Visualization of Spatio-Temporal Building Changes Using 3D Web GIS

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Abstract. Modern laser scanning methods and photogrammetric techniques provide tools for rapid data acquisition and semi-automated 3D scene construction. The common access to measuring sensors allow building digital representation of scanned objects relatively easy. This enables the construction of photorealistic building models and complex GIS/BIM models. Recently, increasing number of government departments and local councils trying to use 3D models as part of their planning, development, promotion strategy can be observed. To date, there is no universal, low-cost methodology that will allow visualizing changes of building facades using the Internet. The article presents a study which explored the possibilities of building a web application to visualize the changes in the buildings with the use of 3D models. It allows to integrate current three-dimensional models with those based on historical data. An interactive web application presenting the spatio-temporal changes of buildings in two study areas was presented (campus of the University of Warmia and Mazury and the Old Town of Olsztyn). The proposed architecture is low-cost and easy to implement. The content displayed on the map is determined by the timeline slider, which allows presenting changes in the building facades over time. Each building has its own attributes, some of which also have one or more 3D models. In the end, the potential stages of the system's development were presented, including the possibility of participating volunteers in the process of obtaining historical data and using the Augmented Reality to present 3D models of the buildings directly in the field.

1. Introduction
The use of mobile devices and applications has increased dramatically over the last decade. In 2014 for the first time in history, there was more mobile than standard desktop PC users. Since that, a growing number of tasks are carried out with the use of modern Internet browsers and mobile devices. The significant technological progress had provided intuitive and innovative ways to design web/mobile solutions. Modern standards such as HTML5 and WebGL enable three-dimensional scenes to be visualized on phones and tablets. [1]

The technologies for creating digital models have undergone an impressive evolution. Traditionally visualization of buildings has relied mostly on drawings, photographs, and charts. Later they were based on 2D plans and elevations. The impact of modern measurement technology caused the rapid evolution
of new techniques and tools. Today users tend to use 3D models, GIS or BIM models, Virtual and Augmented Reality.

The virtual model is a valid tool to interact with 3D models and agents in a virtual environment. It provides realistic scenes and allows to simulate the natural evolution of sites. Virtual Reality (VR) technologies and Augmented Reality (AR) is now commonly employed in the field of architecture design, civil engineering, urban planning, cultural heritage, tourism, and others. An increasing number of government departments and local councils are using virtual 3D city models as part of their planning, development and promotion strategy.

Preparing complex model is still an open challenge. Depending on the application, a different methodology is applied. In the commercial domain Global Navigation Satellite Systems (GNSS) surveys, Terrestrial Laser Scanning (TLS), Airborne Laser Scanning (ALS), Mobile Laser Scanning (MLS), aerial and terrestrial photogrammetry had been in use for many years [2]–[5]. In the scientific world, the use of scanning and photogrammetric methods has been often employed, especially in archaeological and Culture Heritage fields [6]–[8].

In the archaeological and Culture Heritage applications modelling stage is carried out increasingly using a concept of Historic Building Information Modelling (HBIM) introduced by Murphy et al. in 2009 [9]. The authors presented the methodology for historic structures modelling from laser scans and photogrammetric data using Building Information Modelling system. This concept was later improved by integration of HBIM and 3D GIS analytical tools [10], 3D city modelling standards, cloud computing [11] and Augmented Reality [12].

Based on literature Virtual Archaelogy is mainly used for two purposes [13]

- as a means of dissemination, usually associated with small objects or structures, where the user is invited to manipulate the objects remotely;
- as a tool for the reconstruction of objects and structures.

The second option is related to the term Virtual Heritage [14]. This definition assumes that hypotheses about past cultural environments cannot adequately be tested using static two-dimensional (2D) images and lengthy descriptions alone. The author suggests that there is no better way to absorb complex datasets about the past than visually, interactively, and in 3D, just as we do in real life. Words are good; words and diagrams are better; linked databases and interactive 3D worlds are better yet.

2. Methodology

Modern laser scanning methods and photogrammetric techniques allow for quick data acquisition and semi-automatic construction of 3D scenes of entire areas. These enable achieving better management, research, protection, and promotion of places and cities. To date, there is no universal methodology for using historical data to reconstruct the building facades and visualize them using the Web.

