Visibility Analysis in a 3D Cadastre

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Key words Visibility Analysis, 3D, Value Assessment, Geometry

SUMMARY

The implementation of a 3D cadastre is work-intensive and expensive and legitimation of such expenses is necessary. A legitimate path of argumentation is that 2D systems fail to communicate complex legal situations correctly. Also, additional arguments can help to strengthen the position of 3D cadastres and provide support from other professions and social groups.

The paper is based on a newly developed model for 3D visibility. We discuss the model and how it can be used for two different application areas. The first is the assessment of property value, where the visibility or invisibility of specific objects can have a big impact. The other example is spatial planning. Spatial planning shall guarantee that cities are working economically and socially, that space is not wasted, and that the planned environment meets cognitive requirements. For example, evidences in spatial cognition show that visibility of landmarks is an important topic for tourism and navigation and should thus be addressed.

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1. INTRODUCTION

Land administration data is crucial for large parts of public administration. Cadastral maps as the geometrical part of land administration are typically the only large scale maps covering the whole country and thus these maps are used for tasks like spatial planning or property taxation. 3D cadastres as an extension of traditional cadastral systems address the problem of the vertical subdivision of rights. The development of a system like a 3D cadastre has a number of aspects that need attention: Legal issues, processes, modelling, and storage. As a result, various new possibilities emerge and need to be addressed in discussion. Some of these possibilities may not provide sufficient revenues but others may be important enough to legitimate the expenses of a 3D cadastre. In several cases, tasks supported by 3D cadastres have already been performed using a 2D cadaster, for example visibility analysis. If buildings are shown in cadastral maps, visibility between arbitrary points on the map can be analysed. However, since height may play a crucial role in the visibility analysis, the analysis is not reliable. 3D cadastres can provide better results but also need new approaches. Fogliaroni and Clementini developed an approach for visibility analysis based on projective geometry (Fogliaroni & Clementini, 2014). The model allows for determining visibility of objects, e.g., if one object is completely, partially, or not occluded from an observer object by a third object deemed an obstacle. This is computationally simple for a single viewpoint but their solution can do this also for arbitrary viewpoints in a specific volume. In the paper we discuss the chances for new applications provided by this novel approach.

Land administration shall not only provide distinct documentation of the legal situation, it is also the main tool for land tax estimation and the land market. Land tax can be either based on productivity of land or on its value (Muggenhuber et al., 2013). Determination of productivity is usually a decent approach for agricultural areas and does not require 3D. Land value, however, is heavily influenced by its potential use (Navratil et al., 2014). In addition there are other parameters. The value of the location is higher if there is a spectacular view, i.e., if important elements of the surrounding area are visible. Apartments with sea view are typically more expensive than apartments where the view is blocked by existing or planned buildings. In other situations it might be the view across a city or the visibility of an important landmark of the city like the Eiffel tower in Paris or the Westminster Bridge in London. A 3D cadastre provides all information on 3D rights and responsibilities and since these rights are the legal basis for future constructions, they describe potential future blockings. A 3D city model adds all existing buildings to the potential and can answer the question about current visibility. This is possible on a whole planned building or on the level of flats in a condominium only.

A different situation occurs, if the building authority has to decide, whether a planned building fits into the cityscape and can be approved. Visibility of the planned building may be an influential factor. The ensemble of the Vienna city centre is UNESCO World Heritage. Unrestricted creation of buildings would change the ensemble and can lead to losing the status of UNESCO World Heritage. On the other hand, a visible building can also become a landmark of a city. Both cases can be determined by visibility analysis.

The paper starts with a discussion of visibility analysis followed by a brief presentation of the method developed by Fogliaroni and Clementini. Then the available data for 3D visibility analysis is discussed followed by a discussion of two possible applications. Some remarks conclude the paper.

2. VISIBILITY ANALYSIS

Visibility analysis was mainly used in two different ways until the introduction of 3D city models in the late 1990ies: 3D game engines and visibility analysis for terrain models. These applications originally used the 2+1D approach and only later moved to real 3D models. Another peculiarity of gaming engines is that they mainly focus on determining world objects that are visible from a given viewpoint (the player standpoint in the virtual environment). In order to show the limitation of these approaches we start with a discussion of 2D approaches and later explain 3D solutions.

