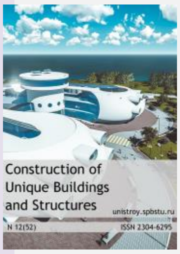

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Laser Scanner Survey Technologies for Historic Building Information Modeling of Heritage Resources in Saint-Petersburg, Russia

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ABSTRACT

Historic Building Information Modelling (HBIM) is an emerging technology used for documentation and management of existing historic buildings. The objective of the paper is to develop of a unified hybrid technology for the processing, storage and visualization of laser scanning and photography data about historical buildings, based on decoding and vectorization algorithms as an information framework for HBIM of heritage resources in St.Petersburg, Russia. The first result of the technology application to historical building (Water Supply Tower of Peter the Great St. Petersburg Polytechnic University) shows the robustness of the technology proposed.

Contents

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1. Introduction

Heritage buildings are crucial to the human perception of culture and identity through time. Accurate three-dimensional representations of cultural heritage sites are highly valuable for scientific study, conservation, and social purposes [1, 2]. Appropriate digital models enable efficient and precise measurement of relevant architectural features [3]. The complexity of historic buildings and monuments, with irregular geometry, inhomogeneous materials and variable morphology poses numerous challenges in the digital modelling of constructions and simulation of structural performances under different types of actions [4]. The designers must always take into account a range of possible and compatible solutions that avoid endangering the cultural significance of the historical building, so the responsible persons must take into account a range of possible solutions that avoid endangering the cultural significance of the historical building [5].

At the present time, in many publications for solving the mentioned problems it have been proposed to use an approach based on Building Information Modelling (BIM), so called Historical BIM (HBIM) [4, 6]. HBIM is proposed as a new system of modelling historic heritage monuments. HBIM can be considered as a library of parametric objects, based of historic architectural data and a system of cross platform programs for mapping parametric objects into point cloud survey data [7]. But analysis of developments in BIM research in the state-of-the-art overview of BIM implementation and research in existing buildings have been shown scarce BIM implementation in existing buildings and following challenges: 1) high modeling/conversion effort from captured building data into semantic BIM objects, 2) updating of information in BIM and 3) handling of uncertain data, objects and relations in BIM occurring in existing buildings [8].

The HBIM approach includes some steps and the first step is remote collection of survey data using a terrestrial laser scanner combined with digital cameras [8-10]. Terrestrial Laser Scanners (TLS) are used more and more as instruments for various tasks in cultural heritage conservation [11, 12]. The paper [13] have discussed the usage of innovative laser scanning surveying technologies for documentation of cultural architectonic heritage and monitoring of buildings behaviour over time during the life cycle management within the overall framework of planned conservation of architectural heritage.

There are some interesting applications of the laser scanning technologies to historical heritage objects worldwide. For example, at studying the ancient part of Palazzo d'Accursio (Bologna, Italy) the laser scanning have been used to detect traces of restoration works [14]. Spatial data derived from laser scanning of archaeological caves have been analyzed for African cultural heritage sites [15]. Historical and cultural surveying by Terrestrial Laser Scanners have been implemented successfully for Tekfur Palace in the Istanbul, which is under protection of the UNESCO [16].

Searching solutions for technical problems of the laser scanning are also under wide discussion. A method for automatic dynamic occlusion detection for sequential laser scanning point clouds captured from one scan position have been discussed in [17]. Also a small handheld laser scanner (Zebedee) can be useful to record historical buildings that previously could not be measured because of the scale and complexity [18].

Digital documentation with 3-d modeling functionality as a tool to derive pictorial, geometric, spatial, topological, learning and semantic information from the historical buildings and monuments had shown advantages in comparison to other methods [19]. Many efforts were devoted to improving of Historic Building Information Modelling (HBIM) according constructions of specific centuries, for example for nineteenth- and early twentieth-century construction [20].

Although recent developments in BIM have introduced advanced simulation capabilities, the numerical characterization of historic buildings is still a challenging task, so in [21] have presented an innovative two-step methodology (Cloud-to-BIM-to-FEM), which is able to convert a HBIM model into a finite element model for structural simulation.

Some papers have illustrated the possibility to move from GIS database and a 3D content model to HBIM for conservation and management of built heritage [22]. GIS technologies are also famous for site selection during surveys [23, 24]. It must be mentioned that for HBIM data capture remote sensing space data also important [25].

The article [26] have presented an approach to the development of an architectural information system taking into account the relationships that can be established between the representation of buildings, such as shape and dimension, and heterogeneous information, such as the technical or historical documentation.

