The Comparison of the Web GIS Applications Relevant for 4D Models Sharing

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Abstract. The paper presents results of the project: Cultural Heritage Through Time (CHT 2, http://cht2-project.eu/) realized accomplished within the framework of the "Joint Programming Initiative in Cultural Heritage" JPI-CH (http://www.jpi-culturalheritage.eu) by an international consortium: Politecnico di Milano (IT), Newcastle University (UK), Salamanca University (ES), and Stanislaw Staszic Scientific Association SSSA (a non-profit organization), (PL). The aim of the project was the integration of 3D models of buildings, cities and landscapes for monitoring and preservation of the cultural heritage. The research was conducted on three levels of detail according to the CityGML standard: LoD0 – regional, landscape scale, LoD1/LoD2 – urban scale, LoD3 – architectural scale, level of detail - building outside. Basing of this assumption, four test sites were selected: i. the city centre of Milan (IT) – urban scale, ii. the medieval walls and the historic centre of Avila (ES) - urban/architecture scale, iii. Hadrian’s Wall and its landscape (UK) – landscape scale, iv. the Fortress Cracow (PL) - architectural scale. Final 4D models were published on the Internet. The paper presents state-of-the art of the technology of 4D models sharing on the internet. 4D models were understood as 3D models solid one and point clouds changing through the time. Results of the practical initial tests of different software (commercial: Hexagon and CityEngine from ESRI and open-source: 3DHOP and Potree) are also shown. Web site: https://cht2.eu/ was created where the 4D models are placed for all the project partners.

1. Introduction

Cultural heritage may perform a significant sociological and economic function provided it will not be understood only as a unique object we are in a sporadic contact with but it will interweave with our daily lives. Following such interpretation, the "new" cultural heritage is not confined to special places but it encompasses everything that surrounds us. Such understanding of cultural heritage becomes part
of initiatives of formal, intentional nature: Faro Convention and European and Landscape Convention [1, 2] but also of those of practical nature [3, 4, 5]. The implementation of conventions' provisions is possible through various activities. Some of them concern organizational, formal and legal issues, relating to direct access to historical goods, or to those that are valuable in any sense. Another way of bringing national heritage closer to daily life is the remote, virtual access by means of various media, and, now, mainly via the Internet. The mode of reception depends on the technology applied. In the simplest case, this may be a Web page, displaying descriptive information, and e.g. photos, or films. One can say that disseminating information on cultural heritage causes it is being brought closer to the daily lives of citizens, while their social and cultural awareness gets extended. They also develop their cognitive skills. Museums or institutes that deal professionally with cultural and national heritage have discerned the significance of the Internet media. They use the Internet to publish information about resources that one can see directly. Also, special organizations and agencies: government and private ones, most often of the non-profit nature, have been established to this end. Information made available as a standard includes a description of a given exhibit, photos, scanned copies of plans, or maps [6]. For some of the museums, 3D models were built and made available on the Internet in combination with spatial data, maps, orthophotomaps, or digital terrain models [7-12]. Additionally, advanced VR (virtual reality) technologies in recent years enable, by using special goggles and other tools, an interaction between an object and the spectator, achieved through various experiences: visual, aural, smell-related, or motor ones. For a relatively small number of cases, their models in virtual reality are available [13, 14].

Summing up, one can say that from the technological point of view, supporting cultural heritage by the Internet media (making available descriptive information, images, films, etc.) poses no problem at the moment [15]. The problem arises in the course of integrating those 3D models with other spatial data: maps, orthophotomaps, and DTMs, or the so-called GIS data. Those data are made available separately for each data type, e.g. GIS data [10] 3D models [11], GIS analyses [12]. The integration of data in virtual reality is far more difficult.

The paper presents results of the project: Cultural Heritage through Time (CHT2, http://cht2-project.eu/) accomplished within the framework of the "Joint Programming Initiative in Cultural Heritage" JPI-CH (http://www.jpi-culturalheritage.eu) by an international consortium: Politecnico di Milano (POLIMINI - IT), Newcastle University (NCL - UK), Salamanca University (USAL - ES), and Stanislaw Staszic Scientific Association non-profit organization (SSSA - PL). In the paper examples of the technology of 4D models sharing on the Internet are presented.

2. Case study

The research was conducted on three levels of detail according to the CityGML standard: LoD0 – regional, landscape scale, LoD1/LoD2 – urban scale, LoD3 – architectural scale, level of detail - building outside. The location of cultural heritage objects examined under the project is presented below (Figure 1).

2.1. The city centre of Milan (Italy- IT) – urban scale

The Roman Circus in Milan. Presently, only fragments of the structure are visible: city walls tower, the Carceres tower which is again being used as a bell tower that belongs to the Monastero Maggiore monastery, as well as certain sections of walls or foundations located within the areas of private real properties, hidden inside them, or in their basements.