2.1 Visibility analysis for 2D scenes

In a 2D scene, objects are typically represented by their projection to the x/y plane. In visibility analysis variation of object shape along the z-axis is ignored. A conical object, for example, would create the same shadowing effect as a cylinder with an identical projection. Cases where an object is visible above or below a closer object are ignored. Situations where an object is visible through another object, either because the object has a hole or it is transparent, are also disregarded.

The advantage of the 2D approach is the computational and conceptual simplicity. The shadowing effect of an object is determined by the tangents to the object. Figure 1 shows the situation where the shadow is determined for a circular object with respect to a single point. The result of such an analysis is a binary decision: Points behind the object are either visible or invisible. Objects lying completely in the object shadow are invisible from the projection point. Finally, objects are partially visible if they overlap with the object shadow.

However, the situation changes if the shadowing is determined with respect to a projection area. Figure 2 shows a situation where the shadow is determined from a projection area instead of a point (compare Figure 2). The object shadow has the property as in the first case: Points in the object shadow are not visible from the projection area, or more precisely, points in the object shadow are invisible to every point in the projection area. Points in the partial shadow are visible only from some points in the projection area. That is, objects in the partial shadow may be at the same time completely visible, partially visible, or invisible, according to the points of interest in the projection area .

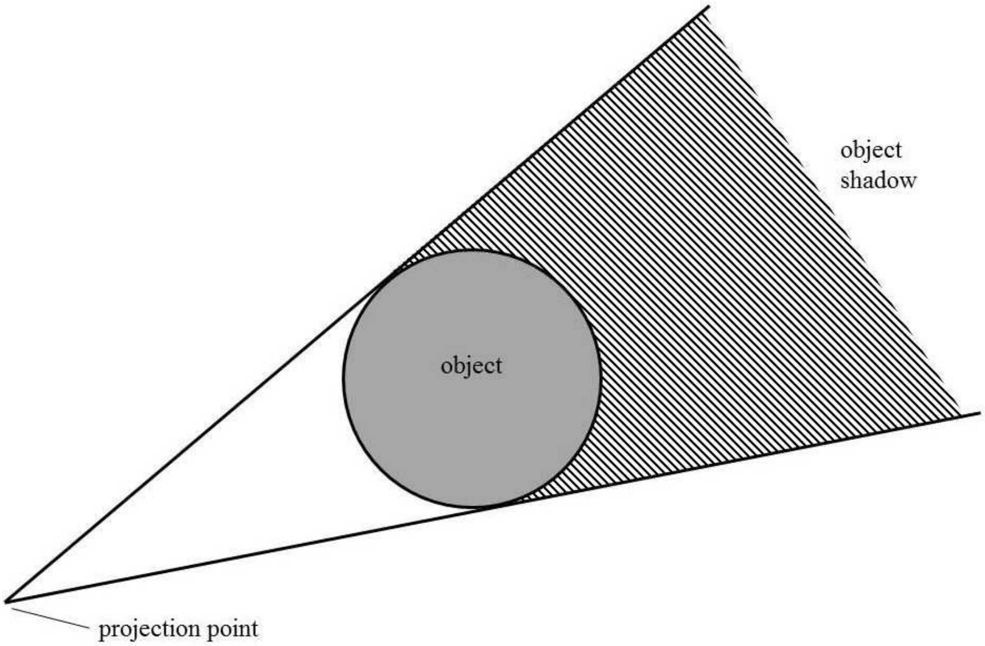

Figure 1. Shadowing effect of objects in 2D

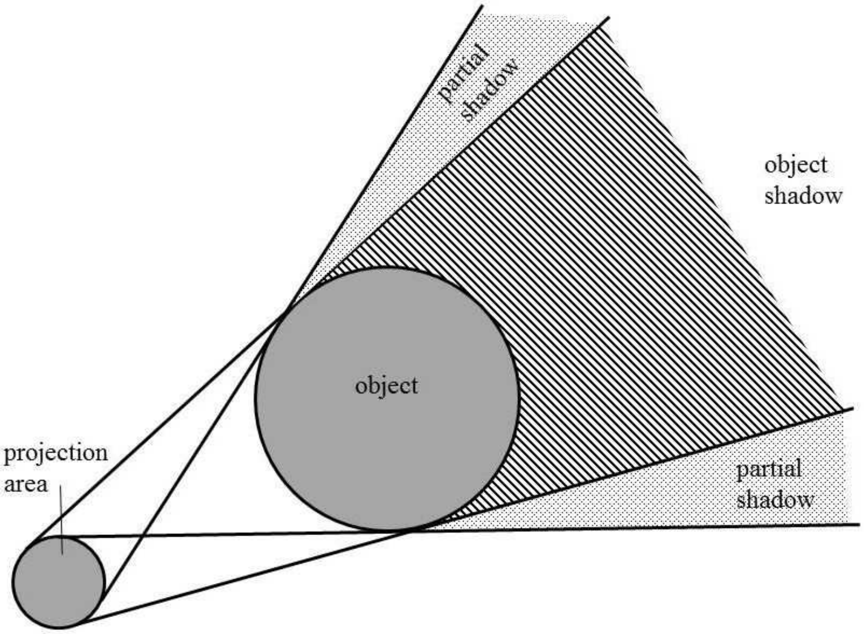

Figure 2. Shadowing effect of objects in 2D with respect to a projection area

2.2 Visibility analysis for 2+1D scenes

The extension of these approaches for the third dimension happened in two steps. At first, the concepts for 2D are applied in situations where data is in 3D space. The best examples for this approach are games from the early 1990ies like Wolfenstein 3D, one of the earliest first person shooters. The 3D rendering of visible objects draws upon visibility analysis carried out on objects' 2D projections. The geometrical problem of such applications is the same as in Figure 1 because all graphics need to be computed from the egocentric perspective of the player. The first games used a completely flat environment but later examples stepwise include height differences (ramps, stairs, etc.).

A classical adaptation of the idea in GIS applications is the view shed analysis. The analysis typically starts from a digital elevation model and determines the visibility from or to a specific grid cell. Unfortunately, the result of such an analysis heavily depends on the used algorithm and its implementation (Fisher, 1993). However, the methodology is still used because the concept is simple and it works for many situations. What it cannot deal with, though, is visibility through holes. A bridge, for example, partially blocks the view but it may be possible to see other objects below the bridge and in between its pillars. Modelling this kind of situation is difficult with standard approaches. Today, all commercial GIS software packages provide view shed analysis for 3D-models, typically for both, raster and vector models. This can be used, e.g., to determine the shadows produced by a planned building. The drawback of the current implementation is that they are typically based on 2+1D (compare, for example, Yang et al., 2007) and holes in building structures are still problematic.

