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SOURCES OF SPATIAL DATA IN THE PROCESS OF 3D MODELING OF BUILDINGS IN ACCORDANCE WITH THE CITYGML STANDARD

Magda Pluta

Summary

3D models of buildings play an important part in spatial management. There are many sources of spatial data based on which 3D modelling Eis possible, but the selection of the most appropriate source should result from the level of detail of the 3D rendering that we are aiming for, and the intended purpose of using the resulting 3D model. The paper discusses the most important data sources – from the point of view of 3D rendering of buildings in accordance with the CityGML standard – and that includes: airborne and terrestrial laser scanning, aerial and ground photogrammetry, as well as vector data accumulated in the BDOT10k database.

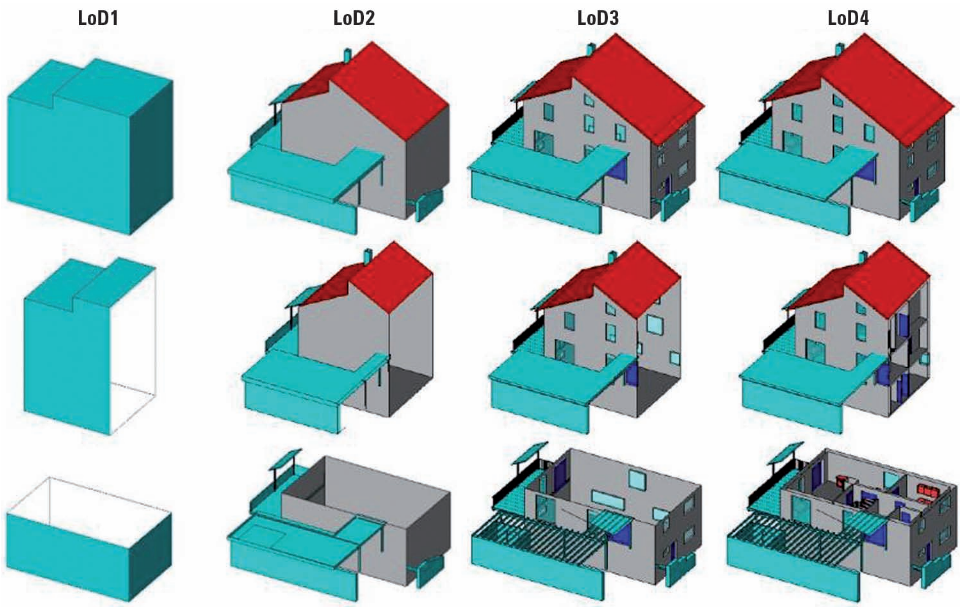
Keywords

CityGML • spatial data • 3D modelling

1. Introduction

3D models of buildings are constructed on the basis of two-dimensional and three-dimensional spatial data from various sources, among which the following deserve our special attention: airborne and terrestrial laser scanning, aerial and terrestrial short-range photogrammetry, as well as vector data collected in generally available, public databases. These methods primarily differ among each other in the way the data is obtained and processed, and also in the level of detail and in accuracy, which determines their suitability for specific 3D modelling purposes. Each of the methods can be supplemented by architectural documentation of building objects, although, as noted by Eckes [2009], the said documentation may vary depending on the age, function, building regulations, or the condition of the built structures concerned; or even it may not exist at all.

For the 3D modelling of buildings, the *CityGML* standard was introduced, which – as noted by Jędryczka [2009] – is the standard for presenting, storing and replacing three-dimensional models of virtual cities and terrain, and it was created in response to the growing demand for a uniform standard of constructing 3D models. According to Jędryczka, one of the most important features of the *CityGML* standard is to determine the semantics, geometry and topology of the modelled objects, as well as to maintain the relationship between semantics and geometry. The semantics consists in defining and describing elements of a building such as a wall, a window, a room, and establishing relationships between them. The geometry clearly determines the position of these elements in the three-dimensional space, while the topology ensures the surface continuity of the model [Open Geospatial Consortium 2012]. Cisło-Lesicka et al. [2014] explain that, according to the *CityGML* standard, the representation of buildings has a semantic-geometrical-topological character, which means that each building possesses descriptive attributes as well as specific geometry in the form of boundary surfaces, within the specific topology. According to the pertinent documentation [Open Geospatial Consortium 2012], *CityGML* distinguishes four levels of detail resulting from the data source and software capabilities in the field of 3D building modelling (Figure 1).



