like view of the world. The possibility of displaying the underground physical and legal objects in 3D cadastre applications is, therefore, of primary importance. In order to have an underground view, the camera should be able to move under the terrain. Although this requirement can seem quite straightforward, many 3D web viewers lack this functionality, an example is Google Earth (Shojaei, 2014). Figure 13 shows an example of underground view of a 3D model.

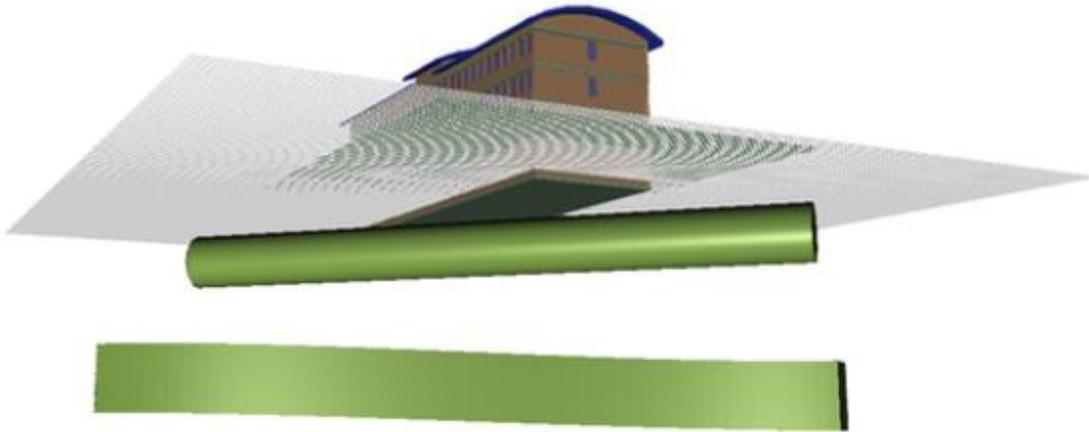


Figure 13 - Example of underground view (Shojaei, 2014)

2.2.10 Open source platform

An open source platform is a platform that provides the source code of the application to the users. The advantage of an open source solution is that the community is encouraged to participate and possibly contribute to the development of the applications (Shojaei, 2014).

2.2.11 Possibility for the platform to be extended

Since cadastre visualization has specific needs, which are rather different from the ones of traditional 3D visualization, using an extensible platform will give the possibility for the software developer to build a custom-made application that perfectly fits the purpose of 3D cadastre (Shojaei, 2014).

2.2.12 2D overview map (orientation)

Including a 2D overview map in the 3D cadastre web viewer would give a vertical view over the scene. This will help the user to understand the location of the camera with respect to the 3D world. The 2D overview map is very much used in games and it is generally a small rectangle on the corner of the canvas to provide orientation during navigation (Shojaei, 2014).

3. ANALYSIS OF WEBVIEWER OPTIONS

Choosing the appropriate visualization application for 3D cadastre is a big challenge because of the wide variety available due to the ever-growing new technologies. For this reason, a good knowledge of existing platforms and their capabilities can help building a successful cadastral

prototype (Shojaei, 2014). The web viewers analysed will be based on the cutting-edge WebGL technology, mainly because of its plug-in free interface.

3.1 What is WebGL?

As described by the Khronos Group (2017) who developed it, WebGL is a cross-platform open source web standard for a low-level 3D graphics API based on OpenGL ES (Khronos Group, 2017). The API context is obtained from the HTML5 *<canvas>* element, which means that no plugin is required in the web browser to use the application (Pereira, 2013). Since WebGL is a low-level API, drawing a simple 3D model needs a lot of work. Consequently, several open source JavaScript libraries have been developed to simplify the programming process. One of the most popular ones is *three.js* which provides higher level access to the API to make programming simpler (Shojaei, 2014).

A big advantage of WebGL is that it brings 3D into the web without the installation of plug-ins and it is implemented directly into the web browser. Most browser vendors like Apple, Google and Mozilla are members of the WebGL Working Group (Khronos Group, 2017). Hence, WebGL is supported by all major browsers and it works on many mobile platforms (Mackey, 2017). The payoff in using WebGL is that it is much faster than the 2D canvas context, so it performs rather well in case of complex visualizations. Also, it can produce a degree of realism and configurability that is hardly possible with other solutions (Danchilla, 2012).

Although WebGL represents the state-of-the-art in 3D graphics for the web, some limitations must be pointed out. First of all, visualizing massive datasets in WebGL can be an issue. Often browsers and mobile devices have a limited amount of cache memory which cannot be exceeded. Hence a smooth visualization is not always possible. Secondly, WebGL has been designed for today's graphic cards, therefore old generation computers may not support it (Shojaei, 2014).

