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Urban Planning

INVESTMENTS IN PRESERVATION AND DEVELOPMENT OF REGIONAL CULTURAL HERITAGE: A LIBRARY OF BIM ELEMENTS REPRESENTING NATIONAL ARCHITECTURAL AND URBAN-PLANNING LANDMARKS

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Abstract

Introduction: The paper presents a methodology for reduction of expenses within investment projects aimed at the preservation and development of cultural heritage sites, based on the combined use of methods of scientific restoration, laser scanning and information modeling, as well as creation of a library of unique BIM elements of ancient city buildings, identified at protected sites of the urban environment, using restoration of a building in the Old Tatar Quarter (Staro-Tatarskaya Sloboda) in Kazan as an example. **Methods:** The authors performed standard (traditional) scientific restoration activities and innovative field studies using laser scanning and built a parametric information model of the cultural heritage site for further development of a restoration plan with account for site adaptation to modern functions. **Results and discussion:** Point cloud processing is carried out to create an information model and a library of unique BIM elements, which can be used repeatedly in restoration and reconstruction, thus reducing costs for BIM-model development in future investment projects. The practical significance of the study lies in the creation of a public good – a library (encyclopedia) of ancient architectural elements in the form of a library of BIM elements for BIM models of architectural and urban-planning landmarks in the region, as well as in the development of recommendations (by individuals, regional and local regulatory authorities) for an efficient policy in urban planning and restoration with regard to similar historical and cultural, architectural and urban-planning landmarks.

Keywords

Investments, preservation of cultural heritage, national color, surface laser scanning, information modeling technology, library of cultural heritage sites' BIM elements, social infrastructure, tourism potential, urban planning, regional economy

Introduction

Generally, investments aimed at preserving and developing cultural heritage sites of the peoples of Russia under conditions of integrated territorial development in cities and regions are made by state, regional and local authorities, legal entities and individuals. They are intended for implementation of investment projects on the preservation of the public good – the property of the people living in their historical lands: identification, preservation, and protection of the cultural and historical environment in settlements, nature reserves and territories of other significant national sites. Care for spiritual and material values makes it possible to achieve social development goals (in terms of charity, culture, education, and socially useful activities) and material goals (attractiveness of urban areas, tourism potential growth in regions, increase in regional and city budget income, regional economic growth).

Implementation of the cultural heritage site's life cycle concept based on the information modeling technology results in the reduction of expenses for reconstruction, restoration, and management of regional architectural and urban-planning facilities.

In the course of the study, the following main advantages of the combined use of traditional and innovative methods for reconstruction and restoration of cultural heritage sites were identified: improvement of building design quality and accuracy; cost reduction at the stage of construction operations due to work activity management and material control; prospective reduction of expenses for management of facilities with new qualitative characteristics due to the use of automated systems of integrated building utilities control.

BIM-model development for investment restoration projects differs from the development of such models for new construction projects in labor intensity as time spent

for the creation of BIM elements (windows, doors, stairs, and other building members that underwent substantial changes over time) increases significantly. Modern information systems and CAD systems used in construction utilize catalogs (libraries) of BIM-model elements for construction projects, which consist of standard elements of various manufacturers (both domestic and foreign).

Government regulation of information modeling technology development in the field of architecture, design, construction, and operation requires infrastructure set-up and development to describe construction products and help manufacturers of building materials to introduce the digitized products into state information systems. Manufacturers have access to the Russian Federal State Information System of Pricing in Construction. Introducing their products in the system, they can subsequently use cost indicators in a BIM model upon expert cost estimation for each element of the model submitted for state expert review.

Works on restoration of cultural heritage sites are the most labor-intensive as each building member becomes unique over time and, in most cases, requires artistic work when BIM elements are created. Problems related to object geometry determination to create a BIM element for subsequent use in an information model arise. Field studies of cultural heritage sites using laser scanning, and modeling of BIM elements, typical for ancient objects, based on the point cloud obtained can serve as an essential complement to traditional analytical methods of research, scientific restoration, and reconstruction of the historical development.