Source: OGC City Geography Markup Language (CityGML) Encoding Standard

Fig. 1. Levels of detail of 3D models of buildings according to the CityGML 2.0.0. standard. The level of LoD1 is the least detailed, while the level of LoD4 denotes the most detailed 3D model

LoD1 (Level of Detail 1) includes buildings with geometry of cuboids, without distinguishing the shape of the roofs; LoD2 comprises buildings with geometry of cuboids and the differentiation in the roof geometry; LoD3 presents the exact geometry of the walls and the roofs, while distinguishing elements such as chimneys, windows, or doors; whereas LoD4 complements the LoD3 model by additionally including the interior of the buildings. Furthermore, textures are allowed at any level of LoD detail. Each level of detail is typified by specific model accuracy and a specific degree of generalization (Table 1). Moreover, according to Jędryczka [2009], the ability to present a given object at various levels of detail constitutes a characteristic feature of the standard.

Table 1. Requirements for 3D models depending on the given Level of Detail (LoD)

	LoD1	LoD2	LoD3	LoD4
rendered area	region, city	city, district	district, building compounds	single buildings
class of accuracy	low	average	high	very high
precision of 3D point location (position/altitude)	5 m /5 m	2 m /2 m	0.5 m /0.5 m	0.2 m /0.2 m
generalisation	> 6 × 6 m /3 m	> 4 × 4 m /2 m	> 2 × 2 m /1 m	generalisation concerns structural elements
building installations	not included	included	included	included
roof structure	flat	geometry diversification	realistic form	realistic form
protruding roof elements	not included	included, if such elements exist	included	included
street furniture	key elements	prototypes	realistic models	realistic models
vegetation, single objects	key elements	prototypes, higher than 6m	prototypes, higher than 2m	prototypes
vegetation cover	area > 50 m × 50 m	area > 5 m × 5 m	< LoD2	< LoD2

Source: OGC City Geography Markup Language (CityGML) Encoding Standard

Table 2. Classification of spatial data sources depending on the Level of Detail (LoD)

Level of Detail	Data source
LoD1	Airborne laser scanning (standard I), vector data from BDOT10k
LoD2	Airborne laser scanning (standard II), aerial photogrammetry
LoD3	Terrestrial laser scanning, terrestrial photogrammetry
LoD4	Terrestrial laser scanning, terrestrial photogrammetry, or the two methods combined

Source: author's study

According to the *CityGML* standard, there are 4 levels of detail in 3D building models, each characterized by a specific model geometry, model accuracy, degree of generalization or scale of presentation, whereas the choice of the appropriate LoD should depend on its purpose and on the intended applications [Cisło-Lesicka et al. 2014]. Before commencing the process of 3D rendering of buildings, it is necessary to assess the suitability of a particular data source in the context of accuracy requirements of the given Level of Detail (Table 2), as well as with the view to the ultimate purpose of the rendering exercise.