Some articles in Russian journals also are devoted to the peculiarities of the application of the latest technology of BIM for the architecture monuments and BIM application in historical and architectural work can fundamentally change in this type of activity in Russia [27-31]

The objective of the paper is to develop of a unified hybrid technology for the processing, storage and visualization of laser scanning and photography data about historical buildings, based on decoding and vectorization algorithms as an information framework for HBIM of heritage resources in St.Petersburg, Russia. The technology also can be useful for processing laser scanning data during the civil-engineering survey for the construction process, engineering survey for roads and railways, creating three-dimensional models of the terrain and topography, urban infrastructure, engineering surveying and modelling of a buildings, and industrial sites.

2. Materials and methods

Civil-engineering surveying for historical buildings is a regulated activity, which is increasingly used modern high-tech devices and equipment. Thus, laser scanning is an advanced geodetic survey method for any surrounding objects. There are terrestrial, mobile (used car, train, etc.) and airborne (carrier - airplane, helicopter, UAV) laser scanning. Appropriate methods are used for filming various objects, ranging from historic buildings to uninhabited territories for road construction [32]. Filming and data processing is currently performed individually on specific objects and territories, according to the technological requirements. Features of laser scanning are the high accuracy and density of the shooting, and the subsequent production of large amounts of data [33]. Three-dimensional point model of the object (point cloud) is the main result of laser scanning systems [34]. The process of obtaining point cloud for each type of scanning system is well understood and the appropriate software was developed by manufacturers of scanning systems [35].

Preparation of vector patterns for point clouds is the most time-consuming step [36]. The method proposed by scanners manufacturers is in vectoring point clouds by importing them into CAD programs directly or by using subprograms. The most popular CAD systems in Russia and in the world are Autocad (Autodesk) and Microstation (Bentley). However, the cloud point, when displaying a three-dimensional graphics environment, is not as clear subject, such as a digital image. In addition, the ability to display a large number of points of a complicated CAD shell is limited [37]. Actually, working with three-dimensional graphics (in the case when you want to create the flat plans or other drawings) is inconvenient. There are also special software packages designed to create specific types of models from laser scanning data (Cyclone, RapidForm, 3Dipsos, as well as almost all the major manufacturers of scanners), but they are all designed to work in three-dimensional space.

Experience in the field of architectural measurements of historical buildings (using terrestrial laser scanning) has shown that the generation of the measuring drawings of the facades and interiors of buildings most effectively performed by vectorization of raster images (orthoimages), which are obtained by projecting laser reflection points on the picture plane [38-40]. A similar approach has been traditionally used in photogrammetry, when, as a routine basis for the creation of maps and drawings the orthophotomap is used - image, on which the distortions caused by the terrain, oblique images, and optics distortion is eliminated.

Mobile Laser Scanning (MLS) is the most advanced and least common practice of Russian production method. But the number of mobile scanners in Russia has already surpassed the number of aircraft scanners. There are a number of promising applications that require the collection of geospatial data by a mobile laser scanning method; however, ways of handling mobile scan data are underdeveloped. Note also that the amount of information per unit of time received by the MLS (up to 3-5 million points per second) several times higher than the volume produced in the course of airborne scanning.

The analysis of the current state of research in this area has shown that there are a large number of publications dedicated to tasks of construction of digital models of buildings, the detection of the surface of the earth and the reconstruction of the road surface, detection and recognition of road facilities on the basis of aerial and mobile laser scanning data, segmenting the data, methods of analysing errors and setting the accuracy of determining the geometry of the buildings according to the terrestrial laser scanning. The presence of a considerable number of articles and dissertation research on algorithms for processing laser scanning data for 2011 - 2015 confirms the relevance of the topic and the great interest in the development of software and mapping systems, which is dictated by the growing need for accurate geographic information on the environment and objects [41, 42]. However, the task of creating the hierarchical processing algorithm of large amount of data that provide a hybrid processing and data compression without loss of accuracy, the possibility of integration with the scan results obtained by various means, seamless linking of data processing in real time, providing the possibility of forming orthoimage based both on a single scan, and combined with a series of scans produced by different scanning means (it provides a reduction in the area of "dead zones" in the ortho) are not currently addressed. The author's method propose a comprehensive solution to the problem by creating a software-based technology for the algorithmic support for the hybrid system, which will provide the data processing received from all types of laser scanning - mobile, land and air, as well as photography. The solution proposed by authors is not the total three-dimensional modelling of urban areas or, for example, historical buildings and structures, but it provides a method for semi-automatic and automatic data processing and visualization and simulation based on Laser Scanning data - forming cylindrical reamers and point clouds, with organization of the network access to different levels of information, provide limited access, granularity and measurements basing on these data. To solve the problems of building information model creation of based on laser scanning data (three-dimensional modelling of local objects) a method for processing large volumes of data for the map information is provided. It provided with the possibility of more accurate detailing of a digital models of buildings with a combination of scan data for each scale and the level of representation of cartographic and geodetic information obtained by different scanning methods are used. To correct the imbalance between the processing power and input / output and data transfer speed of large volumes of information in the implementation of the surface detection algorithms and reconstruction of the building surface based on the mobile laser scanning data, a distributed computing architecture is proposed, with the development of data processing and storage system.

