Visualisation of DSM as 3D-Mesh for Urban Analyses

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Abstract. The study focuses on the application of the Digital Surface Model (DSM) for the visualisation of a city and urban analyses. The DSM is a cloud of points on a regular mesh derived from the airborne scanning (ALS/LiDAR). The accessibility of data is growing and the production cost decreasing. The current scanning precision is sufficient to present buildings including architectural details in the scale needed for urban analyses. Although the DSM can be easily presented at the cloud of points, it is insufficient to make full visualisation of a city and a number of urban analyses. To this end, it is necessary to be able to examine visibility while taking into consideration that facilities may obstruct each other views. In this context, the paper introduces a method of geometric representation and computation of DSM as full 3D-mesh. Key issue is the huge size of such a model, which is a challenge for processing. Results possible to achieve are discussed and they are compared with other types of models (like CityGML, reality-mesh-models). The research was implemented based on software (C++) developed by author. It enables to process areas of the city up to 180 km^2 in DSM resolution (50 cm grid) for the purpose of urban visualisation and various urban analyses.

Keywords: Airborne LiDAR scanning · DSM · 3D-Mesh · City visualization Digital urban analysis · Urban design

1 Introduction

The possibility for 3D city modelling has significantly improved in the past two decades. Still in 2008, the model of Manhattan (NY) in Google Earth was a set of grey boxes imaging building facilities. Now, we can see realistic images of the cityscape in all major cities in Europe and in the world. The number of models has been steadily growing, and the same applies to their resolution and number of interfaces (from smartphone to VR [1]). However, reality-mesh-models [2] presented, inter alia, at the Google Earth platform are inaccessible for urban planning and are used for visualisation only.

Five criteria are decisive regarding the possibility of using a model for urban analysis and designing and spatial planning. First, it is the accessibility of the resource —in other words the availability of data for research and analysis or designing, as well as the cost of licence and data availability time. Second, it is the data structure which

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should be adjusted to specific needs (different for CityGML, LiDAR and DSM). Third, it is the completeness of city imaging—or the completeness of the model as regards all or selected elements of the city space. Four, it is the possibility of processing of the model, e.g. imitations due to the shortage of appropriate software. Urban development necessitates to update 3D models periodically. Five, it is the validity of data, or whether the model reflects the current status of the city and possibility of integrating updates. Selected types of city models in use are discussed in the further part of the article (Chapter "Geometry and Graphics for the Graphic Identity of a Conference on Geometry and Graphics: About the ICGG2018 Conference Logo").

As regards criteria mentioned above, the most important ones are the availability of models, their completeness and structure (including precision of city imaging). DSM models selected provide for quite precise imaging of the city space and by definition they are always complete. The cloud of points covers the entire city space at the same resolution. The most important advantage of DSM models is their availability. For instance, in Poland (in result of ISOK project [3]), DSM models have been developed for all major cities at the 50 cm mesh. Data are available free of charge for research purposes and are relatively cheap for commercial projects (cost of 1 km^2 DSM is about 0.50€). It is, however, difficult to use DSM in urban analyses for studying visibility. This is possible once we provide a geometrical interpretation of the DSM model as a continuous 3D-mesh, which is the main goal of the method presented in this article. Results are discussed in Chapter "Rational Estimates for Irrational Problems: Proportional Geometry in the Work of Leonardo da Vinci".

2 Brief Typology of 3D-City-Models

2.1 CAD-Models

The possibility of spatial city modelling appeared with the introduction of CAD. In 1980s and 90s, it was practically the only form of a digital 3D urban visualisation. At that time, the Internet was fledgling and interactive 3D city images (today it is possible using e.g. Google Earth) seemed to be a mere utopia. Some of the challenges included computing power and availability of spatial data (e.g. height of buildings). Remote detection techniques were still too imprecise for urban/architectural analysis. An example of the model of Szczecin, Poland, of 2005 is included in Fig. 1 [4]. Nevertheless, city modelling in the CAD environment is still used, e.g. for the presentation of the context of buildings planned. The main drawback of such models is the disparity in modelling and data exchange.