Many studies have quantified analyzing the usefulness of laser scanning, photogrammetry, and surveys. Most of them were based on commercial and proprietary software. These solutions offer strong opportunities for creating, analyzing, and visualizing 3D models but are very demanding for the server and client configuration. The hardware requirements limit resource availability and significantly reduce the potential audience. Only a few research demonstrate advantages of web platform [15]–[17].

This study presents the reliable methodology of fast creation of a web application, based on an interactive map and utilizing 3D models of buildings for the spatio-temporal changes visualization of urban construction changes. The presented solutions are a compromise between traditional solutions based on photorealistic models without the capability of analysis and advanced, professional BIM/GIS systems using fully vector 3D models.
Figure 1 lists the source data and methodology used for raw data processing and 3D model preparation. At first, a list of potentially useful methodologies for building modelling was analyzed and applied (historical data collection, city plans and old pictures, up-to-date data, orthophotomaps, topographic and historical maps, raw measurements, and data from terrestrial and aerial laser scanning). Next, the collected data were registered and processed. In the following step modelling was conducted. In the end, two different methodologies were used to share data on the Web. The first method based on authors solution allowing to visualize temporal changes of building facades on the 2D maps and 3D building models for selected objects. The second method is based on popular commercial ESRI city engine interface. Easily to deploy using GIS models.

![Flowchart of the adopted methodology.](image)

2.1 Study area
The research was conducted on two selected objects located in the city of Olsztyn. The first one is a market square located inside the Olsztyn Old Town. The second is Kortowo - the University of Warmia and Mazury in Olsztyn Campus area (figure 2).

Olsztyn is a city on the Łyna River in north-eastern Poland. It is the capital of the Warmian-Masurian Voivodeship and is a city with county rights. The most important sights of the city include the marketplace with medieval Old Town and the Olsztyn Cathedral, which dates back more than 600 years. The picturesque market square is part of the European Route of Brick Gothic. The marketplace is surrounded on all four sides by the frontage of XVIIth and XVIIIth century tenement houses (with arcades on three sides). After the damage caused by the Second World War, these houses were rebuilt in a different shape and usually made higher by another storey, giving them Baroque features and decorating them with modern ornaments[18].
The University of Warmia and Mazury in Olsztyn is situated in a picturesque part of Olsztyn – Kortowo. Kortowo occupies an area of 230 hectares and is surrounded by forest and 4 lakes. On the campus area, there are teaching buildings, sports fields and recreation areas, swimming pool, 10 dormitories, shops, services, sports stadium, medical center, cafeterias, banks, post office, student clubs, parks and greenery and space with well-developed infrastructure, including modern laboratories, lecture halls, research facilities [19].

2.2 Custom-made Web based platform – case study UWM Campus
The possibilities of developing a web service for visualizing spatio-temporal changes in the building structures were tested on the UWM Campus area called Kortowo. A large number of buildings and many changes that have taken place over the last few decades are a good area of test the web service illustrating the history of the Kortowo.

The main result of the work was the interactive web application. The proposed solution shows a thematic map with a layer of buildings in the campus Kortowo. Every object has attributes with information about the year of construction and recreation. The range of content displayed on the map is determined by timeline slider. There are visible only buildings whose year of construction is located within the indicated time range. Figure 3 presents sample buildings constructed between 1900 and 2015.
The raw data presented in figure 1 were edited in QGIS desktop GIS software. After processing stage, the three-dimensional visualizations were made in the Trimble SketchUp based on historical plans and photos. Up-to-date models were created based on photogrammetric data and point clouds from TLS measurement campaign. In the end, all 3D models were exported into COLLADA (COLLaBorative Design Activity) format and saved as dae (digital asset exchange) files.

The proposed platform is based on HTML and JavaScript language. To develop the platform the following Application Programming Interfaces (APIs) have been used:

- CartoDB.js,
- jQuery,
- Three.js.

The sample visualization of temporal changes for selected Faculty of Geodesy, Geospatial and Civil Engineering building is presented in figure 4.
2.3 ESRI city engine – case study Old Town

In the second experiment, ESRI's City Engine package was used to visualize 3D models. City Engine is a stand-alone software product that provides professional users in architecture, urban planning, entertainment, simulation, GIS, and general 3D content production with conceptual design and modelling solution for the efficient creation of 3D cities and buildings [21].

