ЦИФРОВЫЕ ТЕХНОЛОГИИ В СТРОИТЕЛЬСТВЕ И АРХИТЕКТУРЕ

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IMPLEMENTATION OF BUILDING INFORMATIONAL MODELING IN DESIGNING MULTI–STORY MODULAR BUILDING

Abstract: The paper discusses features of employing BIM for designing modular building, using the Steel2Real'23 competition as a case study. The Steel2Real'23 student competition, organized by the Association for the Development of Steel Construction, seeks to enhance the usage of steel in construction. Modular construction is an emerging construction technology. However, a research gap is found concerning the practical usage of BIM in designing multi–story modular construction buildings in Russia. The article performs comparative analysis of the various approaches for process of designing and highlights that have streamlined the work of architects and designers during planning and design phases. The conclusions emphasize the advantages of employing information modeling in modular construction and outline the potential for its integration into contemporary design practices.

Keywords: Autodesk Revit, BIM, Modular Construction, Steel Construction

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ПРИМЕНЕНИЕ ИНФОРМАЦИОННОГО МОДЕЛИРОВАНИЯ ПРИ ПРОЕКТИРОВАНИИ МНОГОЭТАЖНОГО ЗДАНИЯ ИЗ БЛОК-МОДУЛЕЙ

Аннотация: В данной статье рассмотрены особенности проектирования зданий из модульных конструкций с применением BIM на примере задания, спроектированного для конкурса Steel2Real’23, организованного Ассоциацией Развития Стального строительства студентов ВУЗов с целью развития и популяризации применения стали в строительстве. В настоящее время модульное строительство является развивающейся технологией, но, при изучении материала, нами обнаружен недостаток информации в сфере применения BIM для проектирования многоэтажных модульных зданий в российской практике. В работе проведен сравнительных анализ разных подходов к проектированию, систематизирована информация об особенностях моделирования, приёмах, которые облегчили работу архитекторов и конструкторов на стадиях эскизного проекта и проектной документации. В выводах сформулированы преимущества использования информационного моделирования для модульного строительства и перспективы его применения в современной практике проектирования.

Ключевые слова: Autodesk Revit, BIM, Информационное моделирование, модульные конструкции, стальное строительство.

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1. Introduction

Over the past decade, the demand for real estate has increased, leading to advancements in construction sector and technologies overall.

The country's economic situation force companies to consider new materials, technologies in construction and designing processes.

Although reinforced concrete remains the most used material in civil engineering, many organizations actively promote and develop steel structures as another approach for residential buildings. The significant one is modular steel construction with prefabricated elements.

Modular construction provides a number of features, including extensive standardization of components.

The production of standardized modular units in factory setting improves the manufacturing quality, makes the assembly process safe and considerably reduces the on-site construction time. The efficiency of modular construction is noticeable mostly in social housing and dormitories, for which high-speed construction is not only the economic criteria, but also a social one.

In Russia, the most common use of modular units is low-rise prefabricated buildings on a small area or office containers, while the high-rise building is the option too.

The Association for the Development of Steel Construction organized the The Steel2Real'23 student competition, in which participants were asked to develop a project of multi–story residential building with built–attached non–residential premises of public purpose for the resettlement of people from dilapidated and emergency housing constructed of steel prefabs and modular constructions. To accomplish the task, it was crucial to choose an effective design approach and organize collaborative work between architects and engineers. Given the growing trend of active BIM application in design practice, we chose to employ the building information modeling throughout all stages of project, from the initial conceptual design to the final documentation.

The aim of this study is to set out the advantages of employing BIM in designing of multi-story modular building. The following tasks were undertaken based on the literature learned [1–11]:

– analysis of different design approaches and selecting the corresponding CAD;
– analysis of the features of modular construction;
– applying the features of selected cad to create information model and specifications;
– formulating conclusions and advantages of employing BIM in designing of modular building.

2. The analysis and CAD selection

2.1. Selection of design approach

Selecting the right design approach is essential at the first stage of project, since the thoughtful choice of CAD significantly influences the speed and quality of design process.

