BEYOND VISUALISATION – 3D GIS ANALYSES FOR VIRTUAL CITY MODELS

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ABSTRACT:
The successful utilization of 3D city models for business processes of urban planning highlights the benefits of 3D city models. This paper presents an overview of 3D GIS analysis capabilities for 3D city models. Based on realistic case studies the range of 3D analyses is highlighted and structured into categories.

1. INTRODUCTION

The progress of 3D technologies for city modelling during the last years covered the whole production chain and resulted in many applications. Data acquisition, data processing and visualisation technologies for 3D geodata enhance the process of 3D city modelling particularly. New technologies like the implementation of the standards of Web 3D Service (W3DS) and the Web View Service (WVS), approved by the Open Geospatial Consortium (OGC), support these promising developments for 3D city models (cf. Lanig and Zipf 2010). Their main use has been for visualisation purposes, e.g. in urban planning (cf. Ludwig and Mc Kinley 2010). The successful utilization of 3D city models for business processes of urban planning highlights the benefits of 3D city models. The validation and evaluation of competing proposals for an urban planning project and the visualization of planned building modifications for the facility management are current examples for 3D city modelling applications of different scale (cf. Albrecht and Moser 2010). Although these examples are focused on visualisation, they already may require basic 3D GIS analysis steps, e.g. for model validation. On the other hand, applications have been developed that employ more specific 3D analyses, like noise distribution according to the EU noise directive (cf. Kurakula and Kuffer 2008). There, the benefits of utilizing the third dimension for city modelling are much more obvious. Still, for many cities it is difficult to see the advantages that they get apart from visualisation, when the development of a city model is discussed. In order to judge these advantages correctly, the users need to be aware of the entire range of 3D GIS analyses contributing to the unique characteristics of 3D city models.

This paper presents an overview of 3D GIS analysis capabilities for 3D city models. Based on realistic case studies the range of 3D analyses is highlighted and structured into categories. For this systematic approach general categorizations of spatial analysis functions (cf. Tomlin 1991) as well as specific user-oriented categorizations of 3D operations (cf. Albrecht 1996, Göbel and Zipf 2008) are adopted.

2. METHODOLOGY

The objective of this research was to support decisions for the development of virtual city models by presenting a structured overview of 3D GIS analyses that are likely to be applied in 3D city modelling. Based on real and fictive user-oriented case studies from the context of urban planning, possible 3D analyses were identified. The case studies were described from

the perspective of the urban planner's needs for the 3D analysis functionality provided by a 3D city modelling application. For the specific objectives of each case study the required tasks and 3D data were defined. The tasks were decomposed into separate analysis steps for identifying and describing in detail the relevant real 3D analyses. These components were then structured and categorized, with the background of existing classifications of Tomlin (1991), Albrecht (1996) and Göbel & Zipf (2008). As a result, a structured overview of 3D analyses was presented which should be provided by 3D city modelling applications (cf. **Figure 1**).
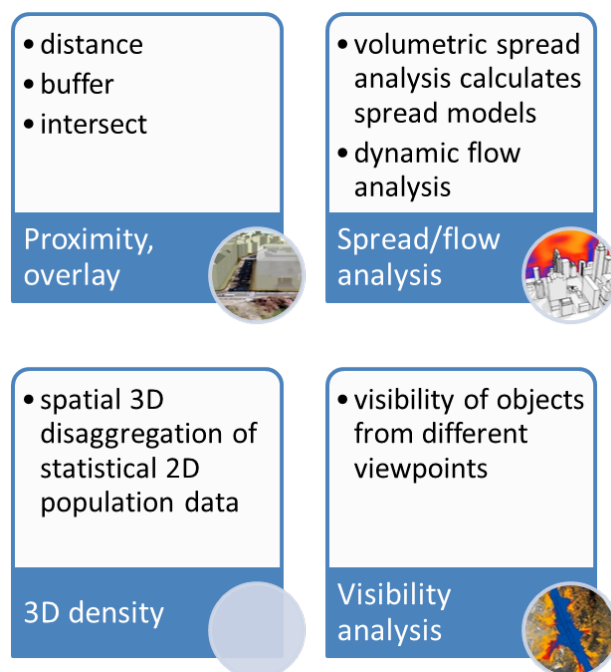

Figure 1. Overview of discussed 3D GIS analyses in the context of virtual city models

3. SYSTEMATIC APPROACH TO 3D ANALYSES

In this chapter the case studies are described to identify possible *3D analyses* within 3D city models. The selection of the case studies was suggested by the main categories "proximity", "spread analyses", "3D density" and "visibility analysis".