Factors determination and evaluation of metrics for the factors that affect the accuracy is not the subject of the method. In the proposed solution the development of the proposed system is performed based on the factors, as indicated in the application: data compression without loss of accuracy and reducing the area of "dead zones" in the orthoimages. The problem of determining the geometry of the buildings is not provided in the main application, and it will be solved with known methods for determining the geometry of an object with the usage of the integrated information obtained by various methods using interpolation and extrapolation of the collected data. However, to support the method proposed an experimental study of the effectiveness of various methods of surface modelling to ensure the declared level of accuracy had been performed.

3. Result and discussions

The task of the research is to develop new algorithms of cloud of points processing (big data processing) received from laser scanner. Creation of the software for the processing, visualization and vectorization of laser scanning data, as well as the presentation of data through the Internet, providing: (1) improved efficiency and accuracy of processing of laser scanning data (decoding and vectorization not less than 99.5%); (2) to provide to the customer of laser scanning process (within the engineering survey) the functionality of the post-processing of results of the scan on the basis of the primary (raw) information about the object(which is most valuable information).

Testing research for the technology proposed was conducted to establish of 3D data for buildings of Peter the Great St. Petersburg Polytechnic University (former St. Petersburg Polytechnic Institute). St. Petersburg Polytechnic Institute was built on the model of Oxford and Cambridge as a complex with thoroughly designed and implemented infrastructure. The construction of the principal buildings of the Institute was carried out after the designs of architect E. Virrich, artist architecture 1-St degree, academician of architecture since 1908, the outstanding representative of rationalist architecture, one of the pioneers in the use of reinforced concrete structures, in 1900 – 1905.

The complex of the Polytechnic Institute interesting as a coherent architectural ensemble, one of the few that have survived in a relatively unchanged form. Buildings represent the unique architectural buildings of the turn of XIX - XX centuries. The complex of buildings and Park are included in the "List of objects of historical and cultural heritage of Federal importance", approved by the decree of the President of the Russian Federation No. 176 of February 20, 1995, and are particularly valuable objects of cultural heritage of the peoples of the Russian Federation as a complex historical, cultural, architectural ensembles and structures and natural landscape monument representing material, intellectual, and decorative value.

One of the oldest constructions on the University premises is the Water Supply Tower built in 1905 (fig. 1A), three years after the Polytechnic Institute was opened. It is the highest point among two- and four-storey institute buildings, and goes in contrast with other constructions because of its intricate and fractured forms. The Water Supply Tower is 46 meters high. Until 1953, it had been used as an engineering construction to provide the work of the water pipe system. When built, the Water Supply Tower became one of the education-supporting buildings on the Institute's territory. In 1905 the annex near the Water Supply Tower housed the Hydraulics Laboratory.

There are many options for creating digital models of large objects, among the highlights of the photogrammetry and 3D laser scanning [1-8]. The complexity of the research required the use both techniques. To establish a 3D model for HBIM of Heritage Resources were used methods of 3D laser scanning and photogrammetric data processing. Creating 3D model involves the following steps: the choice of object of study; collection of visual, technical and historical information; laser scanning and photogrammetric survey to obtain data – point cloud (fig. 1B);detection and extraction of segments of dense point cloud, and the procedure of semi-automatic triangulation (fig. 2A); obtaining external colour models using (fig.2B); export data in applied architectural packages (fig.3A, fig.3B).