2.2 CityGML

An attempt of overcoming data exchange barriers and standardisation of 3D model is to use the CityGML format (Fig. 2a). The is the prevailing format in the majority of European countries, and elsewhere in the world. With the introduction of CityGML, the 3D city model has become independent of any software, in a similar manner as JPEG in 2D graphics. The idea developed already in 2003 [5]. Today, CityGML enjoys the

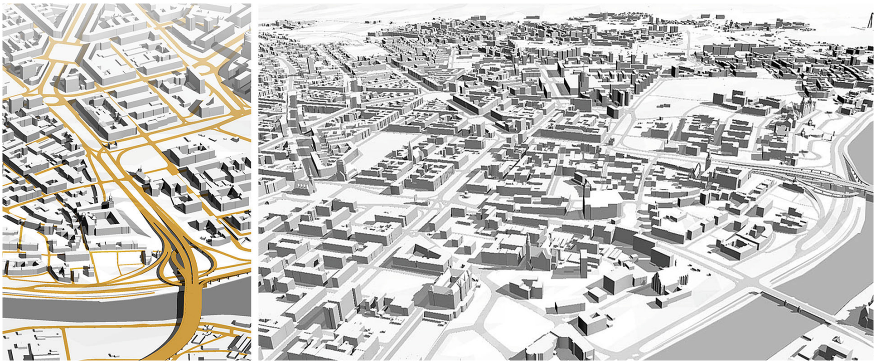

Fig. 1. Model of Szczecin (Poland) developed by author with others in 2005 in Autodesk AutoCAD. The model contains about 15000 buildings, terrain arrangement and streets.

status of an international data exchange format. It is supported by OGC (Open Geospatial Consortium) and is in line with ISO standards [6] and the European INSPIRE Directive. CityGML has introduced 3D model resolution standards in a four stage LoD (Level of Details). It covers various classes of facilities (e.g. buildings, water, tunnels, bridges). Data are organised hierarchically, and geometrical information (shape of facilities) is linked with their significance (information about facility)—data semantics. In the case of CityGML data, a frequent drawback is the incompleteness of the model, which means that not all elements of the actual city space are reflected.

2.3 LiDAR and DSM

Another form of recording a 3D city model is LiDAR, a technique that has been developed for a number of years. Remote detection techniques have rapidly evolved, data acquired have become more precise, and processing cost reduced. LiDAR is usually a basis for developing CityGML models, including automatic generation [7, 8]. A derivative data is the DTM (Digital Terrain Model) which provides the image of the terrain and the DSM (Digital Surface Model) reflecting land configuration, buildings, trees, etc.

LiDAR data at 12 p/m2 enables to develop a DSM model based on the 50 cm mesh. The DSM of such resolution is sufficient to enable the imaging of architectural facilities including roofs, tall components, and chimneys (Fig. 2b). The disadvantage of the resource is the lack of data semantics and consequently the lack of a simple method to separate specific components. An advantage is the completeness of data—or even, objective and full presentation of the urban development in a model.

2.4 Reality Mesh Models

As regards city modelling, the development of photogrammetry was also very important. The latest technique, used for automatic creation of 3D city models for the past 10 years, is the use of oblique high resolution aerial photographs (pixel < 10 cm).