2.3 Visibility analysis for 3D scenes

Different approaches for modelling and storage of 3D cadastres exist. Most of the approaches are object based, since this seems to be the obvious approach. Vector GIS is based on "sets of coordinates and associated attribute data" (Bolstadt, 2012, p. 34). A provable correct 3D visibility analysis for the situation like in Figure 1 would require ray tracing. The concept is quite old (Appel, 1968) but is computationally intensive because it requires following each ray from the observer position and check if it hits any object. The density of the rays is determined by the required quality of the result.

CAD systems have more efficient algorithms implemented. These algorithms are useful to present 3D objects on screens. As a basis they need a geometrical model of the objects including potential holes. Ying et al. (2011) presented a working model using the example of an apartment building with a complex ownership structure. Vandysheva et al. (2011) did the same for a Russian example. Both papers start from the Land Administration Domain Model (ISO DIS 19152, 2011) and prove that the domain model can cope with complex 3D geometry. Chiang (2012) did the modelling based on CityGML and presented a web-based user interface on top of orthoimages. Abdul Rahman et al. (2012) showed how to model underground structures. Work has also been done on aspects other than pure representation and visualization: Form example, Zhao et al. (2012) investigated topological relations and Thompson and Van Oosterom (2011) proposed a model to check data integrity (i.e., to avoid overlaps).

In the literature, other approaches, e.g., using 3D Voronoi diagrams (Gold, Tse & Ledoux, 2006) can also be found. However, they are not yet included in standard software products used in the GI industry.

3. QUALITATIVE VISIBILITY ANALYSIS

Fogliaroni and Clementini (2014) recently developed a qualitative model for visibility relations among three solids in space. The model provides spatial predicates of the form $R_{vis}(A,B,C)$ capturing the semantics of the visibility relation holding between an observer (*B*) and an observed object (*A*) when a third, opaque, object (*C*) acts as an obstacle.

The model is an extension to 3D of previously developed qualitative calculi (Billen and Clementini, 2006; Fogliaroni et al., 2009) and is based on the projective frame of reference depicted in Figure 3. Such a projective framework can be used to partition the space into various sets of so-called acceptance volumes. An acceptance volume is a parametric subset of the 3D space having as parameters 2 solids (*B* and *C*) of any shape. Each acceptance volume is associated a visibility relation (e.g., *Visible(A,B,C)*), meaning that, if a third solid A falls into that acceptance volume, the associated relation holds among the observed object A and the observer B (e.g., A is visible from B when C is an obstacle).

