

AN AMALGAMATION OF 3D SPATIAL DATA MODEL FOR SURFACE AND SUBSURFACE SPATIAL OBJECTS

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Key words: 3D Model, 3D TIN, UML, 3D Unified Model, City Earth Surface, 3D Spatial Objects

SUMMARY

3D spatial data models for city models have advanced for the past two decades and most modern cities around the globe are attempting to create virtual 3D models of their cities. The current city Earth surface is actually an amalgamation of natural and man-made objects above, on and below the city terrain surface. 3D modelling of subsurface objects and their integration with the surface and above surface objects currently lacks behind despite efforts of researchers and the attempt at viewing above surface and subsurface man-made objects for earth realism not achieved. Levels of Details (LoD) for spatial objects has been extensively studied however these has not been extended to man-made features below the surface. LoD 0 maps for surface and subsurface integration exist for most city centres and this does not exist for 3D city modelling. This paper provides a discussion for 3D surface objects, 3D subsurface objects and surface subsurface integration. Various 3D spatial data models currently in existence for the integration of surface and subsurface models are discussed and a geometric, topological 3D object oriented model (3DOOM) is suggested and the UML diagram for the top hierarchy class presented. A conceptual model for surface and subsurface integration is also presented. A simulation of the above and below 3D spatial models for man-made constructions is assessed up to LoD 4 for the subsurface and LoD 3 for the above surface in an integrated model. Simulations for 3D spatial models for the above and below surface models are created using a vector approach are presented. 3D Spatial Analysis is the next phase for this research.

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1. INTRODUCTION

Population growth in most major city centres of countries of the world is of great concern to the authorities of such modern cities. Tourists and visitors both within and outside the country visit these cities on a daily basis. Surface space is limited for a booming city, space above, on and below the city surface is being stretched to its limits and competition for space in these cities have increased thus introducing a high level of complexity for most modern cities. Man-made structures for underground space currently consist of tunnels, buildings, underground car parks, rail transport and road transport. Currently the urban space is a complex cadastre issue where land parcels or lots can be described for the above, on and below surface parcel lots thus further complicating the complexities of objects above, on and below the surface for all cities in most countries of the world. For man-made objects the 3D data is obtainable from vector data or Computer Aided Design (CAD) drawings and can be represented in any 3D data model using the basic geometry element i.e. the node. Description of spatial information for any 3D city object is complex due to the complexities of the various objects that can found in any modern city. Cities around the world are currently catching up on the creation of 3D city models. The city surface for such modern cities is currently just becoming a surface comprising of above, on and below the natural surface of the earth. The construction of man-made structures in cities invariably involves an in-depth study of the subsurface to obtain information such as geology, geotechnical investigations, hydro geological considerations amongst other considerations before a city object is constructed, hence information about the subsurface exists for most city objects but these are not integrated. 3D GIS can support such city models when all the geospace has been unified. Disasters in also underground areas is very possible in city centres and if the underground space is not well modelled, rescue teams could find it very difficult to undertake rescue operations should disaster occur. Recent

disasters in mining areas (Chile and New Zealand in 2010) should inform the geoinformation community of the need to incorporate the integration of surface objects with man-made subsurface objects or cavities. Section 2 is a review of current 3D surface and 3D subsurface models and their integration. Section 3 presents the concept for the unified model and Section 4 presents the methodology, results. Summary and discussions in Section 5. Section 6 is the concluding remarks and future directions for this research.

2. PREVIOUS WORKS

3D city models such as the City Geography Markup Language (CityGML) and the Keyhole Markup Language are currently being used and has been accepted as a standard for exchange for 3D information (Ross et .al., 2009). According to Kolbe (2009) CityGML is to provide a city model which can be applicable to many disciplines such as urban planning, disaster management, rescue operations, flooding, noise mapping, cadastre and facility management, the introduction of Abstract Data Extensions (ADE) will help to achieve more of the application areas.