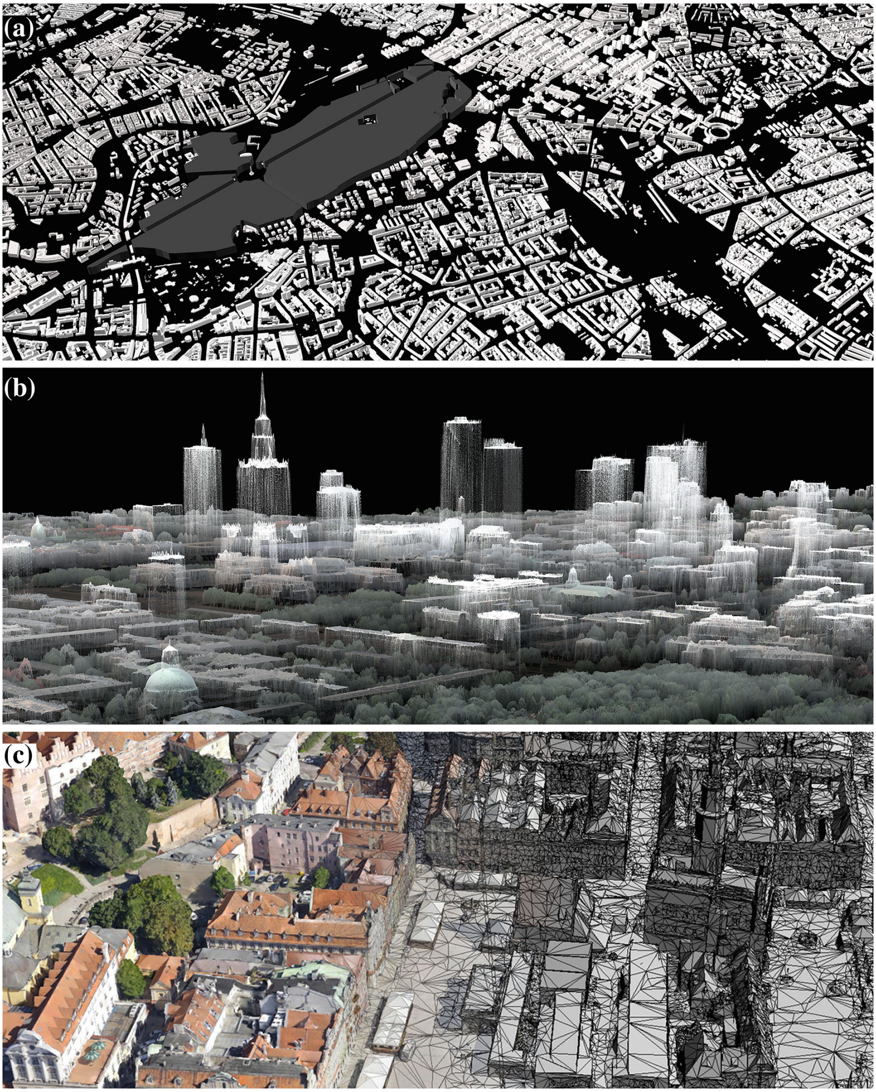

Fig. 2. Different types of 3D city models: **a** CityGML of Berlin (without textures), **b** DSM of Warsaw, **c** sample of a virtual-reality-mesh. *Source* **a**, **b** by author, **c** MGGP Aero [11].

Complex algorithms usually based on five oblique photographs (and also LiDAR) are used to develop the reality-mesh-models [2, 9–11]. The 3D model obtained is used inter alia by Google Earth. The model consists of a 3D-triangle mesh, and its texturing using aerial photographs gives realistic image (Fig. 2c). The basic disadvantage is that data are inaccessible for urban planning and analysis.

3 Application of DSM

3.1 Data & Geometric Structure

As regards the geometrical structure and data organisation, the Digital Surface Model (DSM) is the simplest form of city space imaging. The DSM (like DTM) results from the processing of the cloud of points obtained by LiDAR. The process changes an irregular mesh of points into a regular one. Noise and certain small objects, which are not permanent components of the city space, are eliminated, e.g. cars in streets. This leads to a set of data having an elementary simple structure. The DSM is most frequently recorded in the ESRI-ASCII format covering: coordinates of mesh corners, number of points (x) and (y) in a mesh, resolution (cell size) and list of heights—or (z) values for consecutive points. The 2D DSM visualisation as a raster map and the DMS structure as a 3D-mesh are presented in Fig. 3.