Subject, tasks and methods

The paper presents a methodology for reduction of expenses within investment projects aimed at the preservation, renovation, restoration and reconstruction of historical, cultural and natural sites upon design of cultural heritage sites with the use of an integrated scientific restoration approach, new laser scanning technologies, information modeling technology and development of an object BIM-model to make a thorough restoration plan, through the example of the cultural heritage site of republican significance located in the Old Tatar Quarter (Staro-Tatarskaya Sloboda) in Kazan, which is a historical and architectural landmark: the house of B.-F.Ya. Bagautdinova (Marjani)–B.-Kh.Sh. Apanayeva, architect: P.I. Romanov (1873). The building was owned by a daughter of Shihabeddin Marjani (Shihabeddin bin Bagautdin al-Kazani al-Marjani, 16.01.1818–18.04.1889) – a Tatar enlightener, theologian, philosopher and historian, who laid the foundations for renewal of the Tatars' life: getting secular education, studying ancient, Arab, Russian and Western European culture, achievements of the world culture and science in educational institutions called madrasas[1].

The study was aimed at the following: a system analysis of field studies of the site using a laser scanning technology, point cloud, BIM model of the cultural heritage site; search for a solution to reduce time spent by restoration architects on development of a building information model when modeling unique elements of the ancient site (as new elements of the BIM model); drafting of recommendations for reduction of expenses within investment projects aimed at the reconstruction and restoration of cultural heritage sites due to creation of a public good – a library of unique BIM elements of regional cultural heritage sites for repeated use in investment projects.

The field study of the cultural heritage site in the Old Tatar Quarter in Kazan revealed damage resulting from a fire (Figure 1), construction of a new building on the adjacent land plot, and growth of plants (Figure 2). The damage was initially analyzed during training design at the Kazan State University of Architecture and Engineering by a team of faculty members and students of the Department of Reconstruction, Restoration of Architectural Heritage and Principles of Architecture (using traditional methods of scientific restoration[2]). Then the study was continued with a view to a more accurate analysis of the building based on modern information technologies.

Figure 1. Effects of a fire at the cultural heritage site of republican significance located in the Old Tatar Quarter in Kazan.
Source: photo by the authors.

[1]Official Tatarstan website, National Library of the Republic of Tatarstan. Available at: http://kitahane.tatarstan.ru/mardzhani.htm (accessed on 01.06.2019).
[2]Sadykova D., Garayeva L., Minnegulova Z., Shakirova A., Amirova A., Kuzmichev N. (2018). Architectural description of the building located at 44 Sh. Marjani St. as of September 2018. Advisors: Mukhitov R.K., Fazleyev M.Sh. Kazan, 22 p.

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Figure 2. Effects of new construction on the adjacent land plot and wildlife on the cultural heritage site of republican significance located in the Old Tatar Quarter in Kazan.
Source: photos by the authors.

Initially, the following task was set: practical evaluation of developing a unified BIM model of a real object under the project for reconstruction of the cultural heritage site, applying the method of teamwork involving restoration architects, designers, and building utilities engineers, using methods of laser scanning for high-precision architectural measurements, information modeling to develop design and operation BIM models of the building during inter-disciplinary course design at the Kazan State University of Architecture and Engineering. In the course of the study, another task was set: search for a solution to reduce costs for the creation of ancient buildings' unique elements in the BIM environment.

Historical background

Three cities of the Republic of Tatarstan have sites included in the UNESCO World Heritage List: Kazan (Kazan Kremlin), ancient city Bolgar and Sviyazhsk town-island. Preservation and development of cultural and historical sites in the territory of the Republic are of integrated nature:

1) at the regional level, the Republican Fund for the Revival of Historical and Cultural Monuments of the Republic of Tatarstan was established. As a result of its activity, Sviyazhsk town-island and Bolgar city were restored. In 2014, ancient city Bolgar was included in the UNESCO World Heritage List. The Bolgar historical and archaeological complex is represented by architectural examples of the medieval Islamic city of Volga-Bolgars[3]. In 2017, the Assumption Cathedral of Sviyazhsk town-island was included in the UNESCO World Heritage List (building date: 1556–1560; Pskov architect: Postnik Yakovlev). Thus, the world universal value of Eastern Orthodox Church historical treasures – frescoes of the 16th century, the historical significance of which is in representing decisions of the Council of Hundred Chapters held in 1551, – was acknowledged[4]. Scientific studies and restoration of sites were carried out by archaeologists, historians, surveyors, restoration artists, and other specialists. The spatial and planning structure of a city typical for the middle of the 14th century was developed based on a graphic reconstruction of Bolgar city (Nadyrova, Troepolskaya, 2013).