The frame of reference introduced by Fogliaroni and Clementini can be used to split the space in several manners, each corresponding to a qualitative calculus of different granularity. A coarse visibility model is described (compare Figure 4(a)) that is only capable of distinguishing 3 main relations: Visible, Partially Visible, and Occluded. A finer-grained version of the model (compare Figure 4(b)) is also derived that is capable of distinguishing several types of partial visibility. Namely, the finer-grained model allows for expressing where the visible part of a partially visible object is perceived with respect to the obstacle from the observer viewpoint (i.e. Left, Above Left,…).

The model demands low computational effort (i.e. the definition of the constructive elements of the frame of reference starting from the observer and the obstacle solids) and works in full 3D: that is, it can be used to model visibility relations holding among objects grounded to Earth, but also for flying objects and objects with holes and concavities (the treatment of non-simple solids is discussed in the original paper).

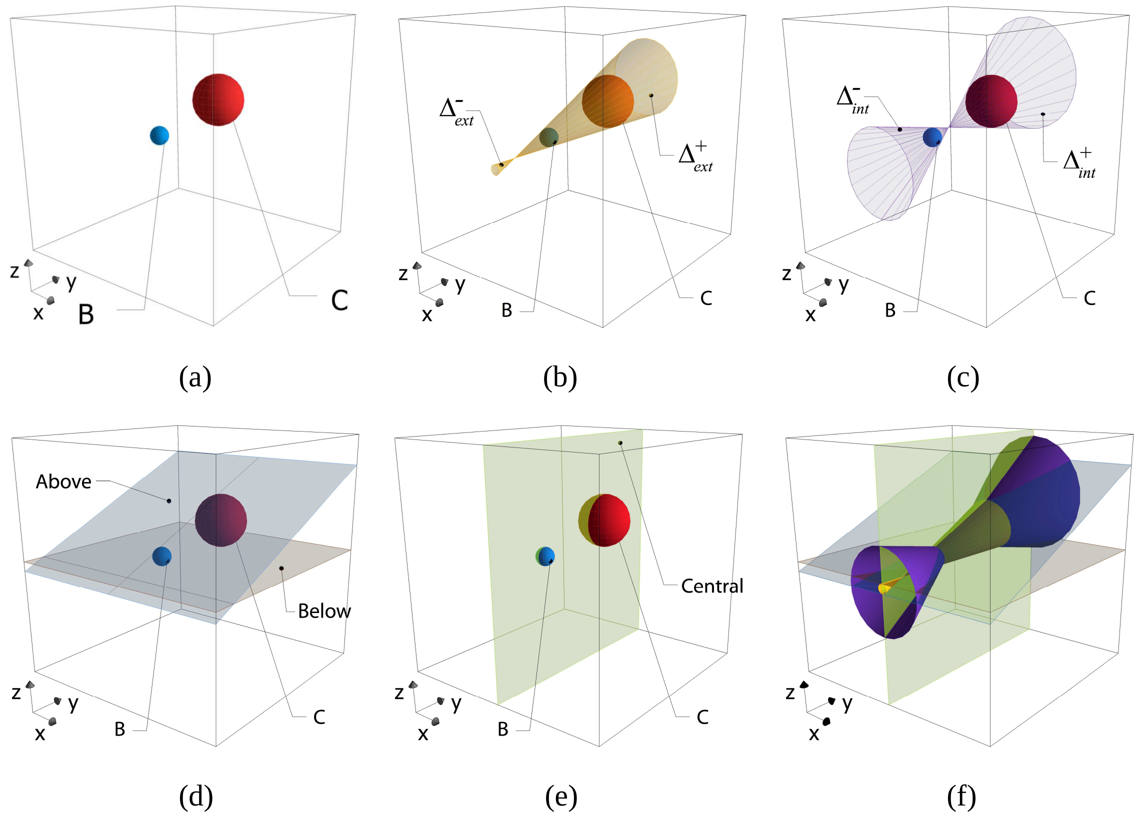

Figure 3. The projective frame of reference for visibility relations (f) draws upon 2 reference solids (a) and consists of 2 pairs of cones (b) (c) and 3 planes (d) (e) tangent to them (Source: Fogliaroni & Clementini 2014)

