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THE IMPLEMENTATION OF BUILDING INFORMATION MODELING TECHNOLOGIES IN THE TRAINING OF BACHELORS AND MASTERS AT SAINT-PETERSBURGMINING UNIVERSITY

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ABSTRACT

The article deals with the quality of bachelors and masters training in the construction majors, capable offering and implementing fundamentally new technical and technological approaches in modern construction design based on the integration of the knowledge obtained from various fields of science and technology. The article presents the experience of implementing interdisciplinary connections using building information modeling technologies (BIM-technologies) in the course of study of general professional and special disciplines, in particular, the concept of an approach to the study of BIM-technologies products, such as Autodesk Revit (Revit) and Autodesk Robot Structural Analysis Professional (Robot) through the implementation of course and diploma projects. The tools of these products allow currently organizing two-way data exchange between them.

Keywords: BIM-technologies, Autodesk Revit, Autodesk Robot Structural Analysis Professional, interdisciplinary connections, structural design, building structures.

1. INTRODUCTION

The construction industry of Russia, namely, modern construction design, currently requires fundamentally new technical and technological approaches, which can be developed and implemented only by specialists, who are able to integrate ideas from various fields of science, engineering, and technology, i.e. to operate in interdisciplinary categories (Kondratyev 2016).

Implementation of interdisciplinary connections, when training bachelors and masters in the construction majors allows students to organize the knowledge gained in the study of general and special disciplines and use them in the implementation of the course and diploma projects. This approach in the training of future specialists allows students to form the ability to think systematically and independently, to use a set of knowledge and skills that allow effectively solving professional problems in the design of industrial and civil facilities using modern computer-aided design.

Currently, the creation of project documentation is possible using the Autodesk Revit (Revit) program, which contains specialized functions for the design and calculation of building structures with specified building materials, as well as allows performing a consistent update of models through bidirectional communication with the calculation programs, in particular (or rather, above all) with Autodesk Robot Structural Analysis Professional (Robot). Due to the advantages of BIM-technology, the level of coordination between designers and architects increases that makes it possible to produce better documentation reducing the number of errors.

The ability to work together in Autodesk Revit allows taking advantage of building information modeling by all project team members. Several users can work with the building model at the same time, saving the results of their work in a single storage file. Joint work can be organized in different modes: within the engineering and design organization, between design engineers, within the architectural and design organization, as well as between architects, and design engineers (NPC - Computer Science: Integrated Solutions for Computer Aided Design: Construction: Autodesk Revit Structure, n. d.).

2. METHODS

A methodological research subject of the present work is a system-functional approach to the formation of interdisciplinary connections when training bachelors and masters in the construction majors using BIM-technologies.

Research objectives are as follows:

- to identify the subject and interdisciplinary connections with the content of professional training of bachelors and masters in the construction majors, whose implementation is possible through the implementation of the latest design technologies in the educational process;
- to develop the concept of phased development of BIM-technologies products when studying disciplines of the natural science cycle, general professional, and special training;
- to develop methodological materials and individual tasks for students in the studied disciplines, whose tool are the BIM-technologies products.

3. RESULTS AND DISCUSSIONS

In St. Petersburg Mining University, when training bachelors and masters in the construction majors, BIM-technologies are used throughout the whole training period in the study of disciplines, such as Engineering Graphics, Computer graphics in design, and Information technology in construction. Students gain skills to work with Autodesk AutoCAD and Autodesk Revit when performing graphic tasks and coursework (Goldobina, Glukhova and Stoikova 2015; Goldobina and Khozyainov 2016; Goldobina, Glukhova and Khozyainov 2017; Goldobina 2018; Trushko, Demenkov and Tulin 2018).

It is known that Autodesk Revit allows constructing a model of the building, including that made based on Autodesk AutoCAD drawings. During the first years of study, students acquire basics of BIM-technologies, when working with Autodesk AutoCAD on architectural and construction drawings. Further, in the course of studying the Architecture of civil and industrial buildings and Information technology in construction, students start mastering Autodesk Revit Architecture program, which is known to create a parametric model of a building or structure. In turn, this model is used to develop the necessary specification documents.

When studying special disciplines, such as Theoretical mechanics, Materials resistance, Basements and foundations, Reinforced concrete and stone structures, Metal structures, and others, students get acquainted with the software and computer complex Autodesk Robot Structural Analysis Professional and other finite-element programs (Ing+, Sofistik, Plaxis) (Demenkov, Trushko and Potseshkovskaya 2018; Demenkov, Goldobina and Trushko 2018; Protosenya, Karasev and Ockurov 2017; Sych 2012), which can be used to perform calculations of various building structures, buildings, and structures.

It is known that Autodesk Robot Structural Analysis Professional allows performing accurate calculations of the most complex building structures and buildings in general by means of automatic meshing of finite elements, nonlinear algorithms, and an extensive library of calculation norms. Autodesk Robot Structural Analysis Professional easily connects with other Autodesk solutions, supporting two-way 3D communication with them.