2) at the municipal level, city authorities and individuals are responsible for the development of historical territories. In an area where the Kazan Tatars historically

[3]Zubkov I. (2014). Rossiyskaya Gazeta official website. Available at: https://rg.ru/2014/06/23/bulgar-site-anons.html (accessed on 12.02.2019).
[4]Rodionov V. (2017). UNESCO included the Assumption Cathedral in Sviyazhsk in the World Heritage List. Available at: RIA Novosti official website https://ria.ru/20170709/1498159565.html (accessed on 12.03.2019).

resided, the “Old Tatar Quarter of Kazan” Prefect’s Office and the non-commercial Fund for Development of the Old Tatar Quarter and Kaban Lake Improvement operate. The purpose of the Fund is to develop the historical area of the Old Tatar Quarter in Kazan and improve Kaban Lakes. The Fund ensures the preservation, renovation, and re-creation of the typical historical urban environment in the area of Kazan city beyond Kaban Lake. Its tasks are improvement, renovation, and restoration of historical sites, creation of new landmarks, maintenance of cultural traditions, arrangement of public events and development of tourism potential with regard to the Kaban Lake embankment [5].

The Ministry of Culture of the Republic of Tatarstan in collaboration with the City Hall and the “Old Tatar Quarter of Kazan” Prefect’s Office implemented investment projects for the development of the quarter territory, renovating blocks of buildings in the historical area. Among those projects are the following: re-creation of a typical Tatar town mansion, renovation of the Sredny Kaban Lake embankment, formation of an eco-system for water birds, revival of cultural traditions (Sabantuy festival, which means “celebration of the plough”), Gabdulla Tukay Literature Club project, renewal of Tatar intelligentsia meetings in the Eastern Club (beginning of the 20th century) to hold evenings with poets, writers, composers, artists developing the Tatar musical and visual art, and literature.

Analysis of investment directions with regard to projects for the development of historical territories as well as urban-planning projects in the Republic of Tatarstan shows that investments are systemic and integrated, their sources are budgets of all levels and private funds, aimed at the reconstruction and restoration of unique architectural and urban-planning facilities, re-creation of the typical historical urban environment in old quarters of cities.

Let us review possibilities of the combined use of traditional and innovative methods for preservation and reconstruction of the architectural and historical heritage of the Republic using the example of such cultural heritage site of republican significance as the historical and architectural landmark “House of B.-F.Ya. Bagautdinova (Marjani)–B.-Kh.Sh. Apanayeva, architect: P.I. Romanov (1873)” located in the Old Tatar Quarter in Kazan (Figure 3).

Figure 3. Historical part of the city near the cultural heritage site of republican significance “Historical and architectural landmark “House of B.-F.Ya. Bagautdinova (Marjani)–B.-Kh.Sh. Apanayeva, architect: P.I. Romanov (1873)” located in the Old Tatar Quarter in the central part of Kazan city, on the embankment of Sredny Kaban Lake.

Source: photo by the authors.

Scientific restoration of cultural heritage sites requires complete, reliable and accurate measurement documentation. Besides drawings and photos[6], it is possible to build a BIM model based on the surface laser scanning technology:

1) a 3D point model of a landmark as a result of its laser scanning (exact geometry) and use of photogrammetry (color data);

2) an ortho-photo plan – an orthogonal projection of a 3D model to a given plane, combining geometric characteristics of the measurement drawing and imagery of photos;

3) point cloud projections used for fixation and measurement of convoluted surfaces. The type of projection depends on the surface form and makes it possible to project the surface with minimal distortions.

[5] Charter of the Fund for Development of the Old Tatar Quarter and Kaban Lake Improvement. Available at: http://fond-sts.ru/regulations (accessed on 12.03.2019).

[6] Architectural measurements (2018). Research and Production Company "Photogrammetria". Available at: https://photogrammetria.ru/18-arkhitekturnye-obmery.html (accessed on 25.03.2019).

