Application of Available Digital Resources for City Visualisation and Urban Analysis

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The article presents two methods for generating 3D city models. The methods are based on LiDAR and GIS-2D data. The first one enables to create automatically simplified city models that include buildings in the LoD1 standard (excluding roof geometry). The second one provides for generating precise 3D city models including all components of the city space, such as buildings, tall green, city infrastructure. This involves direct transformation of DSM (Digital Surface Model) data as mesh-3D. The analyses presented are based on data available in Poland (in particular GIS). The results of the study can be easily applied for analysing other cities in Europe and elsewhere in the world. The article presents possibilities of using such models to urban analyses. The methods and figures included in the article have been developed using C++ software developed by the author.

Keywords: airborne LiDAR scanning, Digital Surface Model, BDOT 10k, city visualization, digital urban analysis, urban design

RESEARCH AREA & RESEARCH GOALS

The research area discussed in the article covers the use of various 3D data for visualisation of the city for the purpose of urban planning, basic and advanced urban analyses and visualisation of their results. Currently available input data include, inter alia, vector 3D models, semantic models, e.g. CityGML, ‘virtual-reality-mesh’ models (known from Google Earth), clouds of points from aerial scanning LiDAR and their derivatives such as DSM (Digital Surface Model) and DTM (Digital Terrain Model), ground scanning data, street view pictures, and digital GIS 2D resources.

The availability of data necessary for the above mentioned applications as well as their quality vary in different countries of the world. In Western Europe and in many other countries, CityGML (Kolbe and Gröger 2003; Kolbe 2009) is the official standard which covers a detailed description of the city space. In practical terms, the data resources are often incomplete and concentrated chiefly on buildings. Poland is one of EU member states having a high potential for implementing advanced 3D applications, since the country has a full LiDAR high quality data (as of 2018) for all cities (Kurczyński and Bakula 2013). For this reason, the scope of the study focused on using data resources developed in Poland. Nevertheless, the analyses also have a universal dimension applicable in other countries of Europe and in the world.

Research presented in the abstract aimed at the following:

1. Possibility of automatic generation of
CityGML LoD1 models for Polish cities using DSM, DTM and BDOT10k (GIS 2D);
2. Possibility of 3D visualisation of cities and advanced urban analyses based on DSM and DTM using 10cm ortophotomaps models;
3. Assessment comparing the efficiency of the above solutions for the purpose of urban planning, architectural design a cityscape development.

The research was implemented based on experience in creating 3D city models and C++ software developed by the author of the article, which enables to process CityGML models and LiDAR data. The software was used to provide advanced urban and landscape analyses for the purpose of urban planning by the team headed by the author and covering several cities in Poland and Germany.

**DIGITAL RESOURCES AVAILABLE IN POLAND AND IT’S EVALUATION IN EUROPEAN CONTEXT**

In recent years, the development of IT technologies, landscape remote detection techniques, photogrammetry and geo-information studies opened new possibilities for the generation of 3D city models. The process can be now implemented faster, cheaper and it can be fully automated (Isikdag and Zlatanova 2009). Finally, while using Google Earth we can view landscapes in the majority of agglomerations in the world, including all major cities in Europe. Not only has the number of models been growing, but also their precision (higher degree of reality) and the number of interfaces that enable to view virtual city models. A factor determining the possibility of using 3D data in scientific research and designing is their availability. The virtual-reality-mesh data (Cousins 2017) [1, 2, 3] presented, inter alia, at Google Earth, are virtually inaccessible for urban planning and they are used for visualisation only. Although, the EU INSPIRE Directive requires all EU member states to facilitate access to spatial data, the degree it has been implemented in those states vary.

In Western Europe, CityGML (City Geography Markup Language) (Kolbe 2009) is the applied and available standard for recording city models. According to the standard, data are independent from their environment, have identical structure for each city and are recorded in the text format (strict XML, GML). The structure of files can be viewed using an ordinary text editor. CityGML enables the following: a) recording the geometry of a city in the form of surface vector model; b) describing mutual relations and hierarchical dependencies between model components (data semantics); and c) good link with GIS resources. CityGML covers various classes of objects that can be presented at a different level of details (LoD). In practice, a frequent drawback of CityGML models is that they are incomplete (partial projection of all spatial elements of city). However, from the point of view of their architectural application, an advantage is their good conversion to CAD.

In Poland, CityGML models are still under implementation. The situation may change, however, in 2018. The CAPAP programme [4] intends to create CityGML models for all cities in Poland; However, the models will include buildings generated in the LoD2 standard. A digital resource which is exceptional in Poland comparing to other European countries is aerial scanning (ALS) and high resolution ortophotomaps. The ISOK (Kurczyński and Bakula 2013) project has already generated DSM models for all major cities in Poland using a 50 cm mesh and 10 cm ortophotomaps. Data are available for free for scientific purposes and relatively cheap for commercial applications (cost of 1km2 DSM is about 0.50€).