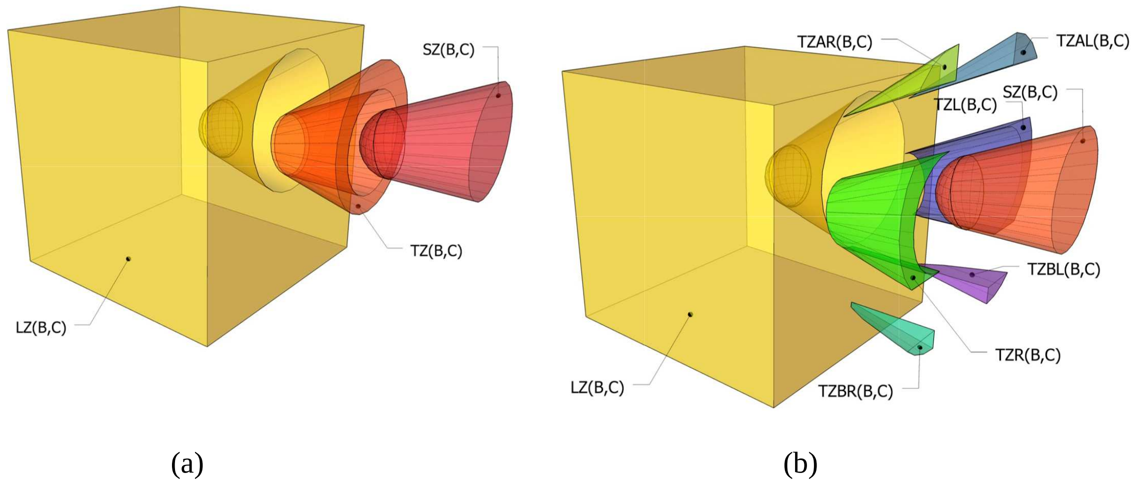

Figure 4. Coarse (a) and finer-grained (b) visibility model.

4. DATA FOR VISIBILITY ANALYSIS IN A 3D CADASTRE

Data for a traditional 2D cadastre are typically stored as a partition: Parcels must not overlap or leave gaps and thus neighboring parcels have a common boundary line. The storage strategy can then focus either on the boundary lines or the parcels. One problem for the change to 3D is, that 3D parcels will be formed sporadically. Even in large cities, only a relatively small number of houses will be registered as 3D property. Thus the 3D cadastre alone will not provide a comprehensive picture of visibility. However, most of the large cities have digital 3D city models showing the existing buildings. The 3D city models represent the physical reality and the 3D cadastre provides additional information on the 3D legal situation. We ignore the alignment problem in this paper and assume that lines and surfaces between 3D city model and 3D cadastre are perfectly aligned. Thus, buildings that do not completely fill the volume of the 3D parcel could, in the future, be enlarged and use more space. The difference between 3D parcel and 3D city model can be defined as follows: A 3D city model allows assessment of current visibility and 3D parcels allow—in combination with building regulations and other public restrictions—assessment of future visibility.

It is important to note, that both data sets must use the same height definition. The difference between geometrical and physical definition (compare Navratil & Unger, 2013) is rather small for typical heights of buildings but a vertical offset would cause serious problems. The heights must also refer to a standard height level and must not refer to terrain level at that point. Otherwise, height differences resulting from the terrain will be ignored, which could lead to wrong results.

The 3D qualitative visibility model presented in (Fogliaroni & Clementini, 2014) can work with any spatial representation consisting of sets of 3D coordinates like, for example, CityGML data. However, the model can also be implemented in a CAD environment. One of the limitations of the model is that the concept is a mathematical model. Thus curvature of the earth is not included. Therefore, vertical errors in the assessment will be inevitable and they will increase with the horizontal distance. In a distance of 1km, ignoring the curvature of the earth causes an error of almost 8cm, which can be neglected for most applications. However, in a distance of 10km the effect sums up to almost 8m.