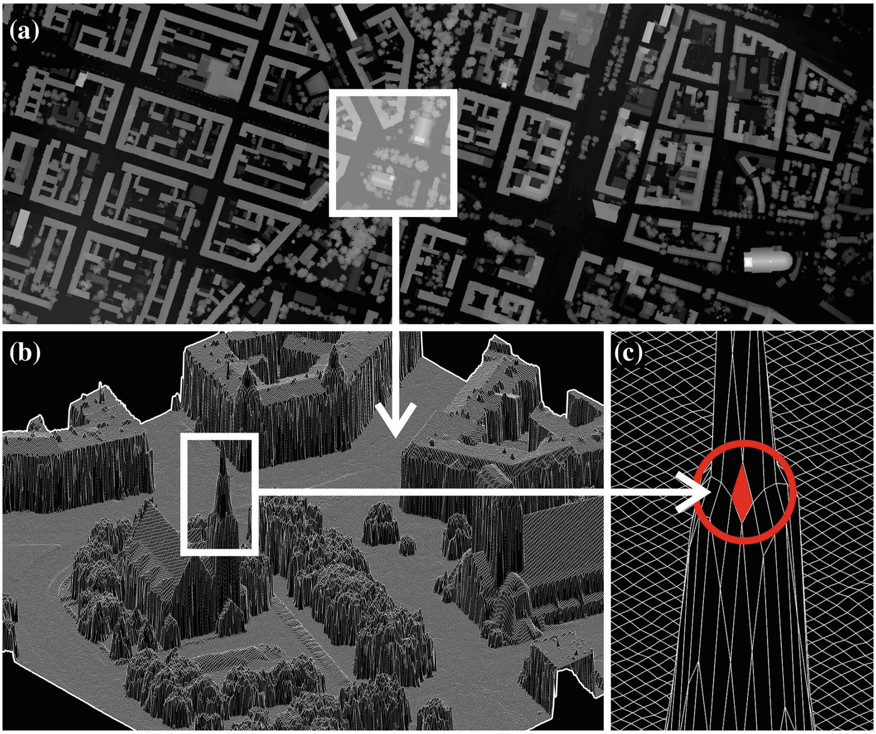

Fig. 3. DMS as a 3D-mesh: **a** visualisation as a raster map, **b** part of Szczecin 200 × 200 m as 3D-mesh, **c** zoom with a single cell (50 × 50 cm). *Source* by author.

3.2 Visualisation

The resolution of the DSM model is crucial for city imaging, designing and urban analysis. The higher the resolution (cell size smaller), the more precise city imaging is provided by the model. It seems that the threshold is the 50 cm cell size. The DSM model of such a resolution reflects bodies of buildings and their architectural details. At the same time, it covers all other elements of a city, including tall green which is important for visualisation and for urban analysis alike.

The simplest form of DSM visualisation is the 2D raster map, where heights of particular points are expressed in colour or shade of grey (Fig. 3a). The result can be recorded e.g. as JPEG or TIFF. Files are relatively small in size and can cover fairly large sections of a city. However, we cannot see space. Another way is the direct conversion of the DSM model to the CAD vector model (Fig. 3b). Then, we can see space, but such a presentation is effective for smaller sections of a city (approx. 200 × 200 m), and in the case of larger ones it become illegible and there are problems with data processing.

Another way of the visualisation is the DSM imaging as a cloud of points, as it is done with LiDAR data. In such an instance, we can easily observe large sections of a city (Fig. 2b). However, there is a problem with reflecting building facades, which in the DSM are not included. It is also not possible to provide analysis of vistas and the visualisation which takes into account that one facility may obstruct the view of the other.

According to the method presented, the DSM model is treated as a 3D-mesh, like in reality-mesh-models. Such an interpretation of the model facilitates a complete study of visibility. Additionally, the use of the DTM model enables to determine the height above ground, and it can be expressed by using, for instance, different shades of grey (Fig. 4b). Facades can be reflected by analysing the inclination of the mesh to make the image more vivid (Fig. 4c). The use of the orthophotomaps ensures better identification of space (Fig. 4d).

3.3 Computation Aspects

The processing of the DSM model as a complete 3D-mesh necessitates using relevant computer algorithms. The main issue is the size of data which is much larger than in the case of reality-mesh-models. Each square kilometre of the 50 cm mesh DSM model includes 4 million points (8 million triangles). At the same time, the fact that points are fitted into a regular mesh enables to use a hierarchical division of the model into sections (bounding boxes). This significantly expedites calculation. In practice, the speed depends more on the complexity of the city space rather than the resolution and size of the DSM model. This bodes well for the application of more precise DSM models, e.g. 0.25 m mesh size. Simulations presented in the article have been creates using software developed by the author (C++). At the current stage, it enables to visualise sections of a city up to 180 km^2. A section of Szczecin presented in Fig. 5 covers approx. 25 km^2.