The modern version of Autodesk Robot Structural Analysis resulted from many years of development and practices of its previous versions. The first commercial version of the solution, then owned by Robobat, was a product called Robot Structure, released in 1985. Six years later, the next version of Robot Structure called Robot V6 was delivered to 40 countries worldwide. Next were versions of Robot 97 and Robot Millennium. With each new version, the program was taking steps forward in both expanding functionality and improving usability. All this led to the fact that in 2008 the rights to the program were acquired by Autodesk, the world-famous leader in the field of CAD. From that moment on, the product became known as Autodesk Robot Structural Analysis and became an important part of Autodesk's integrated BIM solution.

Over the years of its application in the most ambitious construction projects, including the Spyros Luis Olympic stadium in Athens, the Wembley in London, Stade de France in Paris, the Millo viaduct in France, and many others, the software product has demonstrated its advanced capabilities, which is the best recommendation for its application (Demenkov, Trushko and Potseshkovskaya 2018).

A significant advantage of the product is direct two-way communication with Autodesk Revit. The transfer of the analytical model from Autodesk Robot Structural Analysis to Autodesk Revit is performed using a special option. At present, this connection is implemented to the maximum extent. Structural elements, loads and boundary conditions are transferred from Autodesk Revit to Autodesk Robot Structural Analysis that allows proceeding to the calculation almost immediately (Demenkov, Trushko and Potseshkovskaya 2018).

The mutual integration of Autodesk Robot Structural Analysis Professional and Autodesk Revit allows easily transferring models from one program to another. In addition, Robot has established a connection with the calculated extension Autodesk Revit Extensions, which extends the capabilities of Autodesk. The main tools of this extension are Modeling, Analysis, Reinforcement, and Steel components. Revit Extensions software package is constantly changing, something is removed, while part of the tools is becoming autonomous. Basically, the package is intended for the design works.

Due to bidirectional associativity, the calculated and design data are updated throughout the information model, taking into account the results obtained that contributes to the production of agreed specification documents. Moreover, Revit Structure allows transferring analytical information to computer-aided design and structural analysis programs created by third-party developers. The following data can be used together with external software: bindings and boundary conditions, loads and their combinations, and material properties (PSS-GRAYTEK (Petrostroysystem): Innovative technologies of CAD, BIM and enterprise management, n. d.).

In the course of studying special disciplines (Basements and foundations, Reinforced concrete and stone structures, Metal structures, Design of spatial reinforced concrete structures, etc.) and the implementation of course projects as part of their study, as well as when working on the bachelor's and/or master's final qualifying work, students not only get the skills to work with the BIM-technologies products, but get acquainted with the ideology of this technology, widely used both abroad and in Russia (Figure-1).

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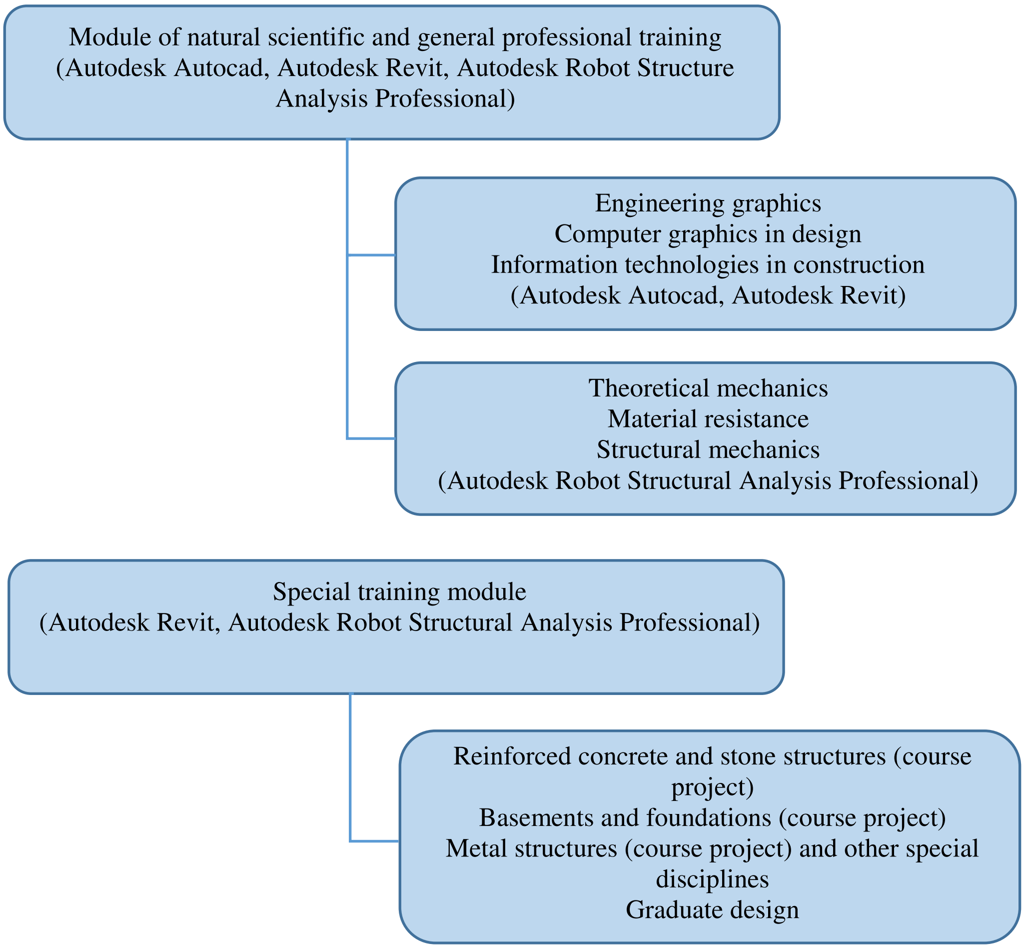