5. SAMPLE APPLICATION “PROPERTY VALUE”

One application of 3D visibility analysis concerns the evaluation of land parcel or real estate values. The value of a land parcel or a real estate depends on several factors including proximity to main roads and transportation means, soil composition and land-use restrictions. Data from numerous sources is necessary to provide reasonable results. A major aspect of land value, for example is the possible land use and potential public law restrictions. A 3D cadastre can be necessary to combine possible use and use restrictions to a coherent picture (compare Navratil 2012, Frank et al., 2012). Another important factor to be considered relates to visibility. For example, the climatic parameters are important for the assessment of land value for agricultural land. This includes the amount of sunlight that land receives (i.e., can “see”) over the year. Visibility analysis can be used to perform such an analysis: sun can be modeled as the observed object and features (e.g. buildings, trees, mountains) nearby the analyzed land can be deemed to be obstacles possibly occluding sun to the land. Similar analysis is required for built environments. Building regulations in many countries provide minimum requirements for exposure to light. This shall guarantee that apartment in the ground floor still get sufficient lightning for adequate living conditions. Current GIS analysis can model the sun as a point moving over the sky and casting a different shadow for each position. These different results are then combined to an average exposure to light. However, the method is difficult when modern, highly fragmented architecture is involved. Correct results would require ray tracing because this is the only method to correctly assess the effects of reflected light and light through transparent parts of buildings. However, the method is not (yet) fast enough for large scale applications. The method developed by Fogliaroni and Clementini can be used as a starting point to discuss the inclusion of transparent parts.

A similar analysis can be performed to have a better assessment of real estate values. In this case, not only sun exposure, but also visibility of visually pleasant landmarks (e.g. a lake or a park) affects the value of the real estate. This is evident by the prices of hotel rooms: Rooms with a nice sight usually cost more than rooms facing a nearby building. The definition of "nice sight" ranges from natural beauty (e.g., lake-view, sea-view, or mountain-view) to monuments (e.g., Victoria Harbour, Eiffel Tower, or Statue of Liberty). The same concept influences the value of apartments on the housing market. The analysis answers the question, if the view between an apartment and a landmark is free, partially blocked, or completely blocked. In a first step, the volume of the apartment is used as a projection area. However, since we typically observe reality through windows and walls block the outside visibility, the walls can be added. After adding the walls, the resulting assessment of visibility will always be partially blocked even if the landmark is visible through all windows because the landmark will not be visible from point immediately behind the walls.

The visibility analysis (and thus the value estimation) can be pushed even forward by considering how the surrounding environment may change in the future. Assume, for example, that a piece of land is today largely exposed to sun because there are no occluding features nearby. However, this situation may change in the future if nearby land parcels are not yet built according to the limits provided by the building regulations. Figure 5 shows an example for such a situation. As long as parcel B is not built, apartments on parcel A have ocean-view. However, if a building on parcel B is taller and uses the complete extent of the parcel, none of the apartments on parcel A may keep the ocean-view. The problem is therefore, that future buildings may change the currently assessed value. The danger of such a development can be assessed using land development plans and compare them to the current building status (from the 3D city model).