2. Sources of spatial data for Level of Detail 1 (LoD1)

Three-dimensional models of buildings, expressed at the level of detail LoD 1, can be rendered based on vector data collected in the BDOT10k database, or on point clouds acquired by the airborne laser scanning method in standard I. BDOT10k collects information about topographic objects, including: spatial location of objects, object characteristics, cartographic codes as well as metadata (Dz. U. 2010 Nr 193, poz. 1287. Art. 3), which according to Świtała et al. [2012] makes BDOT10k one of the most important elements of the national spatial information infrastructure system. Pursuant to the provisions of the Geodesic and Cartographic Law (Dz. U 2010 Nr 193, poz. 1287), one of the data sources for the needs of BDOT10k is the Register of Lands and Buildings (EGiB, Dz. U. 2010 Nr 193, poz. 1287. Art. 7 pkt 1) in which, pursuant to article 20 points 2 of the aforementioned Law, information about buildings is collected in terms of location, purpose, utility functions, and general technical data. Furthermore, for both the buildings constituting a part of the land, and for separate objects of ownership, the EGiB provides information on the number of above-ground and underground storeys (Dz. U. 2013, poz. 1555. Art. 63 pkt 1 i Art. 64). By applying the spatial data collected in BDOT10k, it is possible to develop 3D models of buildings with the lowest level of detail, in the form of cuboids, where the accuracy of situational and altitude positions results from the accuracy requirements for construction objects and equipment included in group 1 (Dz. U. 2011 Nr 263, poz. 1572), and is not less than 0.10 m for situational position (Dz. U. 2011 Nr 263, poz. 1572. Art. 29 pkt1), and 0.05 for altitude position (Dz. U. 2011 Nr 263, poz. 1572. Art. 36 pkt 1).

The three-dimensional building render at the level of detail LoD 1 can also be obtained based on the point cloud acquired from an airborne laser scanner in standard 1. According to the ISOK project assumptions, the density of the point cloud in this standard equals 4 or 6 points per 1 m^2. The situational and altitude accuracy of the cloud point is affected by the accuracy of the system's components, including the laser range finder, the inertial INS navigation system determining the angular orientation of the impulse, and the GPS system determining the position from which the impulse was sent. Furthermore, the position error of the laser point will be indirectly affected by the diameter of the laser spot and the type of surface being scanned as well as the associated reflection level. Distance measurement error is estimated within the range of 0.02–0.03 m, the position measurement error within the range of 0.05–0.07 m, while the ultimate altitude error of laser points is estimated at the level of 0.15 m, and situational error, within the range of 0.4–0.5 m. Depending on the method of measurement, in the case of buildings, only roofs are registered [Borowiec 2010], which is a significant limitation in the context of the needs of 3D modelling of urban built environment. Some authors describe the ways of interaction between three-dimensional data and two-dimensional data [Marjasiewicz and Malej 2014; Tack et al. 2012]. As reported by several authors [Vosselman and Dijkma 2001; Haala et al. 1998; Tack et al. 2012], one of the methods of automatic wall extraction consists in combining 3D information on roof geometry obtained from the point cloud with 2D information about the contours of the buildings acquired from the map. Based on the intersection of the roofs, along with the rendering of the 3D contour of the building, a 3D model is created, where the density, altitude and situational error of the point cloud, as well as the precision of vector data, affect the accuracy. Models at the LoD 1 level, due to their low accuracy and a high degree of generalization, can be used for general visualizations or basic spatial analyses, such as assessing the impact of the height of the planned buildings on the general city horizon, as well as analyses of insolation, noise pollution, or environmental contamination.