2.1 Surface objects

Surface 3D objects in the case of 3D city models have been studied by various researchers using the vector approach (Molenaar, 1990; Abdul Rahman, 2000; Zlatanova, 2000; Coors, 2003). 3D data models such as the tetrahedral network (TEN) (Pilouk, 1996) the constrained tetrahedral network (TEN) (Penninga and Oosterom, 2008), the Object Oriented Data Model (OODM) (Wang, 2006; Wenzhong et.al. 2003; Koshak and Flemming, 2002), Unified Data Model (UDM) (Coors, 2003) and the Simplicial Simplex Model (SSM) (Zlatanova, 2000) approaches have been used for 3D city models. The 3D Formal Data Structure (3D FDS) has been the basis for most models for surface and above surface objects.

The 3D FDS model has been studied and enhanced: Abdul Rahman (2000) enhanced it to 3D TIN using object-oriented techniques, Coors (2003) and Wang (2006) enhanced the 3D TIN using the UDM and OO3D-ISDM respectively. Pilouk (1996) introduced the 3D TEN (TIN)

by introducing the simplex and complex concepts and Zlatanova (2000) introduced the SSM concept using the simplex concept. Shi et. al.(2003) to OODM using concepts of 3D TIN and incorporating the simplex and complex concept from Pilouk (1996) and Zlatanova (2000). This model has also been modified into the cell concept by Zhou et. al. (2008). These models have been used for above surface city models, below surface models (geology) and on surface (terrain) but these have not been integrated for man-made features. Surface 3D objects have made significant impacts in the areas of 3D structuring and topology (Zlatanova et. al., 2002), 3D visualization and virtual reality (Zlatanova, 2000; Coors, 2003; Shi and Yang, 2002; Horne et. al., 2007; Charlton et. al., 2008; Podevyn et.al. 2008, Thompson and Horne, 2010), Surface 3D objects have seen remarkable progress and much more research is being conducted in the area of texturing, rendering, dynamism, change detection and navigation.

2.2 Subsurface objects

Research into subsurface data models have been reported extensively by Breunig et. al., (1994, 2001). 3D subsurface objects have been studied for the past two decades, some of the models that have been represented includes serial sections (Tipper., 1977), TIN (Barry, 1991; Sapidis and Renato, 1991; Tsai and Alan, 1993; Abdul Rahman and Pilouk, 2008), NURBS (Fisher and Wales, 1991), TEN (Tsai, 1993; Pilouk et. al., 1994), block (Simon, 1994), hybrid (Shi, 1996, 2000), octree (Chen and Huang, 1998), 3D voronoi (Gabriel et. al., 2001), tri-prism (Zhang and Bai, 2001; Dai and Zou, 2001; Cheng and Gong, 2001; Gong et. al., 2002) and 3D Voronoi Diagrams (VD) and Delaunay Triangulations (DT) (Ledoux and Gold, 2008). Some of these models have been classified as facial models, volumetric models and mixed models (Wu et. al., 2003) in Table 1

Facial Model	Volumetric model		Mixed model
	Regular Volume	Irregular Volume	
Triangular Irregular Network (TIN)	CSG	Tetrahedral Network (TEN)	TIN-CSG
Grid	Voxel	Pyramid	TIN-Octree mixed or Hybrid
Boundary Representations (B-	Octree	Tri-Prism (TP)	Octree-TEN mixed

Rep)			
TIN	OODM	GTP	OO3D-ISDM

Table 1: Classification of 3D data models for subsurface objects (Modified After Wu et. al., 2003)

Although stand-alone subsurface 3D models have been investigated and implemented (Raper, 1989; Raper and Maguire 1992; Latuada, 2006; Hack et. al., 2006; Apel 2006; Breunig and Zlatanova 2006; Tegtmeier and Zlatanova 2009)) it is yet to be integrated with the on and above surface scenarios, Subsurface objects currently being understudied are in the areas of geology, hydrogeology, geotechnical, oceanography and geophysics, dealing with natural objects such as the spatial distribution of three-dimensional (3D) continuous geological stratigraphy, borehole information and ore modelling of a mineral underground. These objects are referred to as fields whilst the object view approach considers the space as being ‘empty and populated with discrete entities such as buildings, roads etc (Ledoux and Gold, 2008). Most of the research carried out for subsurface 3D models have been to model the natural subsurface: Abdul Rahman (2000) used the 3D TIN for drillhole locations, This idea was extended by Wang (2006). Breunig (2001) carried out extensive research on geological bodies (GeoToolKit) using the TEN model. Tegtmeier and Zlatanova (2009) implemented the simplex concept for subsurface geotechnical consideration. Zhou et. al. (2008) also used the cell complex and implemented the model for geology. All the models above have been used for subsurface natural feature applications. Standards such as CityGML, GeoSciML and Industry Foundation Classes (IFC) has been developed for 3D spatial artificial and natural features above and below the Earth’s terrain, these features have not been integrated due to challenges in geometric, topologic and semantic heterogeneities.

