Research of features of increasing operational reliability of historical buildings in Russia

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Abstract. Considering the high importance of historic buildings in shaping the architectural appearance of Russian cities, the features of reconstruction of these buildings and structures are performed in this paper to ensure the operational safety of the properties and their structural safety. There is proposed a comprehensive approach to solving the problem which includes the following main types of research: studying the design features of historical real estate, analyzing the reliability of structural and finishing materials, including the study of their authenticity. Special attention is paid to assessing the impact of natural and technogenic impacts on the reliability of the structural scheme of the object as a whole and its individual elements, monitoring new construction in adjacent territories, geotechnical monitoring, assessing the impact of building reconstruction on changes in the design scheme of the building.

1. Introduction
Buildings and structures that were built during the XVIII and early XX centuries, form the historical architectural appearance of Russian cities. The operating conditions of these objects throughout their life cycle are very diverse, which determines the different degree of depreciation of the main load-bearing structures of such buildings. Unfortunately, the operation of a significant number of them is no longer possible and even dangerous. But the large part of these buildings, that usually classified as architectural monuments, is maintained in a satisfactory technical condition. The architectural expressiveness of such buildings and their location in the central part of cities are attractive for placement of state, administrative, banking and other structures not only in Russia but also abroad [1].

The experience of inspection of such buildings allows us to formulate the main risks of mechanical safety: lack of project documentation, unauthorized extensions, redevelopment of the inner space; change of the set design situations by increasing the loads on ceilings; the location of such buildings in the central (historic) parts of cities, where the tendency for new construction, including active development of underground space, raises with time. Therefore, to ensure the structural safety and operational reliability of such buildings it is necessary to carefully examine and monitor the technical condition of their structures. The practice of building inspection allows us to conclude that there are
risks of not taking into account the features of deformation of buildings with insufficient consideration of the structural features, physical and mechanical properties of the soil base [2-6].

However, despite the experience of reconstruction, restoration, and renovation of historical buildings and structures that has been formed in recent decades, there is currently no system algorithm for taking into account the unique specifics inherent in such buildings when evaluating their structural safety. Therefore, the purpose of this work was to develop an algorithm for system evaluation of operational reliability of historical buildings.

2. Materials and methods
The development is based on the traditional approaches used in assessing the operational reliability of buildings. First of all, these are methods of preliminary visual, detailed instrumental full-scale, laboratory research [7]. The preliminary stage of the survey is to develop a screening program [7], including work on the definition of the geometrical sizes of the constructions, actual material strength (concrete, rebar, brands of brick and mortar), diameter and number of working and structural reinforcement, design of reinforcement products (cages, mesh, etc.), etc.

To determine the material strength, taking into account the recommendations [8-11], non-destructive methods and laboratory research of samples selected from structures are used [12].

When assessing the technical condition of the building, the following factors are considering: the nature, magnitude and danger of defects and damage, the possibility of their further development, the actual load-bearing capacity and reliability of structural elements in the structural scheme of the building, the amount of physical and moral depreciation of structures, and a number of other factors. The design schemes and loads on structures, operating conditions are evaluated, the necessary physical and mechanical properties of materials are monitored, and the quality of structures, materials and connections is established. Verification static and structural calculations are performed.

3. Results
Experience survey of historic buildings, that carried out by the authors in the last two decades [13-16], allows to identify the main stages requiring inclusion in the program survey of the building and having a critical importance in securing the operational reliability of the object.

One of the difficulties of monitoring the technical condition of historical buildings is the complete or partial absence of design information, operational documentation, including impacts that could entail not only the adjustment of the design scheme, but also changes in the actual characteristics of the materials. This requires a thorough examination of the actual technical condition of the structures in order to obtain the most reliable and complete information.

One of the important stages of reconstruction is often the restoration of the historical appearance of the building. Therefore, the important role during the work is assigned to archival research. Archival materials are often the only source that contains information about the original appearance (project), about the history of operation of such buildings. When examining a historical building, it is necessary to trace the process of development of the building's space-planning solution in order to further analyze the process of deformation of the building. The key task of solving the problem of ensuring operational reliability is assessing the bearing capacity of the ground base, as well as the impact of attached parts of the building on existing ones.

An important factor in the survey is the identification of the architectural and structural composition of the building in accordance with traditional solutions.