In addition, setting up WebGL without a framework is not convenient due to the amount of work needed to build up the application from scratch. For this reason, a good option is use an existing WebGL based viewer in which many of the functionalities needed are already implemented and some others can be added (Danchilla, 2012).

3.2 iTowns

iTowns is an open source JavaScript/WebGL framework for 3D geospatial data visualization based on Three.js (iTowns , 2017). It was initially developed by the French Institut national de l'information géographique et forestière (IGN) to combine street images and terrestrial Lidar point cloud data that were acquired by the 'Stereopolis' mapping vehicle (IGN, 2015). iTowns is a powerful framework for fast and easy prototyping via a modern web interface. Recently the platform developed from version 1 to 2. The new version contains a complete package of 3D visualization tools making it a good candidate for the visualization of 3D cadastre, the only concern is about speed and user experience. The platform is primarily designed to handle various types of geo-data and to make precise 3D measurements (iTowns , 2017). In the following image, we can see an example of an application based on iTowns (14).



Figure 14 - Example of application developed with iTowns: 'WFS extruded on globe' (iTown, 2017).

3.3 Cesium JS

Cesium JS is an open-source JavaScript library which uses WebGL to create 3D geospatial applications. It is led by the Cesium Consortium and thanks to the Apache 2.0 license it is free for both commercial and non-commercial uses (Cesium JS, 2017). Cesium JS supports open formats wherever available and develops new open formats when they are not; in this way, it sets new standards for open 3D geo-spatial formats. The big advantage of Cesium JS is the existence of a big community which supports developers in their work; developers can post questions on the Cesium forum about specific problems and get answers from other members of the community. By doing so, the expertise can be easily shared (Cesium JS, 2017). Furthermore, in Cesium JS it is possible to switch among 3D globe, 2D map and 2.5D Columbus view within a single API. Time dynamic simulations are also supported, together with realistic environment features such as sunlight, atmosphere, fog, water and moon (AGI, 2017). Cesium also includes an interesting application called 'Sandcastle', which provides live coding on the web browser (Chaturvedi, 2014). Figure 15 shows a demo of Cesium JS.

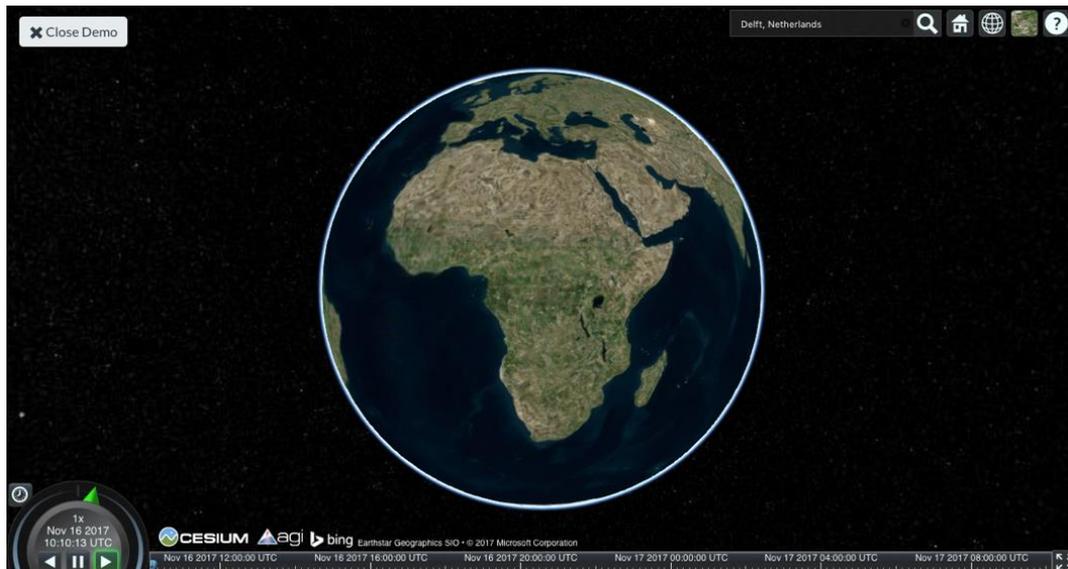


Figure 15 - Demo of Cesium JS (Cesium JS, 2017).