2.3 Surface and Subsurface objects

Surface and subsurface unified models have been studied by many researchers (Abdul Rahman and Pilouk, 2008, Wang, 2006, Breunig and Zlatanova, 2006 and Zhou et. a., 2008). Underlying their research is enhanced forms of the 3D Formal Data Structure (3D FDS) for 3D spatial data for 3D objects for both the surface and the subsurface. Molenaar (1990)

proposed the 3D FDS for 2D GIS and this concept has been enhanced and made applicable for 3D GIS. This model has the point, line, surface and body as the entity object. An enhanced data model of the 3D FDS has been studied by other researchers such as the 3D Triangular Irregular Network (3D TIN) by Abdul Rahman (2000), Simplified Spatial Model (SSM) by Zlatanova (2000), Object Oriented Data Model (OODM) by Koshak and Flemming (2002), Object Oriented 3D (OO3D) by Wenzhong Shi et. al., (2003), Urban Data Model (UDM) by Coors (2003) and the Object Oriented 3D Integrated Spatial Data Model (OO3D-ISDM) by Wang (2006). Current models for surface and subsurface integration by some researchers are presented in Table 2.

Surface	Subsurface Application	Researcher(s)
3D TIN	Borehole data	Abdul-Rahman and Pilouk (2008)
OODM-ISDM	Borehole and Geological data	Wang (2006)
GTP	Geological bodies and engineering excavations	Wu and Shi (2004)
0-3 Cell Complex	Geology	Zhou et. al., 2008

Table 2: Current 3D data models for surface and subsurface integration.

These models were used for city and complex objects, visualization, terrain and geology using the 3D TIN concept. The OO3D-ISDM spatial data model was used for the integration of city objects and drill hole data based on the concept of 3D TIN. Wu and Shi, (2004) proposed a spatial data model based on G-GTP and E-GTP based on the generalized tri-prism (GTP) for geosciences applications, this model basically also uses the idea of 3D TIN to implement the models. The cell complex which also is an enhanced concept from 3D TIN was applied as an integrated model in the area of city objects and geology (Pigot, 1992; Zhou et. al., 2008).

3. CONCEPT FOR A UNIFIED MODEL

The concept for a unified model based on man-made features for above, on and below the earth surface is presented in Figure 1. This shows man-made features connected to the terrain model for above and below surface features and man-made features which are independent of the above and below features. Features for the latter have to be topologically connected in order to show above surface features which have independent features below the surface.

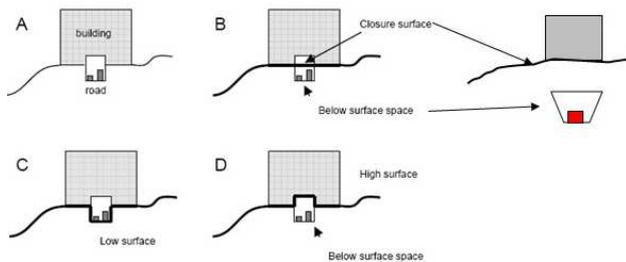


Figure 1: Concepts of surface and subsurface integration (Modified after Emgard and Zlatanova, 2008)

Approach can be modified in various ways to attract more applications. 3D city objects have underground facilities such as storage, tunnels, underground rail systems and underground car parks, knowledge about these man-made objects are required.

Various researchers have enumerated the need to integrate man-made objects for both the surface and subsurface (Zhou et.al. 2008; Ledoux and Gold, 2008; Zlatanova, 2008; Gold, 2008). Concepts from current integrated models (Abdul Rahman and Pilouk, 2008; Wang, 2006 and Wu and Shi, 2004) which investigated models for above, on and below surface objects basically for geology can be extended to include man-made objects for the subsurface, Slingsby and Raper (2007) enumerated the need to link models of objects with the terrain. Emgard and Zlatanova (2008) discussed an information model under development which will

integrate features above, on and below the surface into a common semantic and geometric model by representing two alternatives in a conceptual model. Some of these concepts will be adopted and modified in this research.