Figure-1. Interdisciplinary modules based on BIM-technologies.

For example, currently in Russia, the domestic architects and designers, using BIM-technologies have implemented important Olympic projects in Sochi, such as the Fisht Olympic Stadium (Figure-2a), the Large Ice Palace, the Iceberg Ice Palace, indoor Adler Arena Skating Center, infrastructure facilities of the Olympic village, Football stadium FIFA-2018, the high-rise building of the Moscow City, the second stage of the Mariinsky Theater in St. Petersburg (Figure-2b), and many others (Goldobina and Orlov 2017).

The authors of the article give stages of bachelor's course project on the discipline of Concrete and stone structures, as an example of the implementation of interdisciplinary links using BIM-technologies.

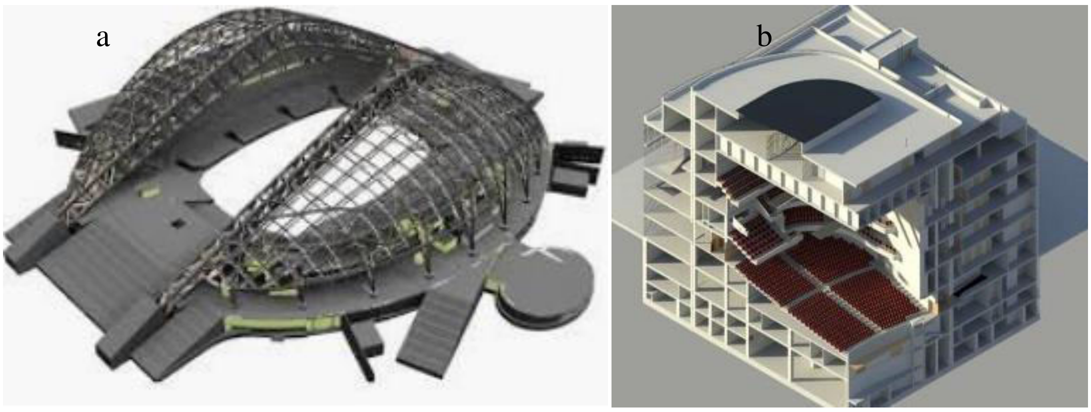

Figure-2. (a) Model of the FISHT Stadium (Sochi); (b) Model of the Second Stage of the Mariinsky Theatre (St. Petersburg).

The course project task on the design of monolithic ribbed ceiling with beam slabs provides for the implementation of the design and graphical part: the design part provides a justification for the choice of a structural scheme of a monolithic reinforced concrete frame with subsequent design and construction of the plate, secondary and main beams of monolithic floor structure, columns and stand-alone socket-type footing; the graphic part should contain design drawings for the execution of all structures of the reinforced concrete frame, made in accordance with applicable standards.

First of all, students manually perform the design of monolithic slabs by known methods and in accordance with the current code of rules for the design and construction of concrete and reinforced concrete structures. In the course of manual calculation, students use the knowledge and skills gained in the study of fundamental and general disciplines (Mathematics, Theoretical mechanics, Material resistance, and Construction mechanics).

Then the students are tasked with creating an analytical model of a reinforced concrete frame using Autodesk Robot Structural Analysis Professional software (Figure-3b), assigning and setting loads based on the results of manual calculation (Figure-3b), performing a static calculation of the frame. After that, it is necessary to perform the theoretical and actual reinforcement of core (column, beams) and plate elements. Results of reinforcement can be printed as a preliminary drawing.