Three fundamentally different design approaches were considered

The first approach is based on making project in two-dimensional space. Within this method, only 2D graphics, specifically drawings of the project, are developed. The approach proves effective when there is an accumulated database of pre-existing solutions that can be reused across various projects. As a main software package, AutoCAD is commonly used. However, over the past few years Russian software nanoCAD is being actively implemented into the designing process.

The second approach involves combined application of CAD and BIM: two-dimensional drawings in CAD and an information model are created simultaneously and independently.

Typically, this approach is used at transitional stage of implementation of BIM into the designing process, as implementation of any new technology requires employee training, the development of standards, templates and families. A sudden departure from the regular two-dimensional drawing system to BIM leads to a decline in a project development efficiency. To implement this approach, the ability to transfer of information from the information model to a program with two-dimensional graphics is necessary. Hence, majority of companies use the combination of software provided by the same developer, for instance, Autodesk AutoCAD and Autodesk Revit.

The third approach includes the creating and application of a Building Information Model at all stages of the design process. Currently, this design approach is considered as the most innovative one and actively being implemented in real-world practice. The objective of this method is the development of an information model, which includes geometrical, architectural and structural information with varying detail levels. Moreover, this approach opens up significantly more opportunities for digitalization and automation in the design field. Not only the required drawings can be extracted from the model, but also material and element take-offs are collected and automatically transmitted to the cost estimation department. Autodesk Revit, Renga, and Model Studio CS are among the most widely used BIM programs

2.2. The application of BIM. Reasoning

We decided to design the building using information modeling due to a number of advantages:

– effective collaborative work between architects and engineers;

– the ability to assess the overall appearance of the building, layouts, technical and economic parameters at the conceptual design stage;

– the ability to make changes in the project and drawings rapidly;

– capability to generate a series of standard modules based on a single created module family;

– automation of specification calculations;

– reduction of the risk of errors due to human factors.

The application of a traditional CAD system proves practical only if there are pre-designed solutions for modular units, including drawings and specifications. However, this type of information and previously developed prototypes are not openly accessible.

2.3. Selection of BIM Software

The building information model is formed of standard modules, each functioning as an individual "element" with specific properties – a family.

The efficiency and quality of creating a model directly influenced by the level of detail in refining these “elements”. Due to this feature, we chose the Autodesk Revit software for the development of project as it provides the most flexible and advanced family editing tools. These tools were utilized to create modular elements, collectively forming a distinct highly parameterized module family.

3. The features of modular building

3.1. Modular unit

A modular unit, or module, is a three-dimensional self-contained structure composed of load-bearing steel elements and enclosing structures manufactured in factory setting, which meets the requirements of strength, stiffness, stability, and thermal insulation.

Modular units are classified by their purpose: residential, industrial – storage, administrative–office, medical – sanitary, and specialized. A module serves as an independent functional unit within a building, such as a part of a living room, bathroom, or a storage space. Depending on its functional purpose and level of prefabrication, a module may include installed equipment, openings for MEP systems, finishing, windows and doors (Fig. 1).

The structure of the module depends on its functional purpose and the height of building. Typically, modules have a rectangular plan, but there are instances of modules with non-standard shapes in foreign projects. Commonly, efforts are made to minimize the use of different module sizes within one project. The dimensions and weight of the modules are compared to the standards on weights and dimensions of transported cargo.

For the project, we developed several types of modules with different functional purposes and dimensions. The building includes residential and commercial sections, hence the modules are categorized by purpose and height. To reduce variability in sizes, all modules share a common width and only two length options.

Main module types (length x width x height mm) (Fig. 2):

– commercial section (height 3.9 m): 5000×3000×3900, 7500×3000×3900;

– residential section (height 3.3 m): 5000×3000×3300, 7500×3000×3300.

In addition to the main module types, auxiliary module sizes with additional pillars for structural enhancement were developed in response to the architectural concept of the building (Fig. 3).