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Results and discussion

Use of laser scanning

Based on a set of works on the scientific restoration of the cultural heritage site, performed by restoration architects, the authors set a task of studying the site using surface laser scanning. Surface laser scanning makes it possible to build models of urban areas (Usikov et al., 2009), study cultural heritage sites precisely (Seredovich, 2009), develop a precise digital model of a site or terrain (Akulova, Krutikov, 2009; Komissarov, 2006), use possibilities of non-destructive analysis methods to evaluate the state of a cultural heritage site (Potapov, Pavlov, Verkhovskaia, 2019), conduct non-destructive testing (Yakovlev et al., 2013). It also can be used in archaeological studies (Prokopieva, 2006). Software analysis aimed at the processing of surface laser scanning results (Shevchenko, Gura, Glazkov, 2016) and analysis of the combined use of laser scanning and photogrammetry (Komissarov, Kalinina, 2016; Pavlov, Vinogradov, 2011) showed the high efficiency of modern technologies in studies of architectural monuments. Scanning for building construction is applied to existing structures (Shevchenko et al., 2016), used for inventory control, measurements of objects (Minaev, 2013) and in new construction. Scanning technology is becoming a critical function necessary to complete the integrated BIM cycle and provides a clear value-add for the integrated BIM workflow (Gleason, 2013). It is assumed that the transfer of BIM models to state expert review authorities will make it possible to reduce the time spent on project analysis and expert review (Lyapina, Borodin, 2018).

A surface laser scanning system consists of a laser scanner (laser range finder and laser scanning unit deflecting the laser beam) and a laptop with special software. Due to laser scanning, it is possible to perform a topographic survey, take geo-referenced building facade measurements, and analyze the obtained point cloud promptly and accurately:

1) scanner settings' management: spatial coordinates of points on the surface of an object are determined by measuring the distance to all points captured by a reflectorless pulse laser range finder:

beam direction (vertical and horizontal angles) is registered;

a distance from the scanner to the points is measured;

for building facades, measurements from four angles are taken;

2) scan recording: high accuracy of the tool makes it possible to take numerous measurements and replicate the surface of the object scanned in the form of a point cloud, creating a 3D raster image (scan) of the object. Each pixel can be an element of a three-component vector (distance; reflected signal strength; real color of each point, expressed as RGB) or a five-component array of points of laser reflections from the object in the sight of the scanner (x, y, z spatial coordinates; reflected signal strength; real color);

3) processing of results: the generated point cloud is transferred to the BIM environment to develop a parametric information model of the object.

The object was studied according to the following algorithm: 1) collection of data on the object (construction and topographical survey), database formation; 2) building siting directly on site using the BIM technology[7].

Results of the study based on the analysis and interpretation of the point cloud generated during in-situ laser scanning of the building facades from four points are presented in Figure 4.

Figure 4. Results of the cultural heritage site's field survey.Source: the results were processed and submitted by M.V. Efremov, TSNRU JSC (Tatar Special Scientific Restoration Department).

[7]Lakin P. (2017). BIM technologies in preservation of heritage sites. Available at: https://www.kgasu.ru/customer/bim/news/universitetskaya-zhizn/v-kgasu-startovali-master-klassy-po-bim-tekhnologiyam-v-ramkakh-grantovoy-programmy-rt-algarysh-/ (accessed on 15.03.19)

The following advantages of obtaining spatial information using surface laser scanning of a cultural heritage site were revealed: high accuracy of measurements and speed of field survey; non-destructive information gathering; safety of works in hard-to-reach areas generated due to dilapidation or partial loss of structures (e.g. using radio-controlled devices).

After completion of surface laser scanning and recording of several scans, studies continue as the development of an information model of the object in the BIM environment, which makes it possible to combine two technologies to create a precise digital model and improve the information accuracy for the corresponding investment project.

Specifics of developing a BIM model for a cultural heritage site

Development of a comprehensive information model for a cultural heritage site located in the historical part of a city shall be performed after its scientific restoration, field studies using surface laser scanning, subsequent design and development of a BIM model for the efficient implementation of the corresponding investment project and further building adaptation to modern functions (a wire-frame model, a surface or solid model in black and white or color with account for the need to preserve, replace or re-create BIM-model elements at the next stages of the architectural monument's life cycle).

The next step is model checking. It is especially important in case of joining the preserved building elements and attaching the old elements to new structures and joints. Tolerances and clearances are also essential. At this stage, it is possible to avoid or reduce expenses associated with actual restoration. Location-based scheduling allows us to perform production control on-site and make teams proactive when managing a project schedule. The combined pro-activeness of scanning information and production control is a key component to mitigating schedule delays on renovation projects. Laser scanning results in a BIM model based on the exact number of elements and allows for more accurate investment project evaluation with account for new and existing elements of the architectural monument (Gleason, 2013).