4.4 OSM Buildings

OSM Buildings is a JavaScript library for visualising the geometry of OpenStreetMap buildings in 2D and 3D. It is free and open source, so the source code can be downloaded and modified. Two versions are available: the classic 2.5D and the modern 3D version (OSM buildings, 2017). The classic version is great for devices compatibility, good performance on old hardware, and shadow simulation. The new version is based on WebGL and it is now available on the Github repository (Github OSM buildings, 2017). This last version is performing well on modern graphic hardware, it can handle big amounts of objects and combine different data sources. An example of OSM Buildings is shown in Figure 16.

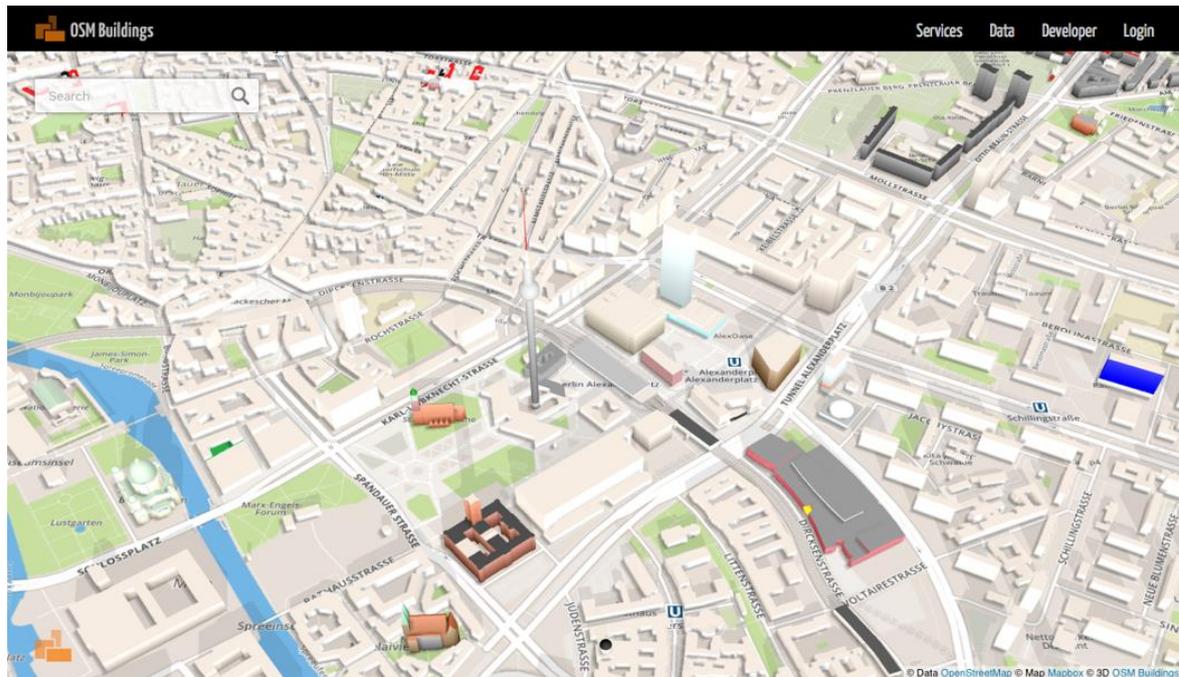


Figure 16 - Example of OSM Buildings (OSM buildings, 2017)

4.5 WebGL Earth

WebGL Earth is an open source software for the visualization of maps, satellite images and aerial photographs on top of a virtual terrain. It is built on top of WebGL and therefore allows to build applications without the need of installing a plugin in the web-browser (Chaturvedi, 2014). WebGL Earth uses ‘under the hood’ the Cesium JS project for the rendering of the data, as can be noticed from the similar interface (WebGL Earth, 2017). Figure 17 shows a WebGL Earth application.

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Figure 17 - Example of WebGL Earth application (WebGL Earth, 2017)

4.6 GeoBrowser 3D

GeoBrowser 3D is developed by GraphiTech. It is powered by WebGL graphics and offers a 3D OGC compliant solution. The application supports maps, vectors graphics surface models and three-dimensional buildings that the user can directly add into the application. It is also possible to perform precise measurements of distances and areas directly on the viewer (Geobrowser 3D, 2017). Similarly to WebGL Earth, also GeoBrowser is powered by Cesium JS. An example of the GeoBrowser 3D is shown in Figure .