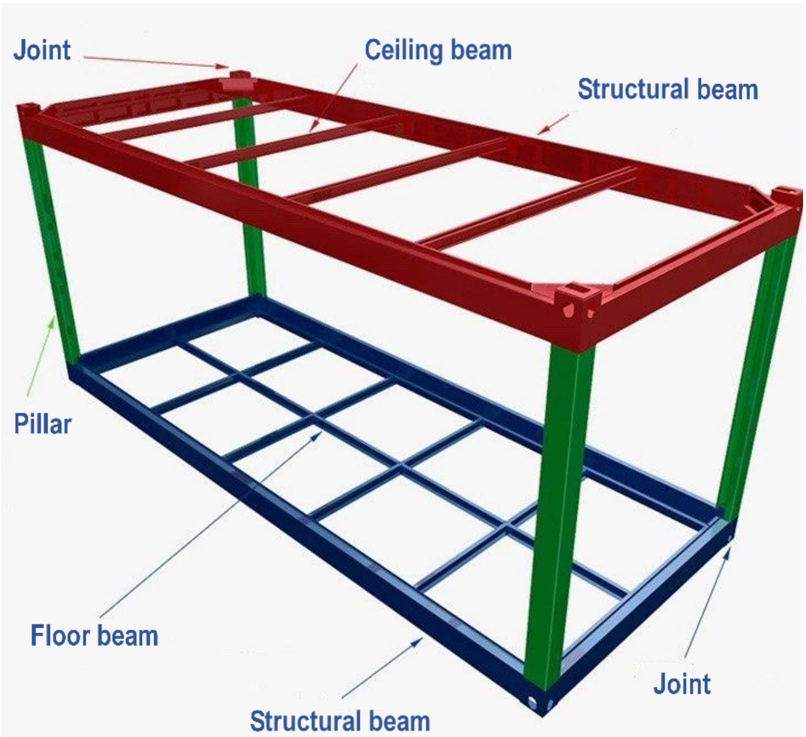

Fig. 1. Modular unit (figure by Kozhemiako E.A.)

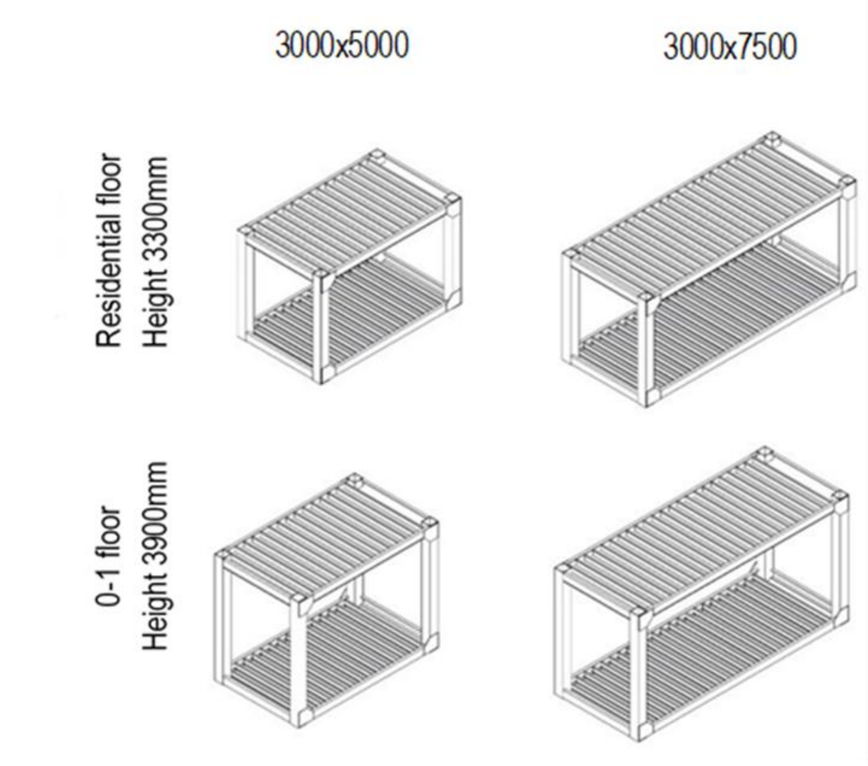

Fig. 2. Basic standard sizes of modules in the information model
(figure by Kozhemiako E.A.)