The DSM (Digital Surface Model) is a cloud of points on a regular mesh derived from the aerial scanning (ALS/LiDAR). It is a set of data of an elementary structure and a huge size. Considering resolution available in Poland (50cm), DSM enables to develop images of architectural facilities while taking the geometry of their roofs into consideration, together with high rising components and chimneys (figure 1). The drawback of the resource is that it does not have data semantics and, consequently, a sim-
Figure 1
DSM (Digital Surface Model) of Warsaw in a quality available for all major cities in Poland (50cm grid)

ple possibility of separating specific components of a city. An advantage of the resource is its completeness - in other words equal, objective and complete coverage of 3D urban substance of a city in the model.

Yet another resource available in Poland is BDOT10k (Chałka et al. 2011). It includes GIS 2D data covering the entire country and all cities. Although ‘10k’ means theoretical precision corresponding to the scale of 1:10000, in fact data are much more precise. This applies in particular to buildings, silhouettes of which are reflected with maximum precision. BDOT10k includes a number of various layers. Additional information is available for various categories of objects. In the case of buildings, they refer to the function of a facility, number of floors and historical value.

RESULTS: DEVELOPED METHODS & PROVIDED SOFTWARE SOLUTIONS
The research discussed in the article proposes two options for the use of digital data in the 3D city visualisation and in architectural design, urban planning and landscape development. Although proposed solutions are adjusted to data available in Poland, methods and software used are universal and can easily be converted to other digital resources.

**Creation of CityGML LOD1 models using DSM, DTM & BDOT10k**
The first of the two solutions is to use LiDAR and BDOT10k data to develop models made to CityGML LoD1 standard and their transfer to the CAD environment to be used by architects and urban planners. The LoD1 3D (Kolbe 2009) model covers bodies of buildings only. It neglects the geometry of their roofs, protruding components and other architectural components as well. The basis to determine the third dimension of a building based on BDOT10k data is to calculate height attributes. The research adopted the calculation of height parameters using DSM and DTM models. It is crucial, de facto, to determine two figures for each facility: a) foundation coordinate, b) height above ground level. The analysis focuses on all DSM and DTM points within the envelope of a building.

The software developed enables automated development of 3D LoD1 models and their visualisation. The final result can be described in the CAD format (e.g. DXF) which covers: a) LoD1 models of buildings, b) land configuration model made to required precision level, and c) vector outline of other BDOT10k data fitted into 3D land configuration (figure 2).

The basis of LoD1 is to calculate height attributes. The more precise the parameters, the closer is the LoD1 model to the actual 3D structure of a city. The application of DSM data gives much opportunities
for precise calculation of an average building height. bdot10k 3d-cad explorer software was developed to support the application of the method. The principle of developing such models has been described in greater detail in a separate article (Rubinowicz 2017) [5].

According to objectives of the method, the resulting 3D model needs to be as simple as possible, and its structure needs to be easily processed in the CAD environment. Such models can be applied, among others, to imaging of the spatial context in architectural and urban projects, analysing the height structure of the city, and examining urban parameters, e.g. development intensity. They can also be used for a more advanced urban analysis in which the simplification of the 3D city model is used (Zwoliński 2014).

**Application of geometry of DMS as a mesh-3D**

The second solution the article proposes is to use full geometry DSM as mesh-3D. LiDAR and DSM data can be easily visualised as a cloud of points. Thus, we can observe contours of buildings, green and other spatial components of the city. There are also a number of programs that can develop a simplified visualisation. However, this is insufficient for the complete visualisation of the city. For this purpose and to provide advanced urban analysis, it is necessary to ensure the possibility of precise examination of vistas including effects of obstructing the view by certain facilities reflected in the model.

The DSM triangulation to mesh-3D is an extremely simple task. The cloud of points can be easily converted to a vector model (by connecting neighbouring points with triangles). However, a key issue is the huge size of such a model, which is a challenge for processing. To reach high fidelity of 1 km² of the city using DSM at the quality available in Poland we need as much as 8 million triangles, which is incomparably more than in reality-mesh-3D or CityGML models (Cousins 2017) [3]. For the desired efficiency of calculation, it is necessary to apply relevant recurrent algorithms and on-the-fly triangulation. The software enables to process large areas of the city (up to 180 km²) in full DSM quality for the purpose of urban visualisation and analysis.

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 like 50cm grid). To increase visualisation quality of valuable data is provided by DTM (Digital Terrain Model). DTM enables to determine the height above ground, and it can be
expressed by using, for instance, different shades of colours. Facades can be reflected by analysing the inclination of the mesh to make the image more vivid. Finlay, application of orthophotomap ensures better identification of space. The result of visualisation of a city based on application of proposed method is shown below (figure 3).