3.4 Urban Analyses

The visualisation of a city is only the simplest way of using the 3D models. However, solutions presented used for visualisation may also be applied for urban analysis and spatial planning. The assessment of visibility of points in the city space is a common

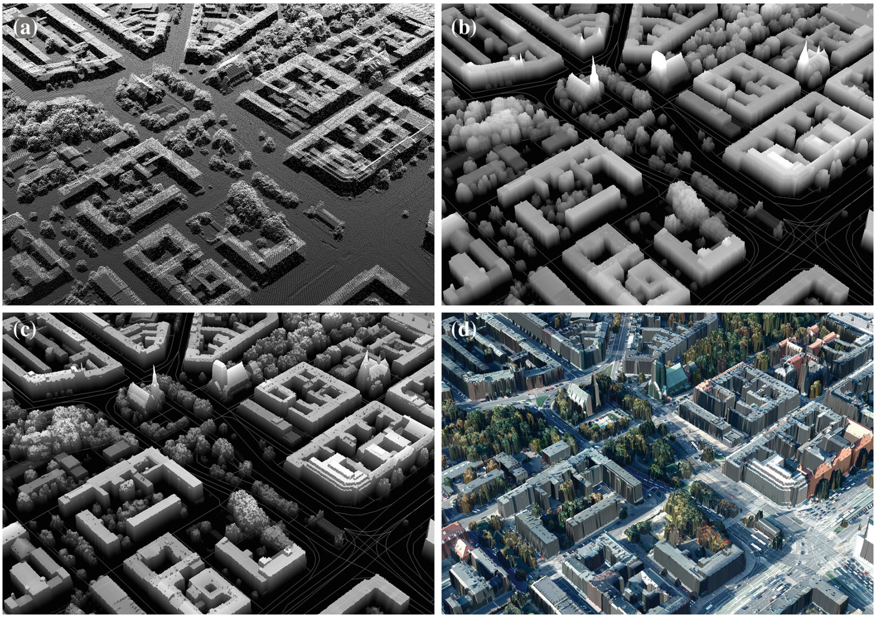

Fig. 4. Consecutive steps of DMS visualisation: **a** as a point cloud, **b** continuous surface with heights of objects, **c** detection of facades, **d** use of the orthophotomaps. *Source* by author.

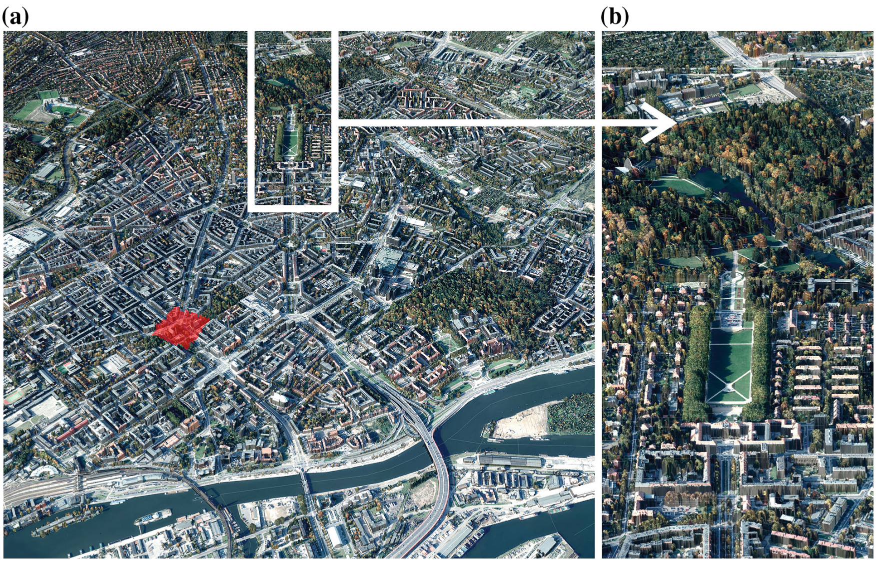

Fig. 5. Visualisation of Szczecin (Poland) based on DSM as 3D-mesh: **a** ca. 25 km^2, **b** zoom. A red mark is an area shown in Fig. 2b (200 × 200 m). *Source* by author.

component for a number of analyses, e.g. sun exposure and shade [12], optimised location of PV panels [13] and tall building impact [14]. DSM models can be used for the implementation of the Visual Impact Size (VIS) analysis [15, 16]. The latter enables to identify all locations in a city from which a given facility can be seen and to assess its exposure. The VIS method and based on DSM are used for urban planning, and the first such project was developed in 2015 [17]. The DSM presented as a 3D-mesh can be a basis for the Visual Protection Surface (VPS) application. The method defines maximum permitted height of a building in a city considering the need to protect panoramas, urban and landscape interiors [18]. Examples of VIS and VPS simulations are included in Fig. 6. The analysis emulation process is much more complicated than the visualisation of a city. Instead of several seconds or minutes (as it is needed to visualisation), it sometimes takes dozens of hours. It is, however, based on an analogous form of using the DSM as a complete 3D-mesh.