Most modern cities have underground rail systems or tunnels or utility lines. Current city models are integration of above and on surface applications. Researchers have been trying to bridge the gap between 2D, 2.5D and 3D GIS for surface objects but this has to be enhanced by looking for the 'missing link' between surface and subsurface 3D models for man-made objects and not for geosciences applications alone. In an urban city model with underground facilities what if disaster strikes underground? What evacuation plans can be put in place? What safe exits can be modelled? How will this affect the surrounding buildings? How will the city authorities be able to indicate precisely where it occurred? City planners should be able to locate all buildings with underground facilities, hence the need to model surface and subsurface man-made objects.

An enhanced 3D TIN model is proposed for the unified model, this seeks to combine 3D TIN with the solid being formed by tetrahedrons or polyhedrons as described by Pilouk (1996). This presents topology as a solid composed of tetrahedrons, surface composed of triangles, a line is composed of arcs and point consists of nodes. The unified geometric semantic model as shown in Figure 2.

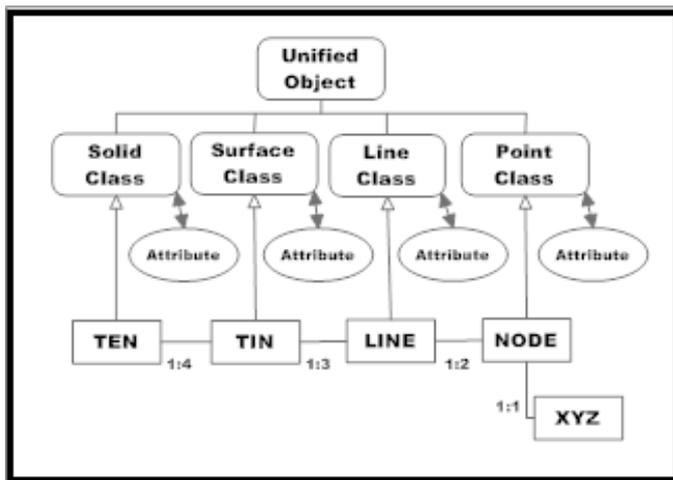


Figure 2. 3D Object Oriented Model (3DOOM)

Implicit geometry will be used to form the nodes with appropriate identifiers, the line identifier will have a beginning node and an ending node with the topological relationship of is on, is in, point and solid, line and solid, line and surface, point and surface being used to form the relationship for the unified model. The TEN is formed by four nodes, six lines and four triangles, to form solids for both the surface and subsurface.

Above surface objects include buildings and city furniture which could be made up of trees, lamp posts etc, on surface objects are composed of the terrain model, landuse and land lots or parcels. Objects below the surface will constitute geology and man-made objects such as parking areas, storage facilities, tunnels, rail lines, basements etc. Buildings are 3D objects above the surface, humans and other living things use above surface objects as places of abode, work, storage, car parks and for other activities. A building consists of facades from all the sides, the roof and its footprint which intersects the terrain model and can be represented from LoD0 to LoD4 as described by Kolbe (2009). Figure 3 is the UML diagram for the top object classes in 3DOOM.