DISCUSSION: EVALUATION & APPLICATION OF RESULTS

Methods presented in the article use LiDAR data (in particular DSM, DTM), GIS 2D data (BDODT10k) and aerial photographs (2D ortofotomaps). Thus, we obtain two kinds of models: a) simplified vector model in line with the LoD1 standard, including bodies of buildings without roofs, b) precise model based on DSM data interpretation as 3D-mesh that covers all spatial components (buildings, trees, infrastructure, land etc.). The precision of city imaging is not decisive regarding the applicability of the model. Depending on planned applications sometimes complete and other times general reflections of the city are more appropriate.

In the case of the first method, we obtain a simplified image of the city in line with the LoD1 standard. The intention of the solution proposed in the article is to create possibility of creating a model in a speedy, totally automated method which is fully in line with the GIS2D resource. Input data include 2D outlines and DSM cloud of points. A similar solution is used, inter alia, in British OS MasterMap Topography Layer (Ordnance Survey 2016). Contemporary studies on geometry of buildings based on LiDAR data are much more advanced from those proposed in the article. Software developed [6] facilitates the reconstruction of buildings in the LoD2 standard (including geometry of roofs). However, the process is not fully automated and some facilities (ca several percent of them) need to be corrected (Xiong et al. 2013). In the case of larger city areas, this necessitates much effort. The process is also directed on examining the geometry of buildings and instead other components of the city are neglected, e.g. tall green.

In the case of the second method (DMS as a mesh-3D), we obtain a full picture of the city, which is developed while taking into consideration of all components of space. The result can be confronted with virtual-reality-mesh models [3]. The technique involved is based on inclined aerial pictures of high resolution (usually <10cm pixel size) and additional LiDAR data. The model is developed automatically by complex algorithms that require major computing capacity and, in practice, requires the use of supercomputers. This produces full and plastic image of a city which we may admire, inter alia, using Google Earth. The idea of virtual-reality-mesh, however, is dedicated solely to visualisation, in particular in online services, as well as in VR (Käser et al. 2017). Source data are inaccessible which excludes their application for analytical purposes and designing. Their geometrical precision is difficult to assess. Undoubtedly, the number of triangles reflecting the city space in the virtual-reality-mesh is much smaller than in the case of direct DSM triangulation. It also seems that the reflection of the tall green in DSM is much more precise.

The visualisation of the model is the simplest form of its application. For analytical purposes, it is necessary to have full access to source data, including the use of their structure and GIS data. The first of the methods that enables to create 3D models in the LoD1 vector form can be used, for instance, with the application of the “3D negative” (N3D) method (figure 4b). The intention of the method (Zwoliński 2014; Zwoliński and Rubinowicz 2016) is to reflect space in between buildings and the analysis of its parameters. In this particular case, the reduces precision of the model is favourable. The second method (DMS as a mesh-3D) is provides a good basis for cityscape and landscape analyses, e.g. Visual Impact Size (VIS) (Czyńska 2015) (figure 4a), Visual Protection Surface (VPS) (Rubinowicz and Czyńska 2015), and Visual Exposure Map (VEM) (figure 4c). The resulting model enables visual impact assessment of buildings (VIS), planning of the cityscape protection measures (VPS), and the identification of strategic vistas in the city.
(VEM). Examples of urban analyses developed using 3D models based on methods presented in the article are presented in figure 4.

CONCLUSIONS

The article proposes two options of using a combination of LiDAR and GIS data for the purpose of architectural design, urban planning and landscape development: a) minimum - LoD1 simplified image of city, and b) maximum - full 3D representation of city based on DSM.

The first option (see section Creation of CityGML) refers to the creation of CityGML LoD1 models. Such a simplified image of the city can be used, interalia, to visualise an urban context for planned spatial transformation. The model can be easily imported to CAD. The software is going to be made open source. It can also be used for the CAAD education.

The second option (see section Application of geometry of DMS) applies to the full precision imaging of the city structure in line with the DSM model. The complexity of the model excludes the possibility of processing it by the standard CAD program. However, the software presented in the article enables to use data for visualisation of cities and various urban analysis.

Solutions and simulations presented are based on data available in Poland. This applies in particular to LiDAR data which are developed in Poland with the highest possible precision for all major cities. Status and quality of digital resources that enable to develop 3D models has been steadily growing globally. In this context, the study presented are universal and can be adapted to analyses in other countries.

REFERENCES


Cousins, S. 2017, ‘3D mapping Helsinki: How mega digital models can help city planners’, Construction Research and Innovation, 8:4, pp. 102-106


Figure 4
Application of proposed methods in urban planning:
a) simulations of Warsaw panorama from one of strategic view identified using VIS (case study from 2015; Marzęcki, Czyńska, Rubinowicz, Zwoliński);
b) 3D-negative (N3D) method for Cracow (compare: Zwoliński and Rubinowicz 2016),
c) application of VPS method for protection of the main landscape interior of Central Cemetery in Szczecin.

Ordnance Survey, 2016, OS MasterMap Topography.


[1] https://www.youtube.com/watch?v=suo_aUTUpps
[5] https://www.youtube.com/watch?v=sB_Avequwws