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Figure 18 - Example of GeoBrower 3D (Geobrowser 3D, 2017)

4.7 ESRI CityEngine Web Viewer

CityEngine Web Viewer was released by Esri and it is based on HTML5 WebGL technology. Users can create their own 3D scenes with the software package ESRI CityEngine or the Export To 3D Web Scene geoprocessing tool (ESRI, 2017). The main difference between this web viewer and the others described above is that CityEngine is commercial and non-open-source, hence it is not possible to modify the source code. Nevertheless, it integrates a Python scripting interface which enables the user to carry out queries and other tasks (Ribeiro, Duarte de Almeida, & Ellul, 2014).

4.8 Comparison of the 3D Web viewers

Five different WebGL based viewers have been identified; mature and in early development stage, open source and commercial. Now, it is time to test and compare them against the requirements defined in the first part of the paper. The goal is to look for platforms which already have a considerable number of requirements implemented to facilitate and fasten the development of the project. If many of the functionalities are already present in an existing demo, this means that there is the concrete possibility to implement them again and find related support to do so. It follows that the extensibility of the platform is a 'must' to develop the remaining requirements.

The testing phase consists of checking the presence of the requisites in demos or prototypes built on top of that specific application. Nevertheless, some requirements are hard to check only based on evidence, in this case the related literature has also been considered. Table 1 summarizes the requirements check according to the different platforms. The green checkmark (✓) means that the requirement has been verified to exist, the orange question mark (?) means

that no evidence has been found or no one still implemented it, and the red cross mark (X) means that it is certainly not possible to implement that requirement. In addition, most of the demos have different purposes than 3D cadastre and many of the functionalities are just not needed for those use cases.

Table 1 – Requirements check in the different WebGL platforms

Requirements	Platforms					
	iTowns	Cesium JS	OSM Buildings	WebGL Earth	GeoBrowser 3D	ESRI CityEngine Web Viewer
Navigation tools and view controls	✓	✓	✓	✓	✓	✓ but not tooltips
Integrating topography and reference objects	✓	✓	✓	✓	✓	✓
Transparency	✓	✓	✓	✓	✓	✓
Object selection	?	✓	✓	✓	✓	✓
Object search	?	✓	✓	✓	✓	✓
Wireframe display	✓	✓	?	?	?	✓
Explode view	?	?	?	?	?	?
Sliding	?	?	?	?	?	?
Cross-section view	?	?	?	?	?	✓
Visualization cues	?	?	?	?	?	?
3D measurement tools	✓	✓	?	?	✓	✓ only through programming
3D buffer	?	✓	?	?	?	?
Display partly unbounded objects and 'complex' geometries	?	?	?	?	?	?
Platform and browser independence	✓	✓	✓	✓	✓	✓
Handling massive data and caching/tiling between server and client	✓	✓	✓	✓	✓	? but foresees the possibility of handling massive cadastral data
Layers control	✓	✓	✓	✓	✓	✓
Database support	?	?	?	?	?	✓
Support different models (vector/polyhedral, raster/voxel, point clouds)	✓	✓	X	X	✓	✓
Support of basic 3D topographic visualization	✓	✓	X	✓	✓	✓

Support for geo-referencing	✓	✓	✓	✓	✓	✓
Ensure spatial validity (3D vector topology)	?	?	?	?	?	?
Underground View	?	?	?	?	?	✓
Open source platform	✓	✓	✓	✓	✓	✗
Possibility for the platform to be extended	✓	✓	✓	✓	✓	✓ Python scripting interface
2D overview map (orientation)	✓	✓	?	?	?	?

The table is divided into two main sections corresponding to the two main groups of requirements described earlier in the paper. In general, all the basic functionalities for 3D visualization, such as navigation tools, transparency, topography support, and so on, are present in all web viewers. On the other hand, there is no evidence of the range of capabilities requested by 3D cadastre, like explode view and cross section view. A possible explanation could be the different purpose of the demos analyzed. Most of them are in the geospatial domain, but also meteorology, history, defense and smart cities seemed to be quite popular fields. Since none of these domains is directly related to 3D cadastre, there is no need for these applications to develop such functionalities. Nevertheless, thanks to the extensibility of the platforms, most of these requirements can probably be implemented.

Considering all the tested web viewers, along with the specified requirements, the most likely applicable and capable of supporting 3D cadastre visualization seem to be iTowns, Cesium JS and ESRI CityEngine. The first two have many of the requirements already implemented and a vast community of users, and on top of that, dedicated forums and blogs are actively helping developers to implement their applications. Moreover, Cesium JS has a detailed API documentation, code examples and tutorials to practice and get to know the library. In the same way, iTowns provides great support for users and a wide variety of examples. ESRI CityEngine is the only commercial and non-open-source solution analysed. The number of requirements met is considerably high and could be sufficient to implement some basic functionalities. In addition, the integrated Python scripting interface enables the user to carry out attribute queries, control repetitive tasks and automate specific actions. As Cesium JS and iTowns, also OSM Buildings provides a good API documentation but it owns less functionalities, therefore this candidate is less likely to be used in the actual implementation of the 3D cadastre viewer. WebGL Earth and GeoBrowser 3D are still in their early development stages, their community is relatively small and therefore they have limited support compared to more mature web viewers. As already mentioned, they are powered by Cesium JS which has a wide community of users and good support for developers. Although, compared to Cesium JS, they have implemented a smaller number of requirements.