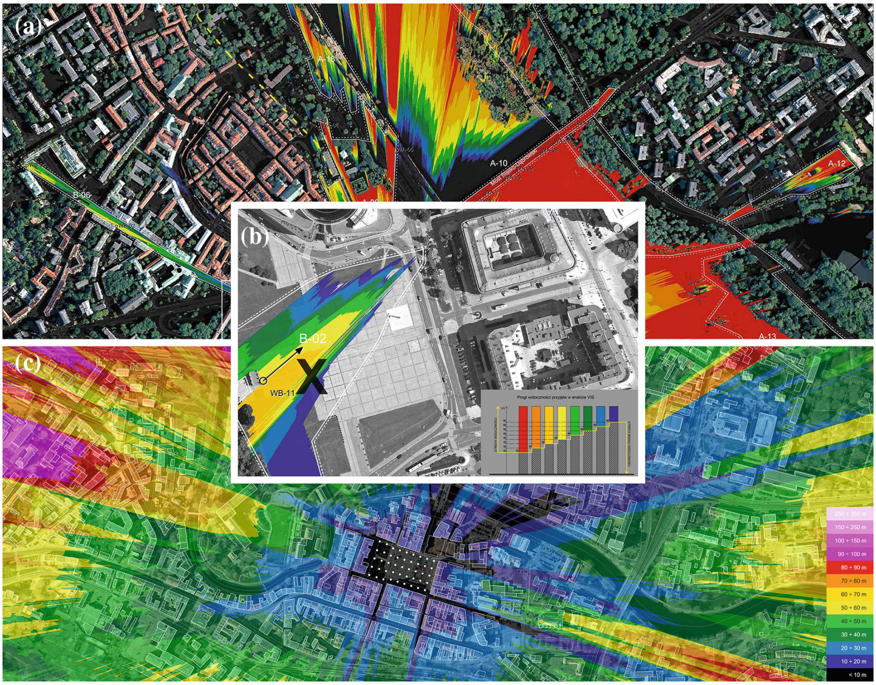

Fig. 6. Examples of urban simulations made using DSM as 3D-mesh: **a**, **b** VIS simulation for Warsaw. **c** VPS simulation for a main square in Bydgoszcz (Poland). *Source* by author.

4 Conclusions

The study presents possibilities of using DSMs (Digital Surface Models) for the 3D visualisation of urban structure. It also shows examples of using the DSM for specific urban analyses. In both instances, it is necessary to have the possibility of providing full examination of visibility.

The method is based on a geometrical interpretation of the DSM model as mesh-3D (with full DSM resolution). On the one hand, the major issue is the huge volume of data (much larger than in reality-mesh-models or CityGML). On the other hand, the regular arrangement of DSM points enables to use algorithms promoting favourable calculation speed (wider discussed in Sect. 3.3).

Visualisation results seem to be satisfactory, in particular for large city areas. To make the image more vivid it is good to reflect building façades (by analysing inclination of DSM mesh) and using orthophotomaps. In the case of smaller city areas, DSM-based visualisations cannot compete with Google Earth reality-mesh-models in which we can see building facades.

However, in urban planning, the visualisation is merely the simplest form of using the 3D model. The method using the DSM model as 3D-mesh can be applied to a more advanced urban analysis. The article provides examples of the DSM model application according to the above formula to analyse a cityscape based on the Visual Impact Size (VIS) and Visual Protection Surface (VPS) methods.

The article points to several criteria for the assessment of the model when used in urban planning. There, one of DSM advantages is the availability of data and complete imaging of the spatial city structure. Visualisations and simulations presented in the article have been created using software developed by the author (C++). They use 50 cm mesh-based DSM models. The research was in part conducted within 2TaLL research project [19].

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