3. Sources of spatial data for Level of Detail 2 (LoD2)

In order to construct 3D models of buildings at the level of detail LoD2, it is recommended to use spatial data obtained by means of aerial photogrammetry or airborne laser scanning in standard II. According to Kurczyński [2014], for the purpose of spatial rendering of the city model, a set of topographic photographs is used, with either vertical or nearly vertical orientation of the camera axis, geometrically tied in, in the process of aero-triangulation, to photo-points constituting the photogrammetric field matrix. The accuracy of aerial photographs depends on the parameters of the photogrammetric flight, as well as the accuracy of implementation in terms of navigational tolerances. According to Kurczyński [2014], the accuracy of situational and altitude measurements depends on the scale of the photographs, moreover, in the case of altitude development, it also depends on the base height ratio. The situational error of the study is inversely proportional to the scale of the image, while the altitude error is directly proportional to the scale of the study. It is assumed that the larger the scale of images, the higher the accuracy of the study, which involves the need to take more pictures, and also a greater financial investment. Ultimately, the accuracy of aerial photographs is also influenced by the accuracy of the photogrammetric flight, in particular regarding the maintenance of the designed flight altitude, maintaining a levelled camera, as well as triggering the camera in the right places so as to preserve the photographic coverage. Based on aerial photographs, it is possible to construct approximate 3D models of urban built environment. As reported by Kwoczyńska et al. [2009], based on the flight stereogram, it is possible to determine the coordinates (x, y, z) of the points describing the structure of the roof, and then, by using available CAD software, to render building walls based on the course of the edge. According to Ulm [2003], for 3D modelling purposes, aerial photographs are taken on a 1 : 5000 scale with 60% longitudinal coverage, which provides altitude accuracy of 20 cm. 3D renders of the built environment obtained in this way include a roof model that takes into account the slope of the roof, some larger details such as projections, as well as approximate course of the walls, without the possibility of recognizing any architectural details.

For the purpose of 3D modelling at the level of detail of LoD 1, airborne laser scanning is also used successfully, where point clouds have a density corresponding to standard II in accordance with the ISOK project classification. The density of point cloud at the level of 12 points per 1 m^2 enables the modelling of roofs, taking into account the slope of the roof and larger architectural details, provided that the altitude accuracy of the cloud points is no less than 0.1 m. Due to the fact that the point cloud allows rendering of roofs, while limiting the data for wall rendering [Marjasiewicz and Malej 2014; Tack et al. 2012] indicate the possibility of integrating three-dimensional data with two-dimensional data stored in the spatial databases.

4. Sources of spatial data for Levels of Detail 3 and 4 (LoD3 and LoD4)

For 3D rendering of buildings at the level of detail of LoD 3 and LoD 4, it is recommended that either terrestrial laser scanning or digital terrestrial photogrammetry be used. As a result of the measurement by a terrestrial scanner, a high resolution cloud is obtained, which institutes a true reflection of the building's geometry [Borkowski and Jóźków 2012], where the accuracy of the point location for both the impulse method and the phase method, depending on the adopted measurement parameters, remains within the range of 0.5–1 cm. Restrictions on the use of terrestrial laser scanning result from the nature of the measured object, in particular the building materials used, as the latter directly affect the accuracy of measurement. An additional disadvantage of terrestrial laser scanning is the lack of accurate spatial information on the roof geometry, hence, for high-rise buildings with low-grade roofs, there may be a need for integration with data from aerial laser scanning [Borkowski and Jóźków 2012]. According to Borkowski and Jóźków [2012], the point cloud from terrestrial laser scanning, due its high resolution, is a good reflection of the actual conditions. According to Nabbout [2012], a colour point cloud is particularly useful for spatial planning, in which the RGB values for each point have been assigned to digital photos taken with a digital camera integrated with a laser scanner. High density of point clouds, as well as the real colours, facilitate the recognition of the smallest architectural details, while the software available on the market for data post-processing makes it possible to generate 3D visualization in the so-called "bird's eye view" [Nabbout 2012], and from the level of a pedestrian's line of sight. In addition, due to the high accuracy of point clouds, it is possible to dimension urban built environment without the need to conduct field studies. According to Vatan et al. [2009], the capabilities offered by terrestrial laser scanning significantly exceed the possibilities of traditional methods for obtaining three-dimensional data, where the main advantage of TLS (Terrestrial Laser Scanning) against the TotalStation method is the ability to record the full geometry of the object, and not just certain selected, typical points.