Building a BIM model of a cultural heritage site, it is possible to obtain measurement drawings of facades, floor plans, drawings in longitudinal section, roof and wall plans, decoration drawings with the indication of actual measurements, elevations of various building elements with the indication of deviations from design values; identify defects and other information depending on the object and objectives.

Information modeling technology allows owners, specialists, facility managers to make right and effective decisions related to facility management due to the precision of information models, possibilities of detecting, monitoring and correcting collisions in a project, scenario forecasting with respect to various restoration options, investment control within a project for reconstruction or restoration of a cultural heritage site.

It has been revealed that a BIM model of a cultural heritage site (Figure 5) is characterized by high labor intensity associated with the creation of unique BIM elements by restoration architects.

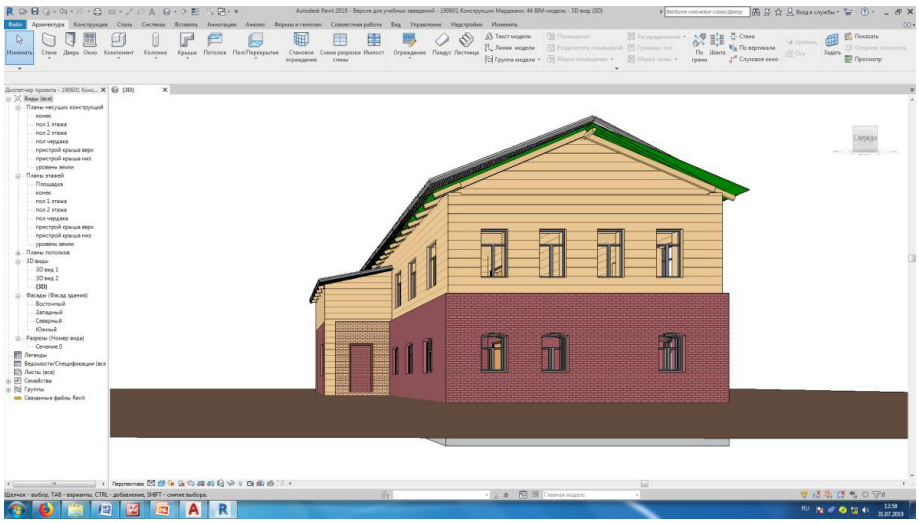

Figure 5. BIM model of a cultural heritage site.

When restoration architects create a unique element of a building of architectural heritage in the BIM environment, the following is considered:

firstly, the geometry of standard elements used during initial construction distorts over time; secondly, similar elements (e.g. windows) could initially have different dimensions; thirdly, plants could also change the geometry of the object (as exemplified by the fire wall of the house) over time; fourthly, modern catalogs of software for BIM modeling and catalogs of building materials lack unique ancient architectural elements to be used to re-create a cultural heritage site, whereas the creation of a unique element is a labor-intensive process (Figure 6).

Figure 6. Examples of unique elements of a building as a part of an actual cultural heritage site and BIM model.
Source: photo by the authors, BIM model.

It is possible to resolve issues related to the efficient development of a cultural heritage site's BIM model by restoration architects, using the following methodology:

1) based on ancient guides, create a library of BIM elements of regional cultural heritage sites and utilize it as a public good within the regional policy of urban planning and preservation of cultural heritage sites;

2) provide the library of BIM elements of regional cultural heritage sites (as elements of repeated use) for the public use.

It will allow all concerned parties to projects aimed at the restoration and reconstruction of cultural heritage sites to use the library in architectural design, perform scenario forecasting, and assess restoration options and site's possibilities for adaptation. Changes in a BIM model make it possible to obtain documentation needed at the subsequent stages of the object life cycle and respect the interests of the society and investors when preserving the architectural heritage of the region.

The following advantages of information modeling with respect to cultural heritage sites (possibilities of implementing the concept of the full life cycle of a cultural heritage site) were revealed: cost-efficient design works due to the development of a unified BIM model; possible repeated use of a library of unique BIM elements related to regional cultural heritage sites in an information model for the purposes of architectural and engineering design, construction management, operation, and repair.