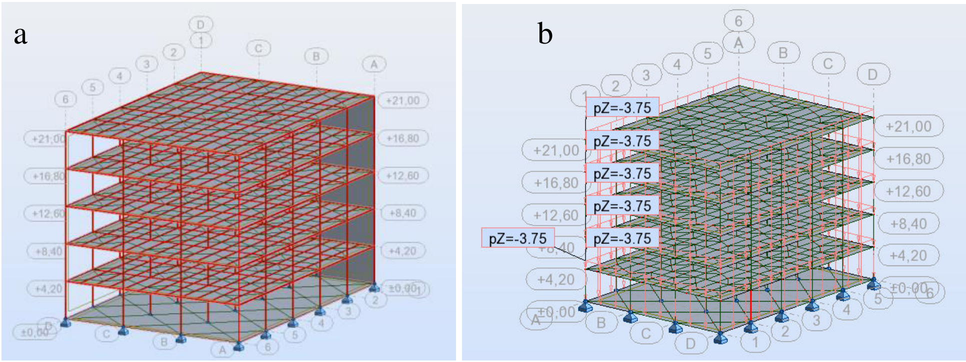

Figure-3. (a) Analytical model of a reinforced concrete frame in Robot; (b) load distribution in Robot.

The results of the manual and computer-aided calculations obtained within the framework of the preliminary design are analyzed and laid in the construction of a reinforced concrete frame of a multistory building in Revit software (in the Architectural template) (Figure-4a). After that, the model is transferred to the load-bearing structure template (Fig. 4b) and an analytical model of the framework is created. By means of existing Revit tools, the necessary loads and connections are set in the form of supports resistance (Figure-5), and then the analytical model of the framework is transferred to the Robot software complex (Figure-6).

The loads transferred in the course of Revit-to-Robot communication can be represented in local or global coordinate systems, depending on how they are defined in Revit. After the Revit model is transferred to Robot, the design of the structure is calculated. Robot creates a computational model based on the finite element method. It is known that the Robot performs analysis of the following types: linear analysis; calculation of steel, reinforced concrete and wooden structures according to various standards; dynamic and seismic calculations, including calculation of fluctuations; nonlinear calculation of geometry and material; and the calculation of the longitudinal bending. Autodesk Robot Structural Analysis Professional implements procedures that quickly process even the most complex structural models. Computational algorithms based on modern technologies allow engineers to achieve the required results faster by optimizing designs, repeating calculations, and evaluating various design options (PSS-GRAYTEK (Petrostroysystem): Innovative technologies of CAD, BIM and enterprise management, n. d.).

After performing the static calculation, Robot analyzes the resulted forces and stresses in the supporting structures (Figure-7), obtained in three ways: manual calculation, the direct calculation in Robot, and calculation in Robot imported from Revit model. Having the data of theoretical reinforcement, the final decision on the actual reinforcement of all supporting structures of the frame is taken (Figure-8).

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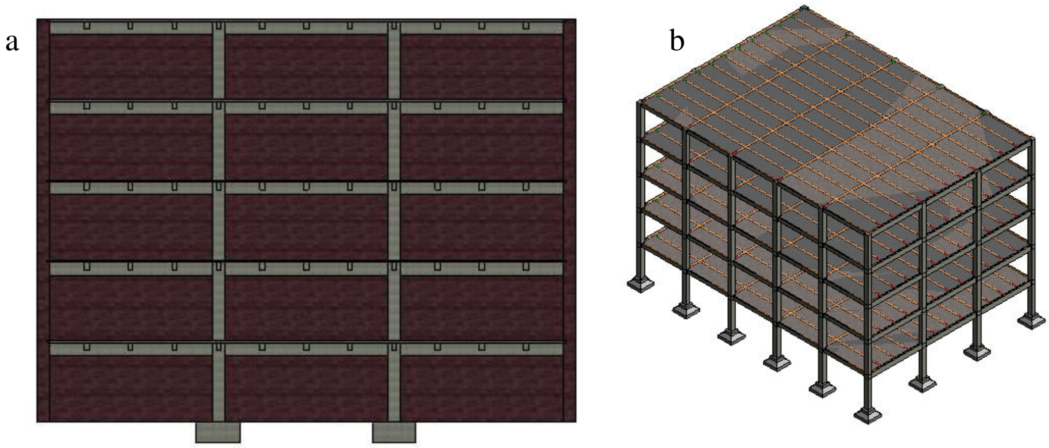

Figure-4. Physical model of a reinforced concrete frame in Autodesk Revit: (a) - architectural pattern; (b) template of the load-bearing structure.

Further, any changes in the design solutions related to the geometric characteristics of the cross-sections of bearing structures, reinforcement products and materials can be transferred to Revit. Integration with Robot Structural Analysis allows changing the geometry of the original design, dimensions of the section, materials, structural elements, and additional components of the design model (stiffening fins, eccentricities, the release of joints, rigid constraints, cushion course), loads, and supports.

Having decided on the final option of reinforcement of load-bearing structures, it is necessary to develop the specification documents with the mandatory creation of specifications and bill of materials.

Drawings can be created by the type of 3D model using Revit tools, specialized drawing tools, which are optimized for the creation of concrete structure elements, such as welded joints, anchor bolts, reinforcing bars, and reinforcement zones.

Revit allows automating repetitive tasks of drawing, inherent in conventional CAD software, speeding up the process of creating views, section views, and assemblies. Bidirectional associativity means that any change in any view extends to the rest of the views, ensuring consistency in the drawings (NPC - Computer Science: Integrated Solutions for Computer Aided Design: Construction: Autodesk Revit Structure, n. d.).