4. INITIAL RESULTS

In this section, we will first give an overview description of the proposed Server-Client System Architecture (Subsection 4.1), which will be the basis of our 3D Cadastral prototype. Next, we introduce the various relevant data sets and our test area: Brisbane, Queensland (Subsection 4.2). The reason of this choice stems from the fact that the Queensland cadastre has the longest tradition and the biggest amount of data available so far. In subsection 4.3, we present our first Cesium based tests with several options for visualizing 3D parcels located subsurface (related to tunnel).

4.1 Server-Client System Architecture

Using a web-based solution makes a lot of sense for dissemination as web browsers offer a relatively hardware/ software independent platform, reaching many possible users without great efforts at the user side. Therefore, at the server side, a web data service (WFS) is established on top of the LADM views in the database, exposing the 2D and 3D cadastral information to the outside world. At the client side a 3D geo-information aware WebGL based solution is applied to visualize the 3D parcels (and reference objects) and interact with the information. Important is that the client uses a selection of information (that is, not all available data in a state or nationwide database) as all information in the DCBD would be far too much; only looking at the 2D parcels this is already too much (more than 2 million parcels, with many attributes). Server-client caching techniques are used to manage well the communication between server and client when panning over the area.

One of the uncertainties of this project is about the definition of the server-client interaction. Therefore, the following question need to be investigated: *What are the options to store and transfer the data? (DBMS or encodings such as XML, JSON, glTF, etc.).* For the back-end storage, the database option seems appealing for two reasons. The advantage of having the data in one place and always up to date, and the fact that the 2D parcels of the Brisbane DCDB are already stored in a DBMS. On the other hand, for the data transfer to the client the use of encodings such as XML, JSON, glTF, etc, can be convenient, since the 3D parcels encoded until now are in XML format.

4.2 Data overview for Queensland prototype

A variety of data will be used in the project:

- 2D cadastral parcels (from Queensland Cadastre)
- 3D survey plans (from Queensland Cadastre), either in 'building format' and in 'volumetric format' More precisely, the volumes will represent three main categories in the real world: buildings, tunnels and air space.
- Registration of rights, restrictions and responsibilities (if available)
- Elevation data (DTM or contour lines)
- Reference data (topographic objects in 2D or 3D - buildings, roads, etc.)

The cadastral data used for the project is taken from the Queensland Digital Cadastral Database (DCDB), a collection of all the property boundaries and related property description of land

parcels in Queensland (Australia) (QueenslandGovernment, 2018). The area of interest is situated in the centre of Brisbane, approximately in the area of the Story Bridge and the Kangaroo Point. The bounding box of the area is shown in **Error! Reference source not found.**