The historical sources report the existence of the Circus until the Longobards era. After that period, parts of the Circus were incorporated into other buildings or structures. The Circus was selected as the test object since it had perfectly been fit for the presentation of a new technology. Presently, one cannot see the Circus, and it is not known to the majority of local residents, except for experts [16].
2.2. The Medieval walls and historic centre of Avila (Spain - ES) - urban/architecture scale

In 1985, the old town of Avila (Spain) was entered on the UNESCO's list of world heritage. For purposes hereof, the medieval defence walls of the town were selected, in particular, the Alcazar Main Gate. This facility is an example of a military structure in the Spanish and Roman style, and an exceptional example of medieval European architecture. The walls served defence purposes, protected the town's community against epidemics, and enabled supervision of trade between the town and its surroundings. Access to the town is possible through nine gates, with the Alcazar Main Gate being the most interesting of them [17].

2.3. Hadrian's Wall and its landscape (United Kingdom - UK) – landscape scale,

Hadrian's Wall (AD 1222) is on the list of the world heritage since 1987. This paper deals with fragments of the Wall, two forts and one settlement: Birdoswald, Corbridge, and Beckfoot. Those areas were selected because of the presence of natural hazards in there: coast and fluvial erosions, and floods. The landscape surrounding the Wall differs considerably from that in Roman times. A large part of the Wall is still visible on the coast, and also within rural and developed areas [18].

![Figure 1. Localization of research objects (https://cht2.eu) with Google Map as a base map [19]](https://cht2.eu)

2.4. The Fortress Cracow (Poland - PL) - architecture scale.

For the needs of this paper, objects forming part of the 1st and 5th Defence Perimeters of the Krakow Fortress were selected [20-22]. This was a sector of the greatest strategic significance because of the close vicinity of the Russian border.

The objects were divided into three categories:

1) fortifications most interesting in terms of their military significance and architectural forms ("Sudół" armoured fort 47, "Węgrzce" main armoured fort 47, Bastion III "Kleparz", "Lysa Góra" artillery fort 47, "Luneta Warszawska");
2) important fortifications ("Marszowiec" artillery fort 45, "Bibice" armoured fort 45a, "Batowice" artillery fort 48, Bastion III "Kleparz", Earthwork 10, Infantry earthwork V/2),
3) other fortifications ("Kościuszko" fort).
3. Data & Methodology

For all test areas, preliminary archival research in various institutions was carried out in order to obtain archival data, e.g.: in Duque de Alba foundation (ES), local museum and municipal office in Avila (ES), in Historic England Archive (UK), University of Newcastle archive (UK). Those archival data (maps, plans, photos, drawings, descriptive documents, historic topographic and geophysical surveys etc.) were used to reconstruct the condition of objects at different times. The present-day condition of the objects was surveyed with the use of Terrestrial Laser Scanning (TLS) and Mobile Mapping Systems (MMS), photogrammetry (aerial photos, UAVs, LIDAR).

The different approaches have been used to create time-varying 3D scenarios:

1) In regional, landscape scale (LoD0 of CityGML standard) digital aerial photogrammetry and airborne laser scanning (ALS), as well the use of re-photographing techniques coupled with GIS systems, allowed the analysis of the same scenarios at different times, with the possibility of comparing image-based or ALS-based DTMs with historical maps. Using this 4D approach it is possible to highlight the transformation of a landscape thought time and to hypothesize future changes due to anthropogenic and natural factors. This type of knowledge is a key factor for all those entities (e.g. cultural, political, or administrative) responsible for managing a territory.

2) In architectural scale (LoD3) Terrestrial Laser Scanning (TLS) and close-range photogrammetry were used which allowed for detail 3D model generation and can be the starting point in object reconstruction and analysis of objects transformations through the time.

3) Urban scale (LoD1/LoD2) is between regional scale and architectural one and all mentioned above technology were applied and used in this case of a varying degree and the method was called a hybrid one.

For the purpose of visualizing the 4D models for all project partners, the web portal https://cht2.eu was created (Figure 1). An open-source Concrete5 environment was used for this purpose. During the studies the following technologies for all 3D/4D models publication were selected for testing:

- commercial: Hexagon, CityEngine,
- open source: 3DHOP, Potree, X3D.

Application TIDOP created by one of the partners (USAL) was also tested on desktop and on mobile devices. Application financed from external funds outside the CHT2 project, based on Cesium JS, an open-source JavaScript library.