3.1 Case Study „proximity" (3D distance, 3D buffer): Subway for Salzburg

The first case study was aimed at investigating *3D buffer* operations in a scenario for urban planning. In a fictive project in the city of Salzburg, Austria, the route of a subway to a new station is analysed within a 3D city model. The route is an extension of the suburban train from its underground station at Salzburg railway station along the Rainerstrasse to the Mirabellplatz, where the new station has to be built. An underground volume is defined that covers all the wider space around the stations and the connecting route, from the ground surface above to a specific depth below. This volume serves as the space where the planned infrastructure potentially can fall into. For the placement of the subway tunnel the available underground space is determined by excluding all the space around objects that would interfere with the new infrastructure. These can be the basements of buildings, underground parking, or similar foundations, as well as wastewater pipes, power lines and other subsurface objects. The corresponding objects within the vicinity of the route along the Rainerstrasse are selected from the 3D city model with a *3D distance* operation. A *3D buffer* with a specific object-related distance is applied to the selected objects in order to identify the interfering volume. With a *3D intersect* operation the interfering volume is subtracted from the potential volume and leaves the space that is available for the placement of the subway tunnel. **Figure 2** presents the 3D buffer around the building basements.
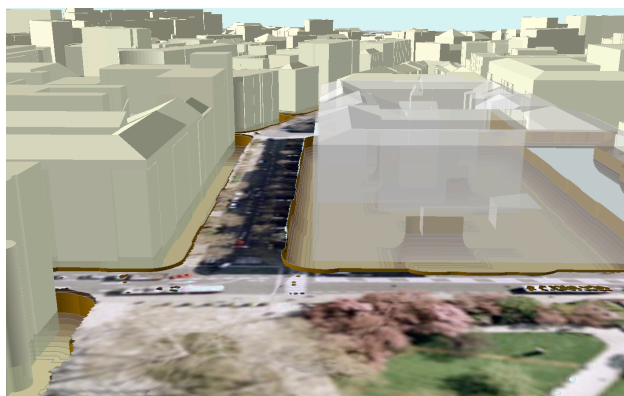

Figure 2. 3D buffer applied to the ground volume around the building basements

The case study also covers the placement of the new subway station where the specific interest lies in identifying the connections of areas on the surface to the station, e.g. for pedestrian access and for ventilation. Apart from the *3D buffer* some more operations could be identified, which were the selection of objects within a *3D distance* and the *3D intersect* operation.

3.2 Case Study spread analysis

There are different applications for *spread analyses* in 3D city models. The distribution of traffic pollutants requires taking single or multiple emission sources into account. On the other end, there exist applications with no emission sources, e.g. with the aim to improve the air circulation within a city to reduce the negative effects of urban heat islands. This case study focuses on dynamic air flow analysis between buildings of an urban district (cf. **Figure 3**). These results can be valuable for urban planning particularly in urban areas with high traffic load. As the traffic load influences aerial exchange, the decision making

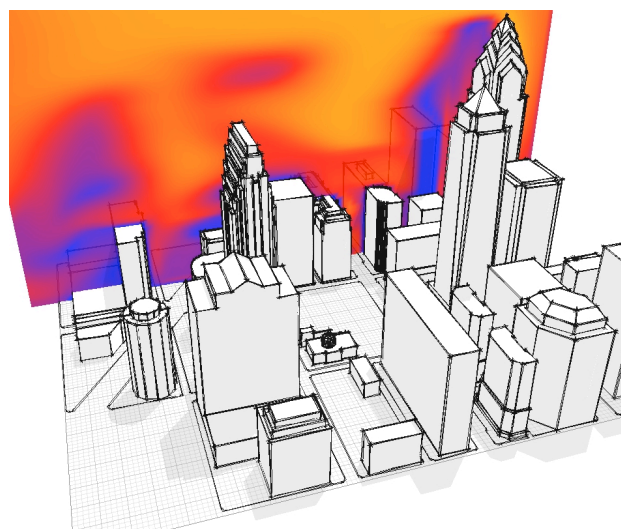process for urban planning measures like the building of "green areas" can be supported.