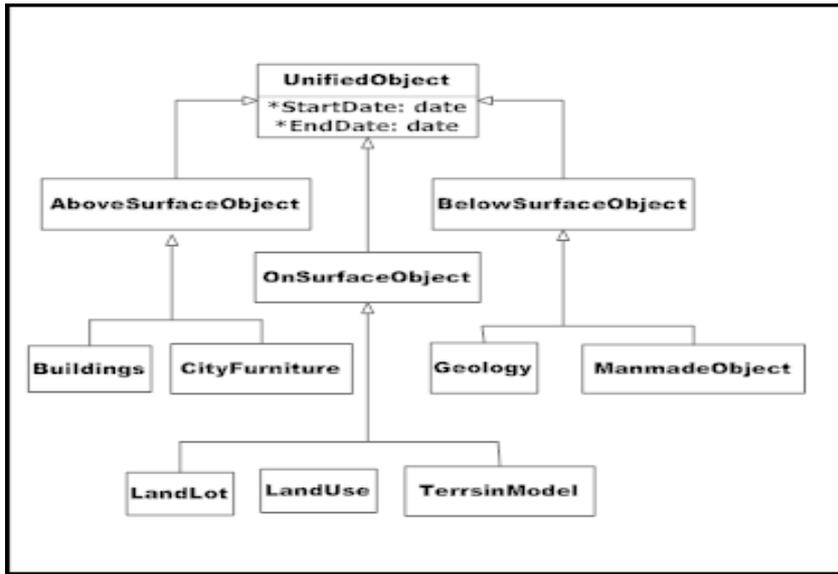


Figure 3. A UML diagram for the top classes in 3DOOM

According to Emgard and Zlatanova (2007) city furniture refers to city lampposts, traffic indicators, bus stops, large floral decors, benches, telephone booths, fences, advertisement signs which are basically man-made. Below surface objects are man-made open spaces below the earth's terrain which may be extended basements, tunnels, railway tunnels and stations, shops, parking lots, underground storage areas, mine shafts, drives and stopes.

4. METHODOLOGY AND RESULTS

The methodology adopted in achieving the concept discussed, was the development of codes using Microsoft Visual C++ version 2010, OpenGL libraries as the graphical user interface (GUI), the workflow is shown in Figure 4.

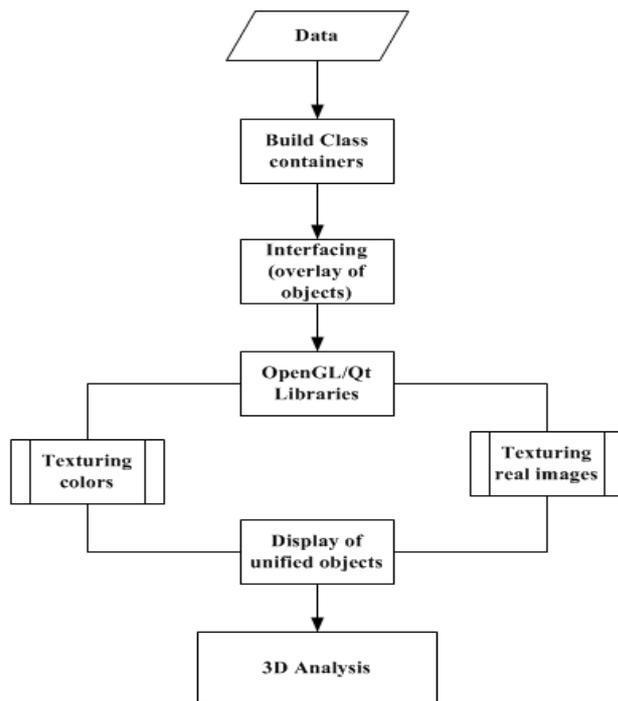


Figure 4 Workflow for the unified model

The unified model was generated using implicit geometry from Computer Aided Design (CAD) data into a process algorithm from which class containers were built as a dynamic link library (DLL) and interfaced using visual c++ codes and graphic libraries for the display after colour texturing.

4.1 Results and Discussions

The unified model for two complex man-made constructions are shown in LoD 1. Figure 5 is where a complex building with an underground parking area has been modelled using implicit geometry. Figure 6 depicts a complex building with a road under the building and a below subsurface man-made construction such as a rail system.