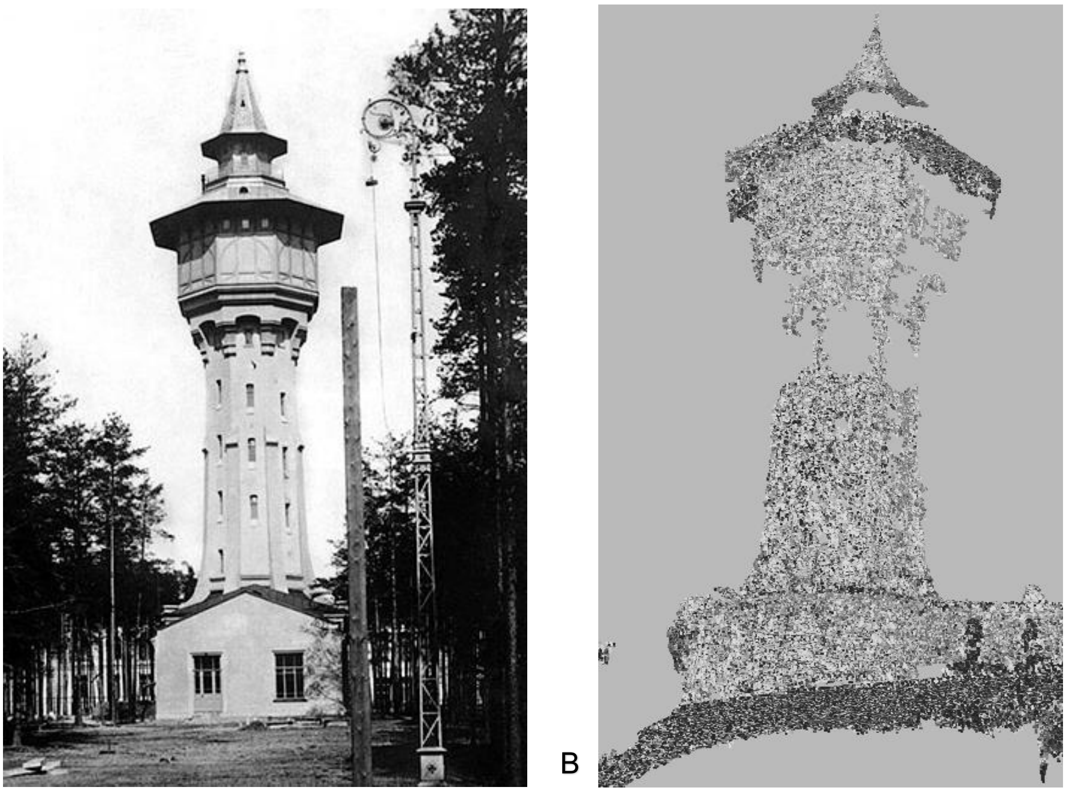
A  B

Fig. 1. A – Water Supply Tower in 1905.

B – Point cloud for historical building.

It was built dense point cloud (fig. 1A) based on image comparison using OpenCV library [38]. A dense cloud of points is 1 point per 1 cm2, in the case of shooting large objects. In the case of this object, the point cloud was 32KK points.