Figure 3. Dynamic Air Flow Analysis (Source: Autodesk Ecotect Analysis 2010)

Basically, when applying 3D spatial analysis such as an adapted 3D buffer, air pollution from a single source of emission can only be described in a coarse approximation. Corresponding results can be achieved in detail only with models from physics. Advanced methods of geosimulation like 3D extensions of cellular automata and agent-based models are applied to imitate the physical properties of the pollution spreading. But these analyses reach a high degree of complexity that is not covered by this case study. Instead, a given voxel dataset of pollution density is assumed for the cloud of pollution that is compared to affected buildings and sensible areas in the 3D city model. Volumes of different density levels are generated by 3D zoning of the voxel data. With 3D intersect or with 3D touch the affected areas and buildings (or building floors, dependant on the detail) are identified.

3.3 Case Study 3D density: 3D disaggregation of population data

Emergency management and the planning of mobile phone coverage can profit from the availability of 3D population density data. But with traditional methods population data are not collected in that amount of detail and are usually provided in an aggregated fashion. In addition to such a detailed spatial distribution of the population, the temporal dynamics of the population has to be taken into account. There exist a different day and night population distribution, and factors like the weekend and the rush hour traffic can be of importance, too. Therefore, the principal purpose of this case study is a spatial *3D disaggregation* of statistical 2D population data. In a complex of buildings different local densities are calculated by considering the usage per floor, like commercial and residential use, and the traffic areas between the buildings. The resulting 3D population density data can then be compared to the 3D coverage of cell phone transmitters or to 3D hazard zones.

3.4 Case Study visual analysis: Evaluation of potential antenna positions for a terrestrial positioning system

Visibility analysis is perhaps the most obvious 3D analysis for city models as it builds on similar concepts as the creation of perspective views, the core of city model visualisation.

Analogously, *visibility analyses* identify points or areas that are visible to a specific observer situated in or around the city model. Instead of generating a perspective view from this information, the *visibility analysis* maps the identified areas according to their geographic position.

The case study[1] presented below combined a number of viewshed analyses (cf. de Smith et al. 2010) that were applied from different observer points to an airport apron and runway (maneuvering area). The analysis results simulated radio frequency propagation and supported the installation of a terrestrial positioning system (TPS) to track moving vehicles for ground traffic control. The *viewshed analysis* determined visual exposure of a specific TPS antenna position based on elevation values from a digital surface model (cf. **Figure 4**).
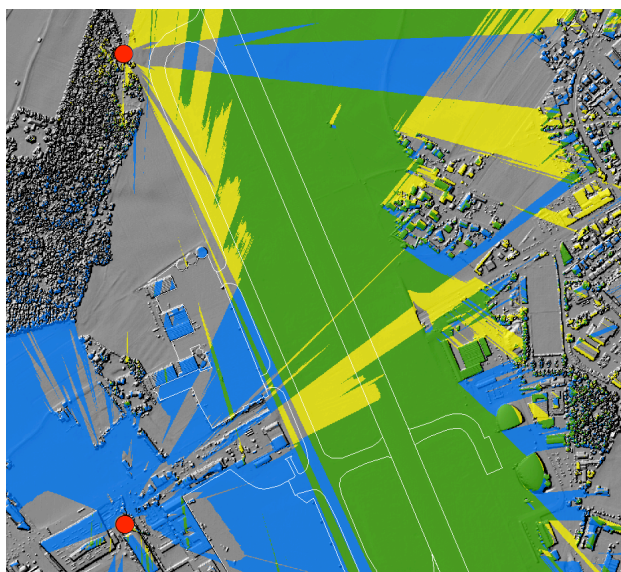