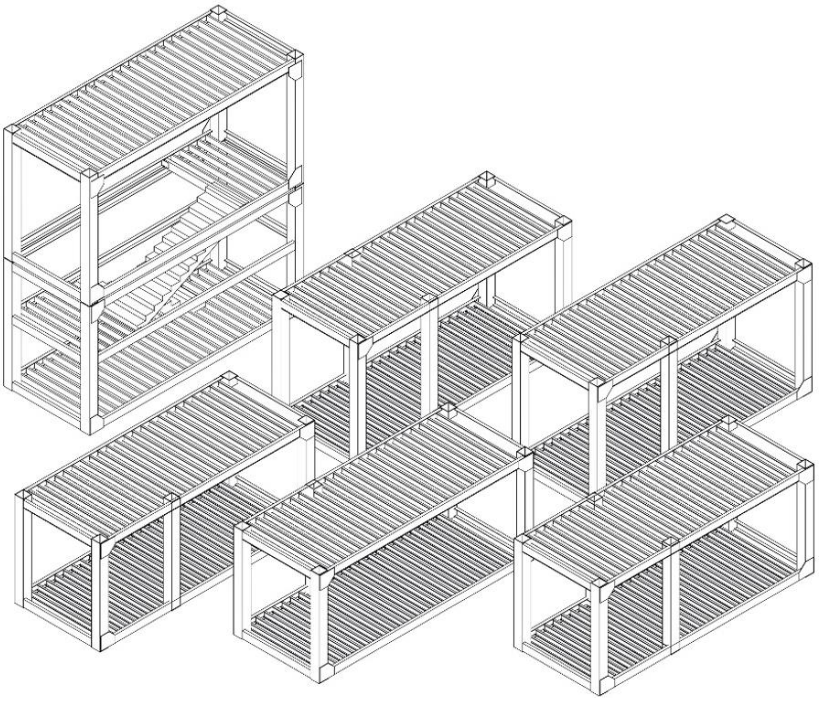

Fig. 3. Some standard sizes of modules with additional racks and additional modules for internal stairs in public premises in the information model
(figure by Kozhemiako E.A.)

3.2. Module Connection Joints (chapiter)

Unlike low-rise reinforced concrete, joints in steel construction are an integral part of the building's structural scheme. Therefore, joints must be thoroughly developed and executed to ensure the building meets the requirements of strength, stiffness, and stability. In modular construction, connection joints can be divided into two groups: intermodular, which connect the modules horizontally and vertically, and intramodular, which ensuring the connection of vertical and horizontal load-bearing elements of the module's frame and non-load-bearing enclosing structures [2, 3, 4].

Additionally, we developed a connection joint of module and structural core.

For intermodular joints, bolted, welded, and connector-based connections are employed. We utilized the "chapiter" as an intermodular connection – an element that links pillars between two adjacent floors (lower and upper)

3.3. Foundation joint

Modular buildings are highly sensitive to uneven settlements; hence, pile-raft foundations are used to support the modules. Typically, the modular unit is fixed to the foundation via the anchor bolts. Alternative solutions include embedding the pillar in concrete or utilizing an embedded foundation detail with a welded connection. The foundation joint performs two functions simultaneously: connecting modules on the lower floor in a plane and fixing the building to the foundation. A foundation joint with a welded connection to a plate, which is secured to the foundation with anchor bolts, was implemented in this project. Due to the absence of geological conditions and specific foundation requirements in the competition task, it was structurally assumed that the modules are supported on a flat raft foundation.

4. BIM practice for each element of a modular building

4.1. Creating the module family

As described earlier, it is necessary to create a well–developed module family that includes the real geometry and characteristics of load–bearing structures for effective work with the information model.

It is essential to use parameterization when creating module families, since it significantly increases the speed of creating all types of standard modules within a project. Based on a single family, standard sizes of various configurations, representing different types of modules, were easily created.

The parameters can include:

– geometric characteristics – height, width, number of beams;

– physical characteristics – material of load-bearing and architectural elements;

– rigidity characteristics – cross-section of load-bearing elements, presence of additional pillars;

– functional purpose – the presence of holes for communications, facing.

We implemented a family with a high degree of parameterization in compliance with the principle of a single family for all standard sizes of modules within the project. A single family that includes all module elements at once significantly increases design efficiency. Several non-parameterized families of different modules would prompt the user to make adjustments, which would lead to design errors and calculation errors of specifications, routine actions with moving elements in the project.