Considering the high cultural value of unique BIM elements created by restoration architects for ancient mansions, natural, cultural and historical monuments, the authors suggest implementing a regional investment project to create a library of unique BIM elements of cultural heritage sites located in the Republic of Tatarstan and developing measures of state support for the creation of such library (digital architectural and urban-planning encyclopedia) as a public good with free access to it (as a cultural layer of historical elements) for the next generations of restoration architects, historians, and art experts, based on repeated use of BIM elements for artwork, restoration and reconstruction of cultural heritage sites, including typical housing development in the historical part of cities and villages of the region.

Conclusions

The combined use of traditional scientific restoration methods, advanced technologies of surface laser scanning, and information modeling for investment projects aimed at the preservation, reconstruction, and restoration of cultural heritage sites made it possible to assess possibilities of implementing the cultural heritage site's life cycle concept (with regard to sites being restored) upon object creation in the BIM environment by specialists of related fields.

Investments in preservation and development of cultural heritage sites based on the combined use of traditional restoration methods, advanced methods of surface laser scanning, and information modeling make it possible (due to high accuracy of design methods) to reduce investment project costs and expenses for operation of buildings, including historical and cultural monuments of the region.

Social and institutional significance of the suggested investment project to create a library of unique BIM elements of cultural heritage sites located in the Republic of Tatarstan lies in the following:

1. Preservation of cultural heritage sites and sites portraying the history of the peoples in the region.

2. Preservation and development of the national color of cities using the example of the Old Tatar Quarter in Kazan.

3. Use of non-destructive technologies of scientific restoration as well as the effective, cost-efficient and high-precision re-creation of historic buildings based on surface laser scanning and BIM.

4. Development of the social infrastructure in a city due to the adaption of sites to socially beneficial functions.

5. Development of tourism potential in the region.

The combined use of traditional restoration and reconstruction methods as well as advanced information technologies will make it possible to implement investment projects aimed at comprehensive restoration, provide conservation of buildings to prevent their subsequent

destruction, and develop projects to renovate historic buildings and adapt them to the improving social infrastructure in the historical part of the city, preserve the national color of the Old Tatar Quarter in Kazan, and improve tourism potential with regard to the regional economy.

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ИНВЕСТИЦИИ В СОХРАНЕНИЕ И РАЗВИТИЕ КУЛЬТУРНОГО НАСЛЕДИЯ РЕГИОНА: БИБЛИОТЕКА BIM-ЭЛЕМЕНТОВ ПАМЯТНИКОВ НАЦИОНАЛЬНОЙ АРХИТЕКТУРЫ И ГРАДОСТРОИТЕЛЬСТВА

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Аннотация

Введение: В статье представлена методология снижения издержек инвестиционных проектов сохранения и развития объектов культурного наследия на основе комплексного применения методов научной реставрации, лазерного сканирования, технологии информационного моделирования объекта и создания BIM-библиотеки уникальных элементов старинных городских зданий, выявленных на охраняемых объектах городской среды, на примере проекта реставрации дома в Старо-татарской слободе города Казани. **Методы**: В исследовании проведён комплекс традиционных мероприятий научной реставрации объектов, инновационных натурных исследований с применением лазерного сканирования с последующим созданием параметрической информационной модели объекта для разработки плана реставрации с учетом современного приспособления объекта культурного наследия. **Результаты и обсуждение:** Обработка облака точек для создания информационной модели и библиотеки уникальных BIM-элементов модели, которые могут быть повторно использованы для реставрации и реконструкции объектов, что снизит стоимость создания BIM-модели в последующих инвестиционных проектах. Практическая значимость работы заключается в постановке задачи создания общественного блага - библиотеки (энциклопедии) старинных архитектурных элементов в форме библиотеки BIM-элементов для BIM-модели памятников архитектуры и градостроительства в регионе, а так же разработке рекомендаций частными лицами, муниципальными органами, региональными органами власти по государственному регулированию эффективной и качественной политики городского планирования и реставрационной деятельности на аналогичных объектах историко-культурного, архитектурного и градостроительного наследия.

Ключевые слова

Инвестиции, сохранение культурного наследия, национальный колорит, наземное лазерное сканирование, технология информационного моделирования, библиотека BIM-элементов объектов культурного наследия, социальная инфраструктура, туристический потенциал, городское планирование, региональная экономика