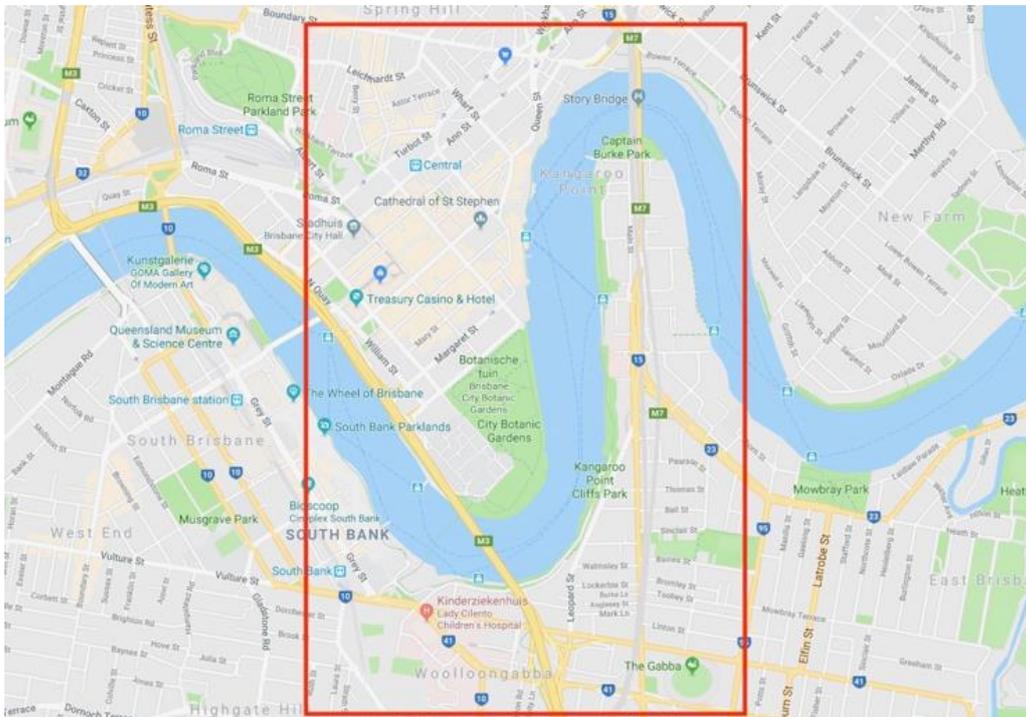


Figure 19 - Bounding box of the Brisbane area

In order to make the visualization more complete and meaningful, the plan is to add a Digital Terrain Model (DTM) containing ground data. The addition of reference objects and terrain elevation data contributes to create a reality-like environment, helping the user to recognize and reference the legal objects that would otherwise float on the canvas. At the moment of writing, the availability of the DTM is still unsure.

The existing data model of the Queensland DCDB is not described using the concepts and terminology of ISO's Land Administration Domain Model (ISO-TC211, 2012). Further, the model does not support 3D parcels and reference objects (earth surface, topographic objects). We are therefore developing an extension of the DCDB to support 3D parcels as used in the Queensland legislations, regulations and existing systems (DNRM, 2013) (DNRM, 2016) incl. the DCDB and collection of submitted survey plans. Next, for a selected study area with all relevant types of 3D Cadastral parcels occurring, both building format and volumetric format parcel (above and below the earth surface, and both covering land and water area's), we convert the information of the survey plan pdf's into 3D geometry as collections of polyhedron faces. These activities consist of a mix of manual interpretation of the survey plans and using a dedicated (Java) programme as support to generate the correct faces of the polyhedron (with

connections between neighbour faces, right orientation, etc.). Currently only planar faces are supported, but survey surfaces do occur (e.g. cylinder patches) and they need to be supported also in the near future (most likely via approximations). The polyhedron faces are then loaded in the prototype version of the extended DCDB (stored in PostgreSQL/PostGIS) and combined with other 2D and 3D spatial data. In this way, it would be possible to check if a collection of 3D parcels is not overlapping. So far, this is still the ‘internal side’ of the 3D Cadastre in Queensland. The next step will be the dissemination and visualization of the 3D parcels.

4.3 Initial results with Cesium based webviewer

Initially, the research is focussing on the capabilities of Cesium JS for the visualization and dissemination of 3D cadastre. The first aspect that has been taken into account is regarding the visualization of the 3D parcels with respect to the earth surface; namely, whether it is possible to properly visualize parcels, both above and below the ground surface.

The main issue is that the topic of ‘underground geometries’ is not included in the documentation and, therefore, not supported by Cesium JS. However, being this a very popular discussion topic, several developers found different options to overcome this problem.

The three main options are:

- The *Ground push plugin*, which allows the user to define a rectangle and push the surface of that rectangle up or down of a desired amount (Figure). The shape of the push rectangle cannot be changed or adapted to a specific parcel once initialised, which means that the rectangle should be big enough to fit also the bigger parcels. One of the issues of using this plugin is that zooming too close can make the rectangle disappear, due to the impossibility for the Cesium camera to go below the earth surface (CESIUM, 2018).