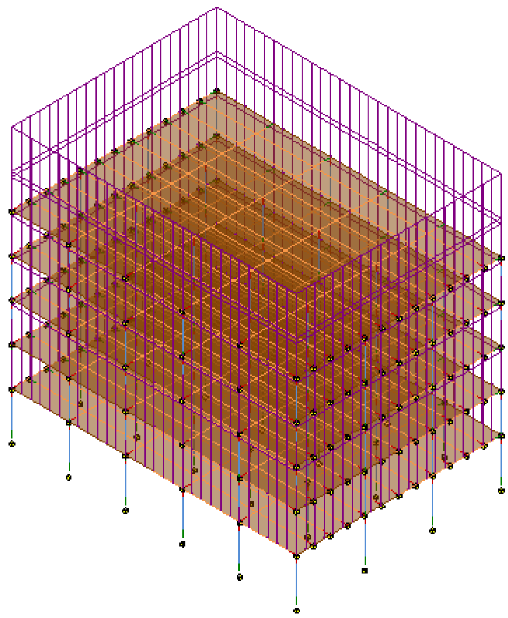

Figure-5. An analytical model of the reinforced concrete frame in Autodesk Revit: Load-bearing structure template.

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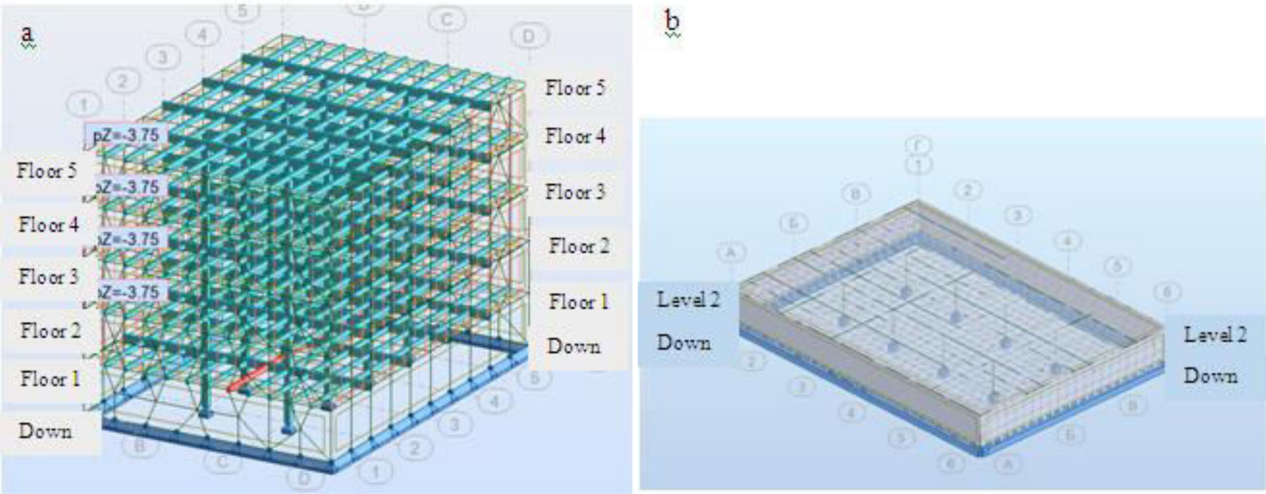

Figure-6. (a) Building models (frame and exterior wall fence); and (b) its floor, as a result of the integration of Revit and Robot Structural Analysis Professional.

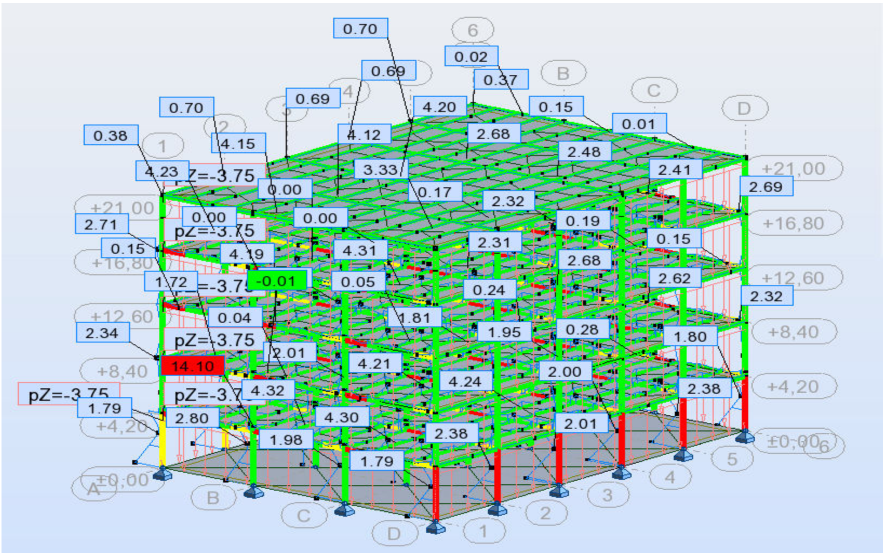

Figure-7. Results of tensions in the elements of reinforced concrete frame (Autodesk Robot Structural Analysis Professional).