4. Results

Various practical tests were conducted within the research framework concerning particular methods of publication. Hexagon Geospatial Portal was a good solution for online visualization of large city models with a generalized geometry of individual elements. However, it was not well adapted to the publication of mesh models. Another issue was the transformation of *.OBJ and texture atlas *.JPG to the internal format *.myVR, because the texture quality dropped drastically (Figure 2). CityEngine WebViewer meets all the criteria for publishing technology. In this solution, it is possible to operate on the common *.OBJ format. Another benefit is the full integration of georeferencing 3D models with orthophotomaps, numerical terrain models, and other geo-referenced data (Figure 3, Figure 4). The assumptions of the project on the publication of several time statuses of objects covered by the study are also met, thanks to the sliding view. The advantage, which is worth mentioning, is the function of lighting a 3D scene changes, dependent on the geographical location of the model with a variable time attribute. 4D models work in the WebGL standard on computers, laptops, smartphones.
(on Android and iPhone) and in all browsers. CityEngine Viewer has a unique solution for simultaneous comparison of 3D models from two time states, the ability to divide the screen into 2 parts and move the arrow of the scope of the visualized 3D model (Figure 5a, b). Despite the fact that ESRI technologies are commercial solutions, the CityEngine WebViewer browser is free, because CityEngine exports the catalogue with the scene and browser files. This data can be placed directly on the private server without the need to purchase additional licenses. Application TIDOP created by USAL: works very well on data from USAL. On mobile is limited to Android and needs special data preparation (Figure 5c).

**Figure 2.** Result of 4D model publication (LoD3) using commercial Hexagon platform: Fort Kosciuszko

**Figure 3.** Result of 4D model publication using commercial CityEngine platform: Milan – Roman Circus
Figure 4. Results of 4D models publication (LoD1/LoD2/LoD3) using commercial CityEngine platform: Avila - Alcazar Gate for time states: 1860-1882, 170-1930, 2016

Figure 5. On mobile phone; 4D models a) CityEngine Web Viewer – Fort Kosciuszko, b) Alcazar; c) TIDOP – application created by USAL (only Android)

The results obtained for publications using X3D technology were not satisfactory, both in terms of the appearance of the 3D model and the functionality of the browser. X3D requires the conversion of the 3D input model to the VRML format. This causes a significant distortion of the model geometry (Figure 6a). The restriction on the input format also occurs in the 3DHOP platform. The publication requires conversion of the 3D model to the internal *.XNS format, which causes problems with the texture. An additional limitation of 3DHOP is the lack of the possibility of publishing geo-reference base maps. The 3DHOP solution works well for small-sized objects, such as museum objects. In the case of architectural objects (CityGML LoD3), there are problems with display performance and texture. An example of the publication of the Avila model - Alcazar Gate (Spain) using 3DHOP is shown in the Figure 7.
Figure 6. The result of 3D models publication (LoD3) using the application a) X3D platform - Fort Kościuszko b) Potree - cloud points of Fort Węgrzce

Figure 7. Results of 4D models publication (LoD3) using the open-source 3DHOP platform: Avila - Alcazar Gate. Cloud points for time states: a) 1860-1882, b) 2016

The Potree application was used to publish point clouds for Fort Węgrzce (6b) and the test area Corbridge in UK (Figure 8). The Potree browser allows the integration of 3D models with GIS data and is more effective than X3D and 3DHOP. Integration of 3D / 4D models is possible at the WebGIS level, with raster base maps shared as OpenLayers (e.g. Google Maps, OpenStreetView), with its own cartographic layers (e.g. a historical map or archive orthophotomap) and active vector objects i.e. with the ability to read the table attributes containing information about objects (websites, photos, videos, animations, etc.) (Figure 9).

Figure 8. Results of 4D models publication (LoD0) using open-source Potree: Lidar Cloud points of Corbridge Roman Site for time states: a) 2006 b) 2016
5. Conclusions

In the context of the 4D data sharing on the Internet, one can specify two kinds of problems. The first is the optimal presentation of 4D models, including making them available on the Internet, and the second, the integration of 4D models with GIS data on the Web GIS platform.

Both commercial software and open-source software can be used to share data. Hexagon Geospatial Portal is a good solution for online visualization of large city models with generalized geometry of individual elements. ESRI technology (CityEngine) has no problem with the format and enables for full integration of the 3D model with the reference data (orthophotomap, DTM) and the analysis of several times statuses of objects (the sliding view tool). The 4D models work in the WebGL standard on computers, tablets, smartphones (on Android and iOS) and in all browsers.

Subsequent to testing open source software (Potree, 3DHOP) for point clouds comparison and initial tests Potree seems to be more effective and supports GIS data. The technologies X3D and 3DHOP require the conversion of the 3D input model which causes distortion of the model geometry and problems with the texture. In addition, the disadvantage of 3DHOP software is a lack of the possibility of publishing geo-reference base maps. The results obtained for publications using X3D technology were not satisfactory, both in terms of the appearance of the 3D model and the functionality of the browser. Integration of 3D/4D models is possible at the WebGIS level, with raster base maps shared as OpenLayers, cartographic layers and vector objects with attributes.

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