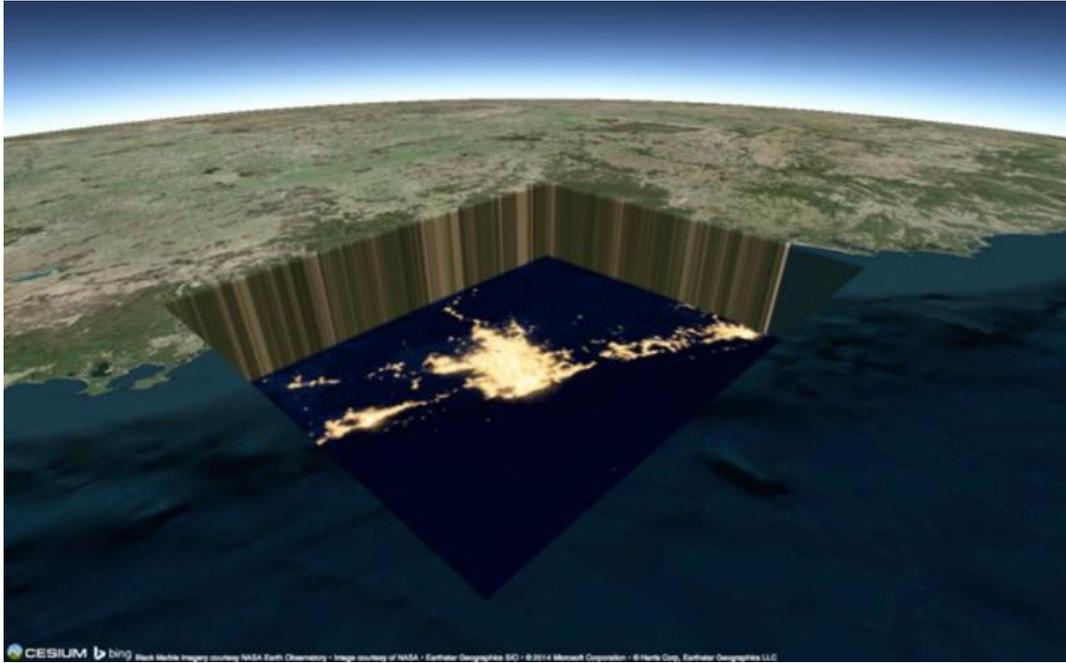


Figure 20 - Cesium JS Ground push plug-in

- *Making the terrain translucent* is another option to obtain the underground effect (Figure 214). In this case, as in the Ground push plugin, the camera does not have the freedom to move in every direction, and probably it is only possible to visualise the underground parcel ‘from above’.

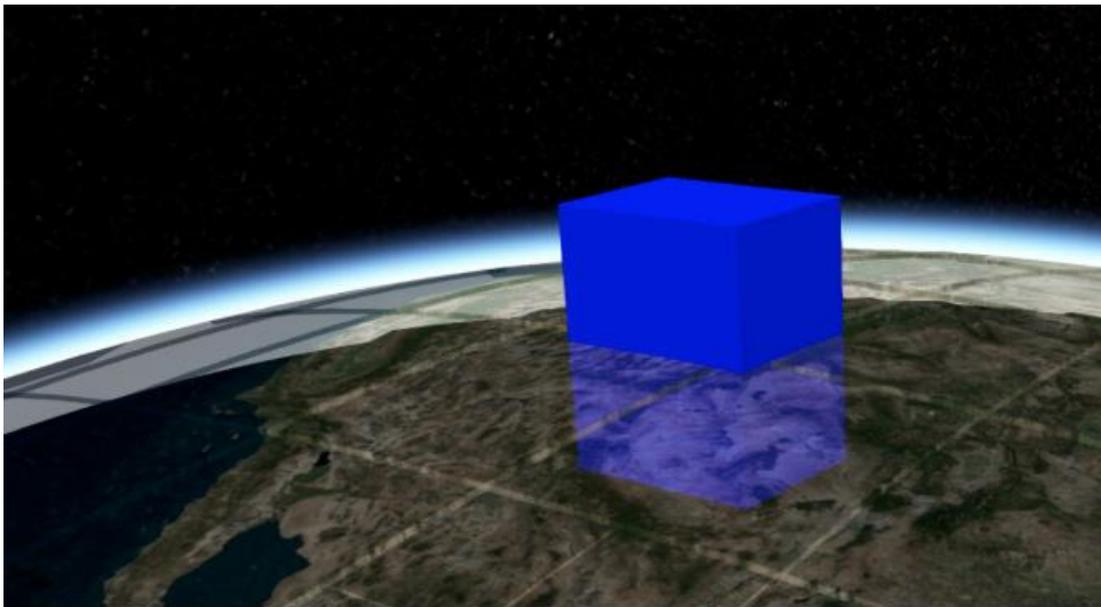


Figure 214 - Translucent terrain in Cesium JS

- Using a *fake surface* on top of the actual terrain surface. In this way, there will be actually two surfaces, and the original one will be ignored. This will allow to overcome the problem of the camera, but it will generate some issues regarding the height values which will not be reliable. As a consequence, also parcels (and reference objects) need to be shifted of a predefined amount to match the height of the face surface. This method has been widely used for the visualisation of subsurface earthquakes (Figure 15).