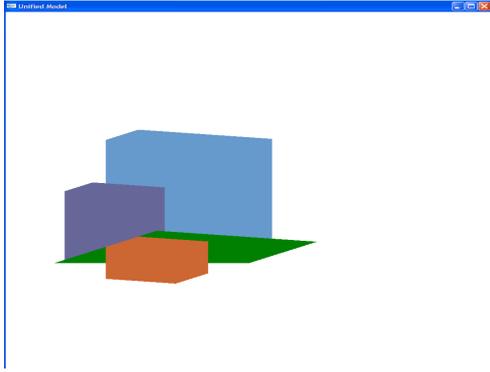


Figure 5 A complex building with subsurface parking area

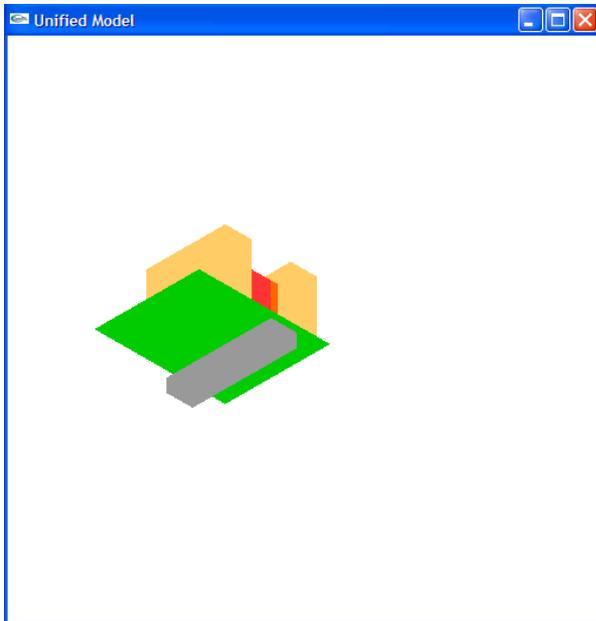


Figure 6 A complex building with a rail system underneath

5. SUMMARY AND DISCUSSIONS

The city surface is currently very complex to define as it actually blends with the above, on and below the city Earth surface, hence the current city Earth surface is actually an amalgamation of natural, man-made objects above, on and below the city Earth surface.

According to Isikdag (2010) Building Information Models (BIM) has more advantages over CAD data for the formulation of 3D city models. Hence BIM data will be incorporated in other simulations. 3D subsurface models have been studied and investigated for the past two decades with many of these models on stand-alone interfaces for various applications. 3D TIN has been adopted as the underlying model for most of the models used for the subsurface.

Unified models in the area of above surface objects and below surface geology has been studied. The concept for a new unified model seeks to enhance this further by incorporating the above surface objects and below surface geology and man-made objects which are naturally part of the complex city Earth surface. The UML diagram seeks to show this conceptual idea and shows the top classes of 3DOOM.

The model presented will be further investigated and made more practicable. The topology and computations of the model is sound (Penninga et.al., 2006; Emgard and Zlatanova, 2008). The practicality of this data will be tested in a database using explicit data types, Another challenge will be the implementation of the unified data model as a geometric model or a topological model or both (Verbree and Zlatanova, 2004). This will further be enhanced by looking at the applicability of including the semantic model as well. Finally the applicability of the model generated will be applied in the areas of 3D analysis for cities, 3D cadastre and 3D mining.

6. CONCLUDING REMARKS AND FUTURE DIRECTIONS

An in-depth review of current surface and subsurface models showed that the concept of 3D FDS has been enhanced in various applications for 3D GIS with 3D TIN being adopted or used in a hybrid model for most applications for the city Earth space.

The 3DOOM will be made practicable in a database using Oracle 11g. The UML top class hierarchy has been developed, the subclasses will be developed to show the development and implementation stages for the proposed unified model.

The city surface is currently very complex to define as it actually blends with the above, on and below the city Earth surface, hence the current city Earth surface is actually an amalgamation of natural, man-made objects above, on and below the city Earth surface and a detailed knowledge for such man-made objects are required by city planners, engineers and architects.

3D TIN has been applied for most research involving above, on and below feature objects and the enhancement of this model in order to finally realise a functional 3D GIS platform should be intensified.

Unified models in the area of above surface objects and below surface geology has been studied. The concept for a new unified model seeks to enhance this further by incorporating the above surface objects and below surface geology and man-made objects which are naturally part of the complex city Earth surface. The UML diagram seeks to show this conceptual idea and shows the top classes of 3DOOM.

Current integration techniques for the surface and subsurface objects are related to geology, geotechnical and hydrogeology considerations, the addition of man-made features at the

subsurface will complete the complexity of the city Earth space for above, on and below the terrain surface to address the effective management of most cities. The algorithm for the unified model if adopted will make information readily available to city authorities and help avert disasters should they occur.

6.1 Future Directions

The unified model will be improved in the areas of 3D topology and 3D analysis. Real textures to show the combination of LoD 3 for above surface and LoD 4 for below surface objects is on-going. An algorithm to fully integrate the above framework in a database will be part of the next phase of this research. The automatic integration of BIM data into 3D GIS will be considered as part of the next phase.

Finally the applicability of the model generated will be applied in the areas of 3D analysis for 3D buildings, 3D cadastre in city modelling.

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