The raw data listed in figure 1 were edited in ArcGIS Pro software. The three-dimensional buildings from Old Town area were built using Trimble SketchUp. The up-to-date 3D models were created on the base of photogrammetric data and point clouds form ALS. The past models are a historical reconstruction of the buildings. They were created on the base of old photographs and other sources from the thirties of the 20-th century. The main object of the marketplace is the building of the Old Town Hall. The sample view of the Old Town in the thirties is presented in figure 5.

![Figure 5. Old Town – reconstruction of building facades based on historical photos.](image)

3. Results and discussions

The main objective of the research was to develop a methodology for the creation of 3D building models (both current and historical) and their visualization with the use of web platform available for normal users. The result of work is the application hosted on a server of Institute of Geodesy in Olsztyn. The website is available at http://budynki.kgsin.pl/. At this moment the application includes more than 200 buildings with ten 3D models of five buildings. All of them have 3D models: before and after the renovation. The sample visualization of temporal changes for selected Faculty of Geodesy, Geospatial and Civil Engineering building was presented in figure 4.

The process of creating historical models with the use of plans and historical photographs is well described in the literature [22]–[24]. The basic problem is to find the required number of materials (plans, photos) in the quality to reproduce the appearance of the building for a specific period. The conducted tests have shown that there are many sources and materials which make it possible to prepare models of buildings. The development of 3D building models for specific time periods allowed for the analysis of changes in time and their visualization with the use of a user-friendly, easy to implement web solution.
Creating models based on up-to-date data is well explained in the literature [25], [26]. The common access to modern measuring sensors which generate mass data allows building digital representation of scanned objects relatively easy. This enables the construction of both photorealistic building models and complex GIS/BIM models. The professional 3D models that meet strict scientific standards have the important drawback of being hard to manipulate, because of the amount of information associated with the files. The conducted works showed that it is possible to make high-quality historical models using tools available to any user, visualize them and compare with up-to-date models using Web (figure 6).

![Figure 6. Temporal changes of Old Town Hall (on the left – version built in the second half of the 14th century, on the right up-to-date version).](image)

Traditional virtual city models rely on 3D models. The complexity of this models and problematic process of creating them caused that this is a time-consuming challenge. VR applications are known for their realism and high interactivity. On the other site they have high hardware requirements. Due to a big number of possible hardware devices and software development kits they are also hard to implement as a web platform.

Classic two-dimensional visualizations do not allow users to have a good perception of buildings changes during the time. Due to the complexity, the solution with virtual models not always is an optimal choice. In the literature, Remondino points out that despite the intensive work there is no available powerful, reliable and flexible commercial package with expected functionality [6]. Geospatial web-services (e.g., Google Earth, MS Bing, NASA World Wind) have very limited capabilities in handling complex 3D data. The existing on the market development tools for 3D geo-data processing and sharing using Web-based solution (Unity3D, OSG, OGRE3D, OpenSG, 3DVIA Virtools, etc.) have limited capabilities in loading and displaying large geometric 3D models.

4. Conclusions
The main objective of the present work was to describe the simple methodology to visualize temporal
changes of faced buildings. The proposed solution constructed and implemented by the authors allow to analyse and visualize temporal differences.

In the first case study, a custom-made technical solution was developed. The system allows to visualize the spatio-temporal changes in the buildings on the 2D map, choose an individual building and examine the three-dimensional changes on the model. In this solution, great emphasis was placed on the flexibility, intuitive and easy-to-use interface. The built environment is a universal solution working both on mobile devices and on the Web. In the second solution, new three-dimensional building models were developed and shared using ESRI’s City Engine commercial software. This solution allowed an attractive presentation of 3D models and changes in the building facades over time. It has also included several additional tools for their later analysis.

The works showed that is possible to create dedicated solutions based on widely available, often free software. The first solution confirmed to be much more flexible. It has more options and can be easy to extend. The second solution is dedicated to professional engineering applications. It is based on a commercial solution, which makes it necessary to purchase a license and limits the possibilities of expanding.

The next challenge for research should be the transition from the concept of web platform into user-friendly network services. The results of the case studies here examined could be a starting point for a shift from traditional closed solution towards 3D publicly available service. It will allow presenting spatio-temporal changes in buildings structure using 2D map, 3D models and directly in the field using Augmented Reality.

A key factor in the development of the platform is the access to historical three-dimensional building models. The ability to involve normal users in the construction process may allow extending the amount of data. Many people have the resources to recreate a building. The construction of a web platform, which will allow adding photos and automatically process them to build a 3D model, will be one of the future directions of research.

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