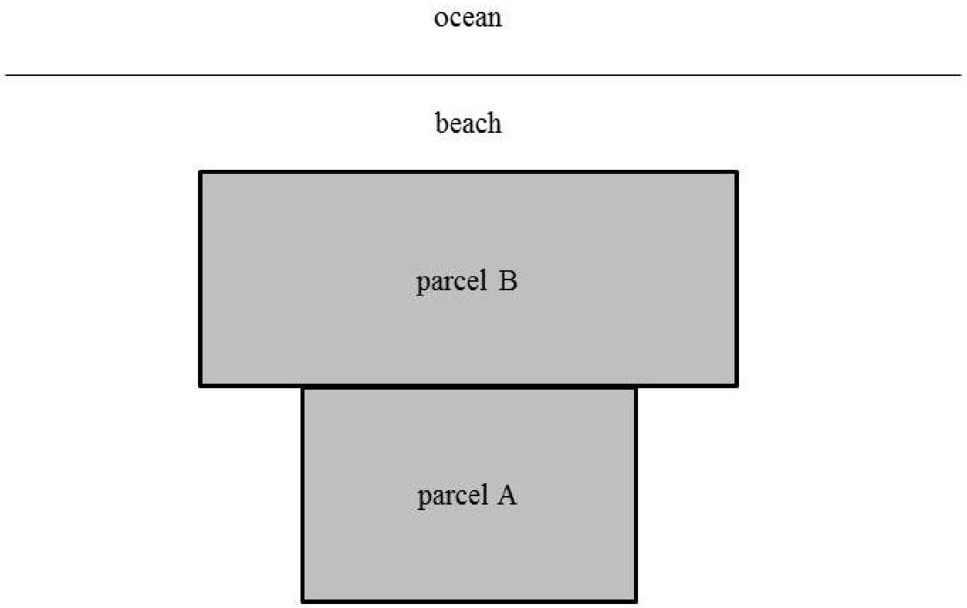

Figure 5. Example of possibly blocked view

6. SAMPLE APPLICATION "SPATIAL PLANNING"

As shown with the first sample application, 3D visibility analysis can provide a more comprehensive evaluation of real estate value. However, it can also be used for spatial planning and land administration. For instance, land administrators can be supported in decision making about land use. Some parts of the landscape are visible from large areas. Changes in the land use of these parts thus have a strong effect on the visual attractiveness of an area. Wind power plants, for example, have two negative effects: They produce noise and are not visually attractive. Both need to be discussed in a process of approval. While the discussion of noise is easy (the definition a maximum noise level and the measurement of produced noise at the plant can be used to determine a minimum distance to villages), visibility is a more difficult problem. A nice, visually attractive scene can be a strong basis for tourism because many tourists are looking for relaxing places.

The same problem also occurs in built areas. Monuments in cities are buildings with a specific historic or artistic significance. Hiding these monuments behind other buildings will make it more difficult for tourists to find the buildings. St. Stephen's Cathedral in Vienna, for example, is visible from numerous places in Vienna because the street network consists of concentric circles and radial roads. The radial roads lead to the city canter where St. Stephen's Cathedral is situated and thus the cathedral is often visible. Originally this should help the orientation and today it is attractive for tourists.

Visibility can also have implications on UNESCO World Heritage. The city center of Vienna is an example for this. The justification for inscription is defined as: "*Three key periods of European cultural and political development – the Middle Ages, the Baroque period, and the Gründerzeit – are exceptionally well illustrated by the urban and architectural heritage of the Historic Centre of Vienna*." (Bundesdenkmalamt, 2000). A new construction may have a significant impact of the visual appearance of the World Heritage. Thus the effect needs to be assessed. One possibility is to identify the change in visibility for the World Heritage. The project may be prohibited if it blocks too much of the World Heritage and changes the visual appearance in a negative way.

Landmarks can also help people navigate in an unfamiliar environment. The instruction "follow the River Thames in the direction of Tower Bridge" is easy to understand if you stand at the river bank and see the bridge. However, if the view to the bridge is blocked, there is a 50% chance to start walking in the wrong direction. Visibility analysis using 3D city models can then be used to improve navigational instructions and 3D cadasters can help assessing possible viewpoints.

7. CONCLUSIONS

The paper showed a computational approach to assess visibility of objects from areas. The approach allows assessing the situation where a target object is visible or partially visible behind other objects from a projection area. From some points in the projection area the target object is visible while it is blocked from other points. We briefly discussed two applications for such a model and showed that there are questions where such a model can provide helpful information.

Both applications do not only need data from a 3D cadastre but also from a 3D city model. Combining both sources requires spatial congruency. The data sets are typically created differently: 3D city models are created from airborne laser scanning or aerial photogrammetry while 3D parcels for the cadastre are often constructed from building plans or terrestrial survey. Therefore reaching congruency includes some interesting research questions like deciding if a horizontal distance between two vertical planes should be eliminated or not.

The visibility model presented by Fogliaroni and Clementini can also be improved. Transparent objects and mirrored views are not yet addressed. They could be added in future versions. The model also assumes certainty about the geometry. This is a reasonable but probably unrealistic simplification. A building with a flat roof, for example, may be used as a terrace and plants or other objects may be placed on the roof. This will change the height of the building slightly and may change visibility. Geometrical imprecision of the objects could thus be another direction of development for the model. Also issues of Earth surface curvature can be addressed in future improvements of the model.Finally, the integration of 3D visibility analysis in current tools should be discussed. This includes ideas about aligning of data from different sources, e.g., 3D cadastral and CityGML data.

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BIOGRAPHICAL NOTES

Gerhard Navratil is a senior researcher in the Research Group Geoinformation at the Department for Geodesy and Geoinformation of the Vienna University of Technology. In 2007 he received the Venia Docendi (the right to teach) from the Vienna University of Technology. His research interests are data quality, land administration, and the problems combined with the historical development of land administration systems. He is a member of the IUGG Committee on Capacity Building and Education and a member of the editorial board of Spatial Statistics, the International Journal of Sustainable Society, and Geodetski Vestnik.

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