Restoring the historical appearance of a building often requires research on the authentic finish of the building. This task is an integral stage in the restoration of historical buildings of worship [17]. The study of the composition of the finishing coating is performed in the course of laboratory research of samples taken from various parts of the building on the basis of chemical, elemental, x-ray, and analytical methods. Determining the composition of the plaster layer is performed using chemical analysis, which allows to identify the features and nature of the binding material.
In the second half of the twentieth century a significant number of historical buildings, primarily for worship purposes, were converted into industrial buildings for various purposes. This predetermined the active impact of aggressive technological environments on the structures and materials of such buildings, significantly changed the chemical structure of finishing coatings. Therefore, the content of calcium oxide and thinning impurities, such as sand (determined by the content of SiO₂) and hydraulic impurities (P₂O₅), is crucial for the identification of the binder. The feedstock also has different characteristics.

Microscopy was used to study the morphology of the interior decoration composition. In particular, the authors used a raster ion-electron microscope QUANTA 200 3D. Structural images of the sample surface were obtained using a secondary electron detector, which has the highest lateral resolution (up to 3.5 nm), and has a strong topographic contrast. In combination with the large depth of field characteristic of scanning electron microscopes, the use of this method allowed us to study the shape, size of particles, the degree of their agglomeration for powders, and to study the surface morphology of pressed materials on cuts and chips. The sample layers were photographed in high and low vacuum modes. In low vacuum mode, the microscope chamber was purged with water vapor, so that the working pressure in the chamber was 100-120 Pa. This provided a good outflow of excess negative charge from the sample [17].

The final method of inspection of the technical standing of historical buildings and structures carried out in order to ensure and improve their operational reliability is shown in Figure 1. This algorithm takes into account the specifics of the historical real estate, which will allow to conduct a comprehensive accounting of factors that affect the operational reliability of buildings.

![Figure 1. Algorithm of survey of technical condition of historical buildings.](image)

The importance of BIM modeling for historical buildings has grown significantly in recent years. That’s clear, structural and functional stability of historical buildings are the biggest challenges in
development. Historical buildings are almost always under very strict restrictions referring to the functioning abilities, opportunities for structural and network reconstruction, while these buildings structures contain a numerous defects and shortcomings, incurable because of the structural age and condition and permitted according to the historical importance. The way the building should be surveyed and operated needs more accurate, relevant and actual tools for seeking, parsing, archiving and analyzing of these defects, so 3D-modelling and updating the actual state with the mostly remote defects’ measuring are the keystones of BIM-system efficient application for the historical buildings [18].

BIM-modeling for historical buildings should be based on several outstanding steps significantly distinguished from the BIM stages for the newly erected ones. Historical building informational model (HBIM) (Figure 2) should be based on cloud of points instead of detailed digital twins of the structures, because a lot of variance of real structures positions, translations, deflections, etc., accumulated in the centuries of structures’ life cycle. Cloud of points could be easy scanned and smartly manipulated within numerous modern scanners, like compact, easy to operate and fully software supported Leica BLK 360, the positive experience of their usage is accumulated by authors in several HBIM cases. On next stage cloud of points is to be filled with 3D-smart objects, used for storing all the information dealt with defects’ propagation, sizes, level of damaging. All the smart-objects are geotagged and timestamped with uploading into datasheet, that gives the opportunities for their retrospective analysis and predictive computation with dashboards and highlighting under user’s criteria. 3D-smart-object could be made within standard tools, embedded to all popular BIM-software, authors are proceeding them as the *.gdl objects in GDL-creating media in ARCHICAD. Thus, based on these basic principles, well popular and widely used in civil engineering, BIM-modelling techniques are getting more applied to historical building, being focused on the set of their special issues. HBIMs, based on cloud of points and smart-objects are useful and efficient for historical buildings’ operating through their life cycle [19].

Figure 2. Hardware and details of HBIM processed by the authors: a) Leica BLK 360 scanner; b) cloud of points as a basement of HBIM; c) 3D-smart object for modelling cracks in walls.

4. Conclusion
The developed algorithm for assessing the technical condition of historical buildings allows us to take into account: architectural style features of the real estate, the history of the development of architectural and space-planning solutions and their impact on the structural safety of the objects, the assessment of the impact of the development of adjacent territories on the state of the ground and foundation structures. An important step in solving the problem of restoring the historical appearance of the building is the archival search for design, operational or other documentation. When reconstructing religious buildings, it is particularly important to study the structure and authenticity of finishing materials, which involve extensive laboratory research of the structure of finishing coatings.

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