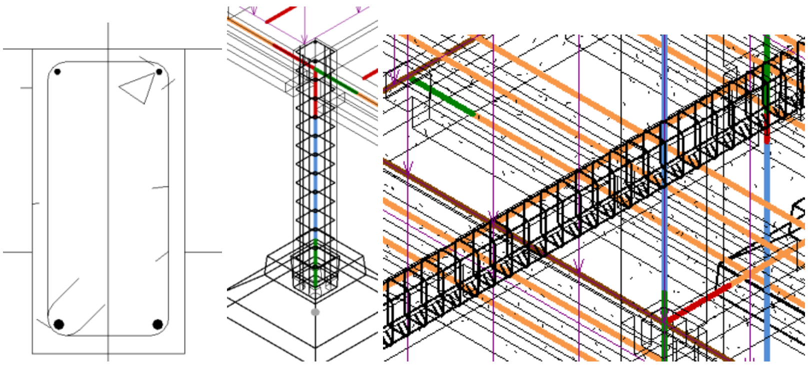

Figure-8. Completion of design solutions and development of specification documents in Revit.

Another example of the use of BIM-technologies is the implementation of students' final qualifying works, whose subject and scope go beyond the subjects studied by bachelors in the course of four-year training.

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One such work is the design of a shopping complex in Yekaterinburg (carried out by student A.I. Suchkova, supervisor L.A. Goldobina). The main task set for the student was modeling and designing the load-bearing structures of the shopping complex with a covering in the form of a flat shell of positive Gaussian curvature.

The student developed various space-planning and constructive solutions of the shopping complex building, justified the choice of the main load-bearing structures, developed technological and organizational solutions for the construction of reinforced concrete spatial coverage and load-bearing structures of the building.

The two-storeyed building of the shopping complex with underground parking has a rectangular outline with axial dimensions of 192×72 (m) (Figure-9). The frame of the building is made of a monolith with precast slabs. The covering is made in the form of a shell of positive Gaussian curvature consisting of precast concrete panels 3×3 (m). Truss diaphragm with a span of 24 meters is made of standard rolled sections and has a sliding hinge supports.

Using the Autodesk Revit zoning tools, preliminary versions of planning solutions were developed, after which the final volume-planning solution of the shopping center was taken, and spaces were calculated. By means of basic tools for the creation of forming elements, a conceptual model of the building was proposed, which allowed getting an insight into the projected object, as well as the main technical and economic indicators (TEI) (Figure-9).

Figure-9. Conceptual model of the shopping center building designed in Autodesk Revit.

The main part of the work is devoted to the design and construction of bearing elements of the covering, in particular, a flat concrete shell of positive Gaussian curvature, and a steel truss-diaphragm. Shell structures made of reinforced concrete make construction objects very expressive, in addition, they are economically viable, but they have a number of drawbacks, of which one is the complexity of calculations of their design. The BIM-technologies allow performing them accurately and quickly. The finite-element method along with modern computer technologies creates opportunities for modeling and calculation of structures of any complexity. The covering is multiwave in two directions, while its shell section is a square with a side of 24 m. The shell is assembled from flat ribbed plates with nominal dimensions of 3×3 (m) (Figure-10).

Calculations of elements of precast concrete spatial covering in the form of a shell of positive Gaussian curvature and steel truss diaphragm were performed first manually using known designing methods of such structures and then using the software and computer complex Autodesk Robot Structural Analysis Professional. Based on the results of the calculations, a comparative analysis was performed, which allowed defining the optimal parameters of the load-bearing structure elements. The specification of documents developed on the basis of the 3D model of the building is executed using the Autodesk Revit software complex, which operates based on the principle of information modeling of buildings.

No less interesting and well-developed is the final qualifying work on design of bearing reinforced concrete structures of multistorey frame house in seismic areas (student A.E. Startseva, supervisor L.A. Goldobina), demonstrating the implementation of interdisciplinary connections using BIM-technologies (as a result of the study of disciplines, such as Theoretical mechanics, Construction mechanics, Reinforced concrete and stone structures, and Information technology in construction).