Terrestrial photogrammetry is based on terrestrial images, whereas the latter, as a result of the development of photographic technologies, are obtained in digital form, using non-metric cameras for the purpose. Due to the common accessibility, as well as the relatively low cost of non-metric cameras, they are successfully employed, in short-range photogrammetry in particular, while the photographs obtained using this technique constitute a valuable source of data for the 3D rendering of architectural objects [Kwoczyńska and Rzepka 2013; Kraszewski 2011]. According to Kraszewski [2011], non-metric cameras can be used in short-range photogrammetry, provided that it is possible to manually set the focal length of the lens, which will ensure the invariability of internal orientation elements when taking the photographs. In addition, Mitka [2013] indicates the need to calibrate each body of the camera with a lens for a given shooting distance, and points to the condition of repeatability of internal orientation elements, which consist in maintaining the internal orientation elements each time the camera is turned on / off, and each time a lens is changed. Current legal regulations in the field of photogrammetry do not regulate issues related to obtaining terrestrial images, and the practice indicates that the measurements are made on the basis of analogies with airborne projects, while the accuracy requirements and the scope of studies are determined on the basis of the conditions set by the contractor [Mitka 2013]. According to Mitka [2013], the basic parameter defining terrestrial photogrammetric project is the terrain size of the pixel of the photographs, which determines the shooting distance for a given digital camera. In addition, the terrain pixel size determines the terrain coverage of a single image, which can be calculated either as the product of pixel size and matrix dimensions expressed in pixels, or as the product of the denominator of the image scale and matrix dimensions expressed in millimetres. For the purposes of vector documentation of objects, it is recommended that normal photographs are taken [Kraszewski 2011], with an area pixel size of 2 mm, with a minimum transverse coverage of 30%, and a minimum longitudinal coverage equal to 60% [Mitka 2013]. In addition, taking into account the elimination of dead fields and optimization of the number of images taken, it is important to choose the right arrangement of photos – either vertical or horizontal, adapted to the geometry of the subject.

According to Chmielewski and Szulwic [2005], the quality of results depends on the correct calibration of the non-metric camera. For the needs of spatial planning, non-metric photographs are mainly used to render 3D models of architectural objects. 3D modelling of architectural objects using a non-metric camera can be performed based on two approaches – the accurate photogrammetric approach, and an approximate approach based on perspective images of the object. According to Kwoczyńska and Rzepka [2013], the photogrammetric development of the 3D model involves several stages, and it is preceded with a non-metering camera calibration process, as opposed to perspective modelling, which results in an approximate, non-metric 3D render of the object. The 3D model developed photogrammetrically, in terms of cartometry, can be used for spatial measurements, whereas in the case of a model developed on the basis of perspective photographs, it serves only a visualization function.

5. Conclusions

When setting out to create 3D models of the built environment, it is necessary to first determine the purpose for the subsequent use of these models, because this will determine the level of detail that the models should possess, and thus the source of spatial data, based on which the said 3D models will be rendered. The 3D models with the level of detail of either LoD1 or LoD2, due to their low accuracy and high degree of generalization, can be used for general visualization, or for basic spatial analysis. For their construction, it is recommended to use point clouds obtained by means of airborne laser scanning, aerial photographs, or vector data collected in the BDOT10k database, although when we take into account 3D modelling speed, airborne laser scanning enjoys an advantage compared to other methods of spatial data acquisition. 3D models of buildings with the level of detail of either LoD3 or LoD4 accurately represent all architectural details, in addition to the main body of the building, and point clouds from terrestrial laser scanning or photos acquired by a non-metric digital camera can be successfully employed in their construction. According to Mitka and Pluta [2016], 3D rendering based on data from terrestrial laser scanning is faster than in the case of modelling based on terrestrial images, and the resulting 3D model is more accurate, in particular for homogeneous surfaces such as buildings' walls. Due to the large size of spatial data, 3D models with the level of detail of LoD3 and LoD4 are created for smaller building compounds or individual objects, and they are used for architectural valorisation of the landscape, or for detailed spatial analyses such as for instance the insolation of relevant external and internal parts of the building.

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Dr. Inż. Magda Pluta
Uniwersytet Rolniczy w Krakowie
Katedra Geodezji Rolnej, Katastru i Fotogrametrii
30-198 Kraków, ul. Balicka 253 a
e-mail: magda.pluta@outlook.com