A B

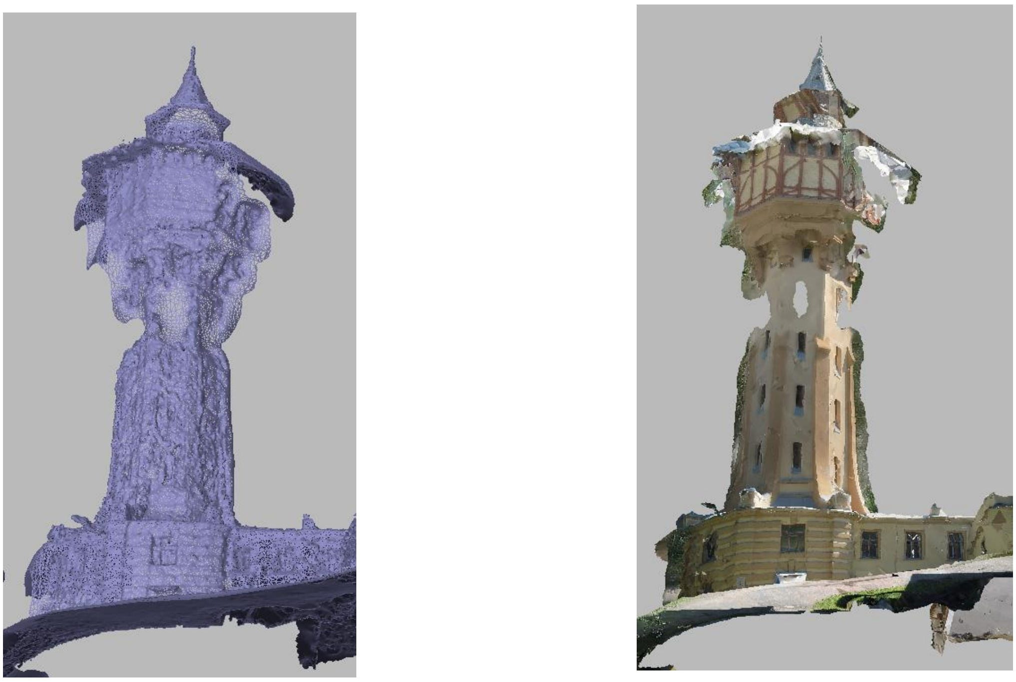
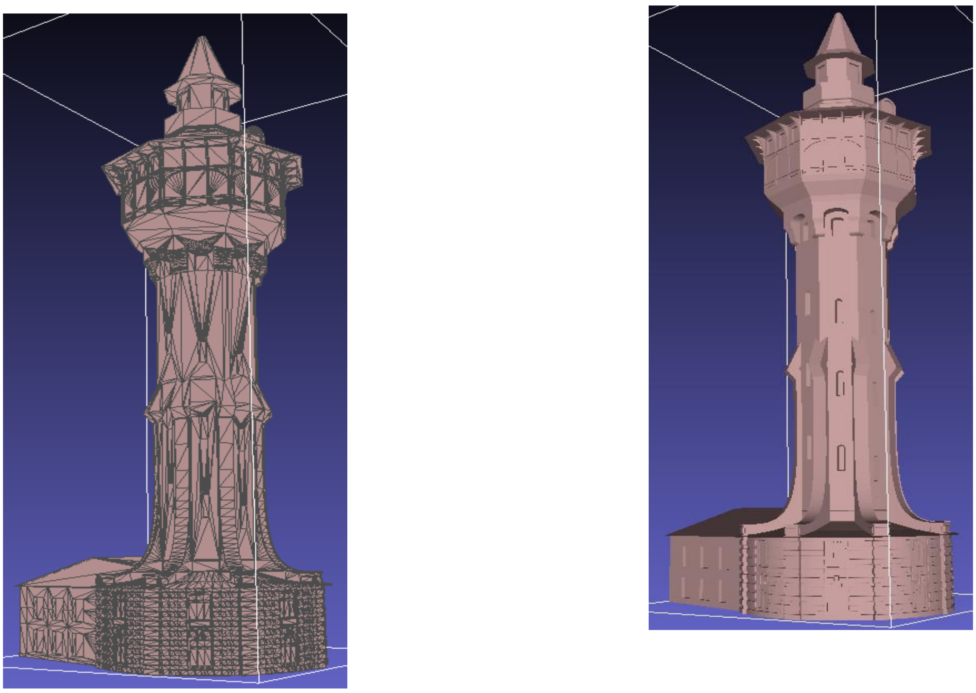


Fig. 2. A – Result of semi-automatic triangulation. B – External colour model.



A B

Fig. 3. A – 3D mesh for BIM. B – 3D model for BIM.

Processing this amount of points makes no sense and is extremely costly in terms of hardware resources. For this purpose, it is necessary to reduce the number of points. For large objects, having a complex geometry optimally reduce the number of points is in 10-fold to 3.2 KK.

The resulting grid is still redundant, so you need to apply anti-aliasing. The best option for polygon surfaces – "Laplacian smoothing polygon meshes". For each vertex in the grid, the new position is chosen based on local information (e.g., position of neighbours). This method helps to simplify the mesh even stronger than in 4 times, up to 800K points.

4. Conclusions

Unified hybrid technology for the processing, storage and visualization of laser scanning and photography data about historical buildings, based on decoding and vectorization algorithms as an information framework for HBIM of heritage resources in St.Petersburg, Russia is proposed. The first result of application the technology to historical building (Water Supply Tower of Peter the Great St. Petersburg Polytechnic University) shows the robustness of the technology proposed.

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Обзор технологии лазерного сканирования для исторического информационного моделирования зданий и сооружений в Санкт-Петербурге, Россия

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АННОТАЦИЯ

Историческое информационное моделирование зданий (HBIM) - это новая технология, используемая для документирования и управления существующими историческими зданиями. Цель работы - разработать единую технологию для обработки, хранения и визуализации данных лазерного сканирования и фотографий исторических зданий, основанной на алгоритмах декодирования и векторизации в качестве информационной основы, для исторического архитектурного наследия в Санкт-Петербурге. Первый результат применения технологии к историческому зданию (Гидробашни Санкт-Петербургского Политехнического университета Петра Великого) показывает надежность предлагаемой технологии.

Баденко В., Зотов К., Зотов Д., Гарг Р. Д., Жан Л., Болсуновская М., Федотов А., Обзор технолоиии лазерного сканирования для исторического информационного моделирования зданий и сооружений в Санкт-Петербурге, Россия// Строительство уникальных зданий и сооружений. 2016. №1 (52). С.93- 101 .

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