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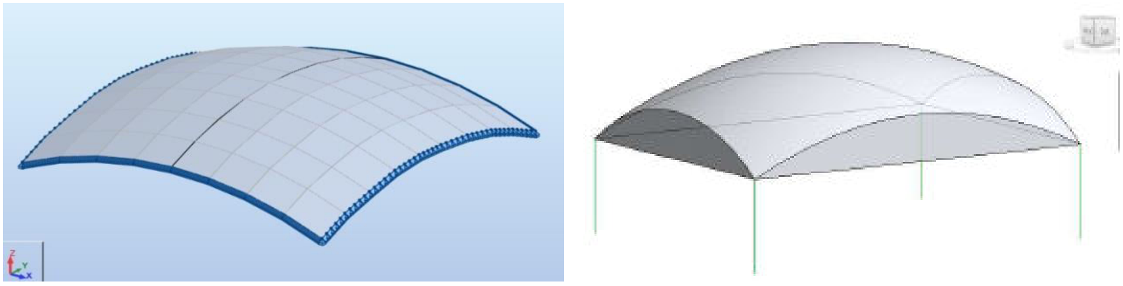

Figure-10. Shell element constructed in Autodesk Revit.

The relevance of the work is dictated by the fact that a significant part of the territory of Russia is located in seismically dangerous areas, where earthquakes lead to a significant destruction of buildings and deaths. Moreover, despite the high level of seismic design and seismic engineering, the destruction caused by seismic effects still occur. Therefore, to prevent possible damage, it is necessary to approach with special responsibility to the choice of structural and design schemes of the building, static and dynamic loads distribution, and the design of load-bearing structures based on the obtained strains, taking into account all regulatory requirements (Ayzenberg and Smirnov 2013; Goldobina, Startseva and Saveliev 2018).

It is known that in recent years, with the implementation of BIM-technologies, software and computer systems, such as SCAD, Lira-CAD, Robot Structural Analysis Professional, Ing+, and Sofistik are used widely. These software products are mainly developed by foreign companies. With the existing differences in the design of reinforced concrete structures according to domestic and European standards, including those performed using software and computer systems, the results obtained analytically (by manual calculations based on known analytical methods) not always coincide with the results obtained by means of various calculation packages.

Surely, the computer-aided design allows obtaining the rated tensions and structural reinforcement cards faster. Moreover, based on the virtual model of the building, one can quickly consider multivariate design solutions. Therefore, in order to be able to trust the results with a certain degree of probability, the goal of the final qualifying work was formulated as follows: to identify the design features of the building capable of perceiving earthquakes of expected intensity with minimal damage, and to find design solutions with optimal technical and economic indicators as exemplified by designing a monolithic reinforced concrete frame of a residential building to be constructed in a seismic area (in Gelendzhik).

The projected building has a complex configuration: it consists of three residential and two intermediate blocks, including a staircase and an elevator shaft. The blocks are separated by antiseismic seams, which made it possible to perform the seismic calculation for one typical residential block (seismic block). At that, the space-planning solutions of the seismic unit are designed in such a way as to ensure the structural regularity of the block frame in plane view and heightwise, as well as the coincidence of the shear center and the center of mass with the geometric center of the seismic block spot.

Analytical calculation of the seismic impact was carried out in the following order: determining seismicity of the area and the construction site; forming the estimated dynamic circuits of the building and determining its parameters; determining periods and forms of the frame oscillations, the estimated seismic load, forces in the frame elements caused by the action of seismic loads, forces in elements of the frame caused by the special load combinations; considering reinforcement options of the main load-bearing structures of the frame, checking the bearing capacity of structures and components of their connection (if reinforcement is already known) (Goldobina and Startseva 2018).

The static design scheme of a multistorey frame building with a simple design and planning solution is a multistorey frame presented at Figure-13. When determining the calculated seismic loads on the building, the calculated dynamic model of the building was used, which was consistent with the calculated static model, taking into account the distribution features of the loads, masses, and stiffness of the building in plane view and heightwise, as well as the spatial nature of the structures deformation under seismic effects (Nurieva 2010; Nurieva 2019). The loads in the model are taken as concentrated in the nodes of the design scheme, while only the loads that create inertial forces were taken into account. The dynamic design scheme of the building (mass model), used in the determination of seismic forces, is taken as a weightless cantilever rod, pinched at the base with loads (masses), concentrated at the level of floors and covering. Since the building is multistorey, a multimass model with loads concentrated on the floor level was considered. The forces in the frame caused by the action of horizontal (seismic) forces were determined by the torque points method. This method is based on the following basic principles: zero centers of moments are located in the middle of the strut heights; for the struts of the first floor, the position of the zero centers of moments is taken at a distance of two-thirds from the lower sealing; the sums of the overlying horizontal forces for each strut are distributed along the struts in proportion to the ratio of the linear stiffness of a single strut to the total linear stiffness of all the struts of the tier in question (Nikolaev 1990; Sarkisov 2015). Moments in the struts and crossbars of the frame were determined consistently, as well as transverse and longitudinal forces at the main combination of loads. According to the obtained moment diagram, using the rules of construction mechanics, the corresponding diagrams of transverse and longitudinal forces were constructed.