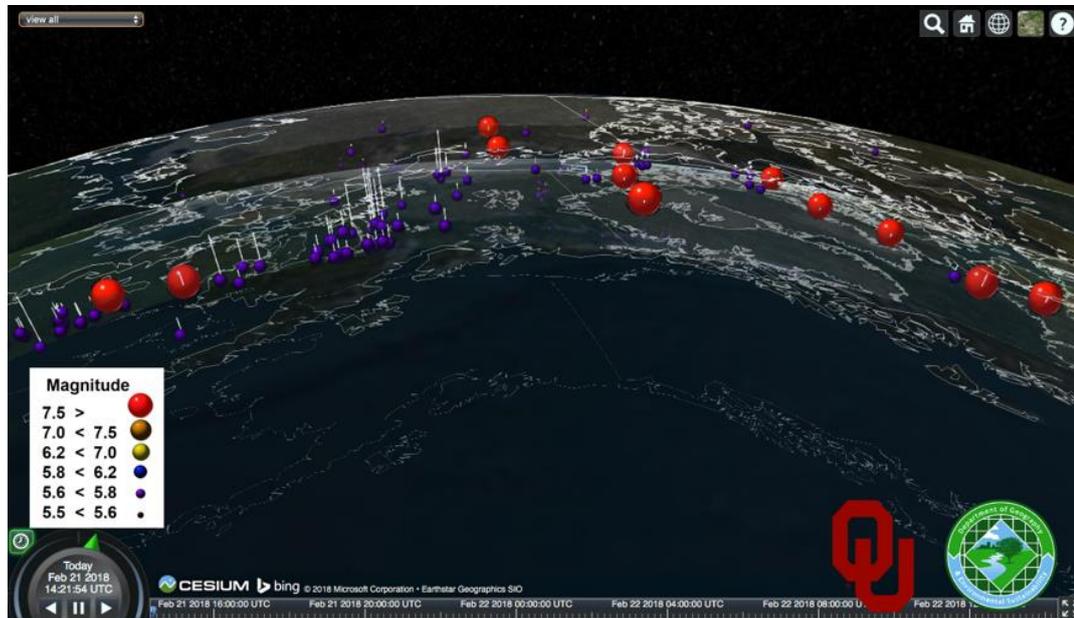


Figure 15-Using a fake surface for the visualization of subsurface earthquakes

5. CONCLUSION

The purpose of this paper is to overcome the issues of 3D cadastre visualization, such as occlusion, distortion, unbounded volumes and perception of position, size and shape of an object, through the implementation of a web-based prototype. The initial focus is on the requirements for 3D visualization and for the implementation of the prototype. After that, the choice of the WebGL based platform is crucial to continue the research. And finally, the first hand-on experimentation took place starting from the underground geometries in Cesium JS. This issue is central in cadastral applications since today's cities are expanding in all directions, and in particular under the ground surface.

In the future, the goal is to implement the highest possible number of requirements listed above in order to obtain a clear, proper and not misleading visualization of 3D cadastre. Usability tests will also be carried out among possible user groups of the prototype in order to assess its reliability and effectiveness.

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BIOGRAPHICAL NOTES

Barbara Cemellini BSc Urban Planning at Politecnico di Milano and now MSc Geomatics student at Delft University of Technology. She is currently working on her MSc thesis project on the topic of the current paper.

Rodney James Thompson has been working in the spatial information field since 1985. He designed and led the implementation of the Queensland Digital Cadastral Data Base, and is now advising on spatial database technology with an emphasis on 3D and temporal issues. He obtained a PhD at the Delft University of Technology in December 2007.

Marian de Vries holds an MSc in Economic and Social History from the Free University Amsterdam, The Netherlands (VU). She worked some years at the Free University and the University of Nijmegen, then switched to become a software developer. Since 2001 she works as researcher at the Section GIS Technology, OTB, Delft University of Technology. Focus of her research is on distributed geo-information systems. She participated in a number of projects for large data providers in the Netherlands such as Rijkswaterstaat and the Dutch Cadastre.

Peter van Oosterom obtained an MSc in Technical Computer Science in 1985 from Delft University of Technology, the Netherlands. In 1990 he received a PhD from Leiden University. From 1985 until 1995 he worked at the TNO-FEL laboratory in The Hague. From 1995 until 2000 he was senior information manager at the Dutch Cadastre, where he was involved in the renewal of the Cadastral (Geographic) database. Since 2000, he is professor at the Delft University of Technology, and head of the 'GIS Technology' Section, Department OTB, Faculty of Architecture and the Built Environment, Delft University of Technology, the Netherlands. He is the current chair of the FIG Working Group on '3D Cadastres'.

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