Figure 4. Viewsheds of two observers and their intersecting area

The goal of the case study was to provide information for selecting the six most appropriate locations out of twenty possible antenna positions. Security regulations and technical specifications provided by the customer required the use of specific parameters to control the visible area of each TPS antenna. These parameters included a vertical offset of the observation point from the terrain as well as a minimum distance. Below this distance the saturation effect of the TPS antenna confused the measurement. The resulting raster provided information about the area seen from each observer station, i.e. the quality of each potential observer position, and the combination of observer points visible from each position in the raster. For a safe positioning measurement the system must guarantee that each position is visible from at least four observer points. If one antenna becomes inoperative, the position can still be calculated with the other three. This information forms the basis for selecting the optimal combination of observer stations to position the antennas for the TPS.

Current algorithms for the calculations in the above example are raster-based. When a city model is the basis for the visibility analysis, the model would need a conversion to a raster surface.

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[1] SESAAM (2010 - 2012), Geo-Spatially Enhanced Situational Awareness for Airport Management, http://zgis16.plus.sbg.ac.at/research/index.php?option=com_content&view=article&id=101:sesaam&catid=58:ffg-take-off&Itemid=119

This conversion introduces error through the reduction to only one z-value for each x-y-position, which results for example in slanting walls. With an iterative *line-of-sight-analysis* that recognizes the building objects. A viewshed could be calculated from the city model without the conversion. The *line-of-sight analysis* calculates the visibility along a polyline between two points based on a surface model and vector objects in 3D space. The point from which the visibility is calculated is the observer, whereas the opposite end of the line is the target point. The analysis determines which targets are not visible from the specific observer point, i.e. if the line between the points intersects any part of a building or of the terrain. An iterative process of placing target points with a certain interval between each point on a specific surface area enables a broad overview of visible zones/locations (cf. **Figure 5**). This model can then be converted into a raster file, comparable to the *viewshed analysis* mentioned above.
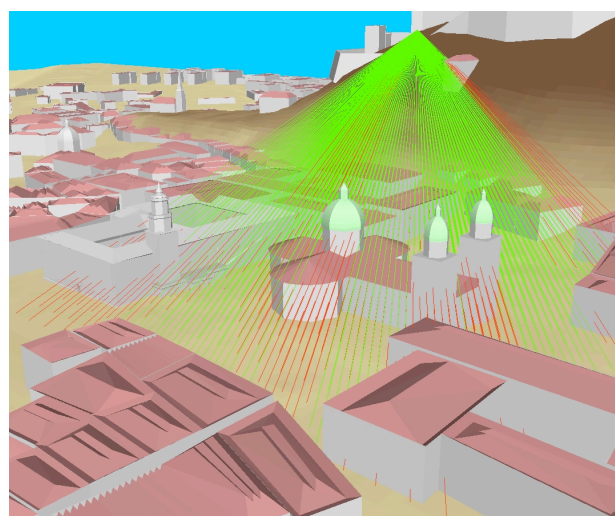

Figure 5. Iterative line-of-sight-analysis applied to lines from one observer point to a number of evenly distributed target points

4. CONCLUSIONS AND FUTURE WORK

This paper highlights 3D analyses in a structured form with the objective to illustrate the wide range of 3D analyses. The overview can support the decision if a specific application requires 3D representation of urban objects. These results can contribute in the design of a 3D city modelling software and indicates the benefit of integrating 3D city models in working processes of communities. This paper was mainly focused on 3D geometric analyses. Continuous research will concentrate on further case studies which are aimed at exploring the described 3D analyses more detailed and at 3D analyses which are not covered yet, e.g. modelling real 3D cell phone coverage. By extending the case studies, the discussed 3D analyses will be supplemented and further categories will be defined. Of particular relevance are 3D analyses which consider the 3D proximity due to the intended exploitability of 3D topology in 3D city models. Case studies in this context may concern 3D network topology analysis for routing in buildings or emergency planning in buildings. The results of 3D analyses can be varying by the use of 3D objects with different quality characteristics. This can be targeted and validated by providing adequate 3D datasets before start of analyses. Our approach illustrates 3D city modelling and urban planning in a broad sense. The prerequisite of 3D city models that they essentially

become "computational tools" (Döllner 2009) is established, our research fits in this tendency.

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