To verify the results of the manual calculation, in the application Shell Design of the Autodesk Robot Structural Analysis Professional software and computer complex, an analytical model of monolithic reinforced concrete frame of the designed building was created (Figure-11a). The monolithic load-bearing frame was created from reinforced concrete columns, beams, and floor slabs with the same input parameters (section sizes, classes of concrete and reinforcing steel materials) that were incorporated into the manual calculation. After that, static (permanent and temporary) and seismic loads were applied to the supporting frame, grouped into main and special combinations, taking into account the coefficients regulated by SP 20.13330.2011 Loads and effects (Figure-11a); static calculation of the spatial framework in the main and special combination of loads was performed, which allowed performing a comparative analysis based on the diagrams of bending moments and longitudinal forces. The results of the obtained forces in the rods are partially presented in Figure-11b. The results of these two calculations have a sufficiently high convergence that gives the right to further use this software-computing complex to create multivariant models.

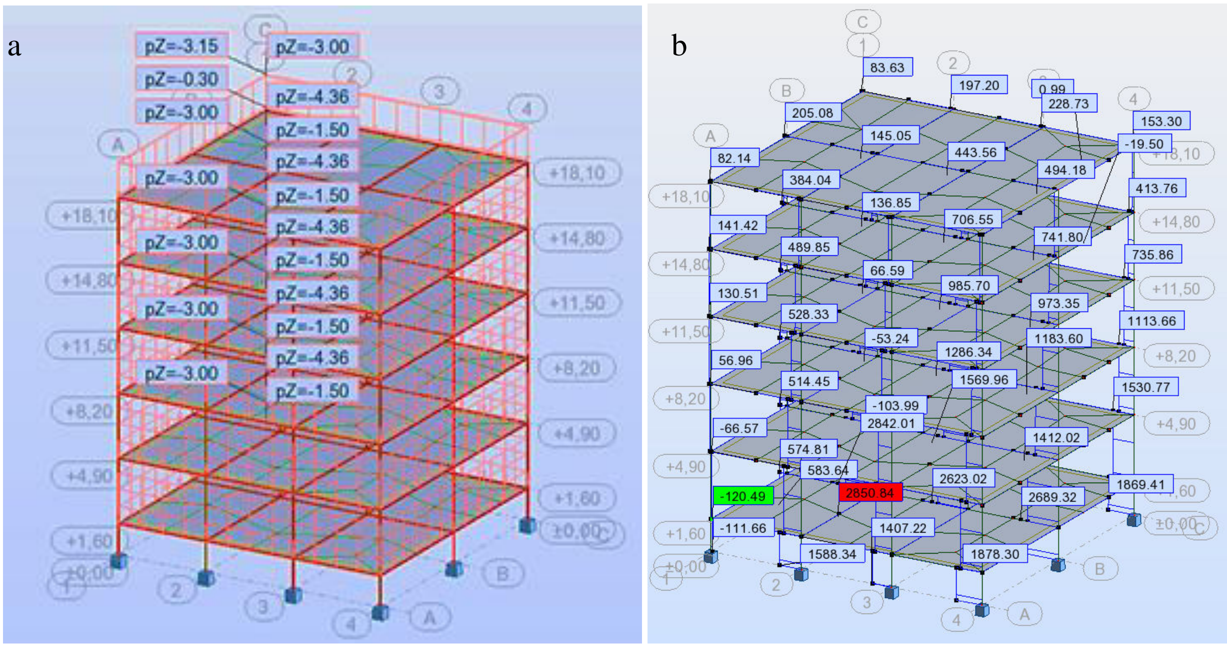

Figure-11. An analytical model of the multistorey frame (a) and longitudinal forces in rods (b) (special load combination COMB1).

Based on the comparison of the results obtained by the manual method and using the Autodesk Robot Structural Analysis software product, recommendations were proposed for the reinforcement of reinforced concrete structures.

The obtained results confirm the possibility of using the Autodesk Robot Structural Analysis Professional software and computer complex to obtain an overall picture of the behavior of similar structures, experiencing static and dynamic loads. Thus, the advantages of such computing systems, allowing creating multiple design schemes with various source data (design concept, the geometric characteristics of the cross-sections of load-bearing structures, materials, structural elements, and loading parameters) are quite obvious.

4. CONCLUSIONS

Implementation experience of BIM-technologies at St. Petersburg Mining University, when training bachelors and masters in the construction majors, clearly shows that students study various disciplines with great interest using software technology that allows information modeling of buildings, as well as demonstrate a high level of mastering these technologies.

The implementation of BIM-technologies in the educational process allows not only acquainting students with the technique, how to coordinate the development of a construction project from its concept through its construction and commissioning, but also to organize the educational process in a comprehensive and systematic manner, taking into account interdisciplinary connections and integration of general technical and special disciplines.

The Bologna System, being currently in force at the higher school of Russia, according to which bachelors and masters are training, including those for the construction industry, should be adapted to the needs of the construction industry. Therefore the implementation of the measures for the stage-by-stage implementation of BIM-technology in Russia should begin at the stage of training students in the construction majors. This will allow giving students the necessary knowledge, skills, and experience with modern computer technology, allowing graduates to continue to be in demand in the labor market of the construction industry, as well as participate in international projects for the design and construction of buildings at any level.

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