The module family consists of the following elements:

– vertical pillars (load-bearing columns) – hot-rolled steel square tubing shape column;

– crossbars (load-bearing beams) – hot-rolled steel channel shape column in accordance with GOST 8240–97;

– beams – cold-rolled steel beams in accordance with GOST R 58774–2019;
– gussets – hot-rolled steel plate in accordance with GOST 82–70.

For the project, we created ten standard sizes of modules, differing from each other in dimensions and the presence of additional pillars. Two standard sizes of modules are designed for internal stairs in public premises additionally.

4.2. Module Connection Joints (chapiter)

As mentioned earlier, the modules must be connected to each other. Based on projects from previous years and existing standard solutions, we implemented the “chapiter” joining in the project (Fig. 4). Due to the complex configuration of the building, both in plan and height, standard connection unit between the columns could not be used in the project. Therefore, a non-standard column connection unit is required, taking into account the number of pillars in the unit.

For this purpose, the parameterized family of “chapiter” is developed with the following parameters: the number of pillars coming from the top; the number of pillars coming from below, the dimensions of the connecting plate; logical dependencies that consider different positions of the pillars coming from below and from above (Fig. 5).

For the project, we created fourteen elements of different configurations, repre-

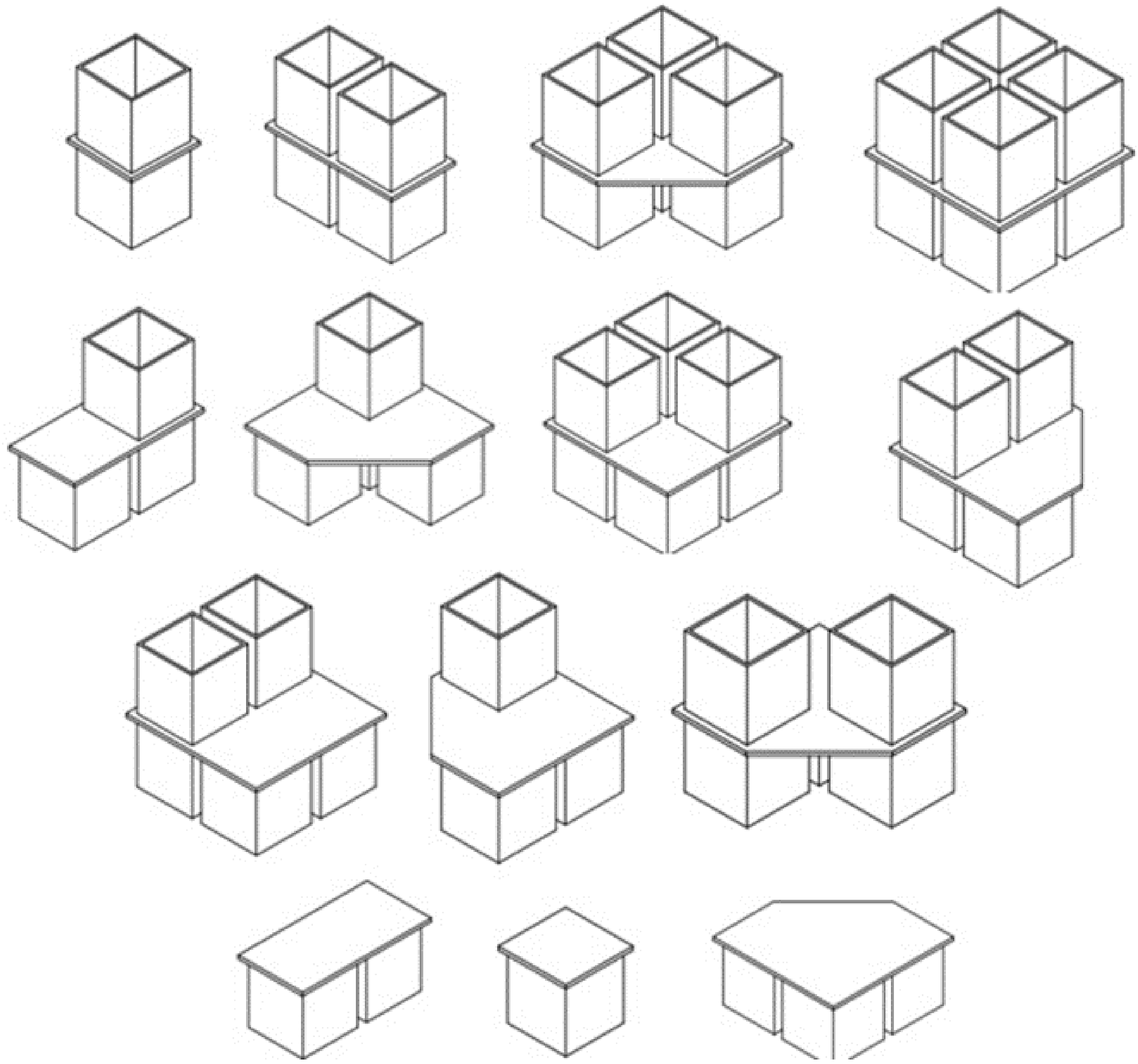

Fig. 4. Standard dimensions of “chapiter” (figure by Kozhemiako E.A.)

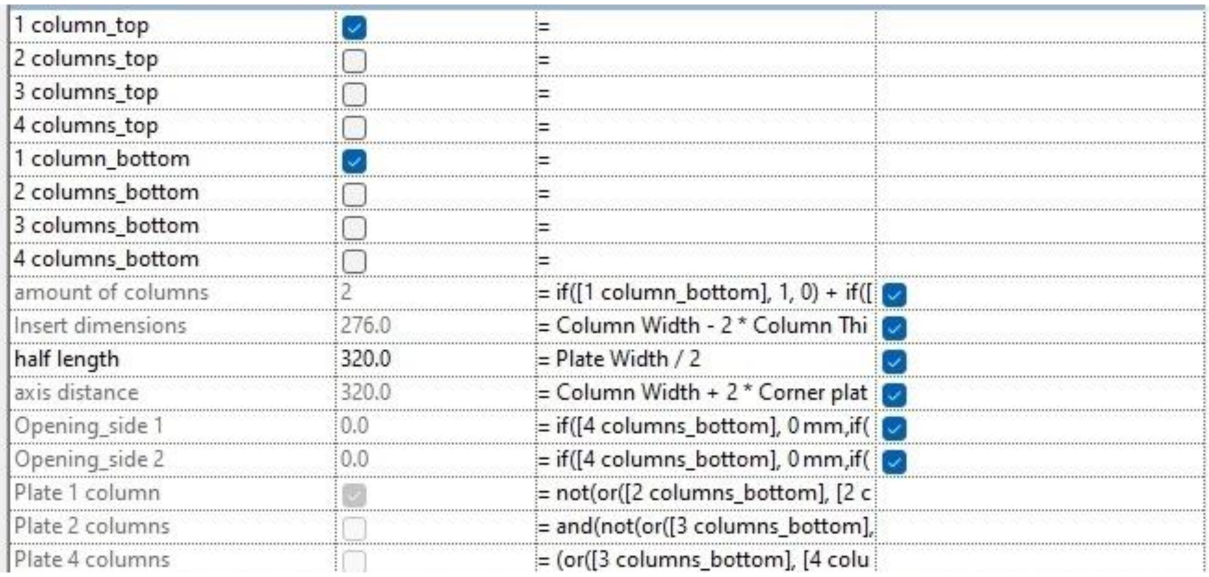

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Fig. 5. The example of how the “chapiter” works (figure by Karimullin I.S.)

senting standard sizes of the same 'chapiter' family, which consider the various relative positions of the modules. Figure 4 shows all the “chapiter” configurations. At the junction point above and below relative to the plate, both the same and different numbers of racks are possible in the project from 1 to 8, taking into account the different positions of the racks relative to the plate.

Both from above and below directions of plate junction may include equal or different number of pillars, in total from 1 to 8 pillars in different relative position.

For top floor modules, the upper connection joints are also constructed.

Based on the forces entered by the user, the welded connection of the plates and racks is checked for the following parameters: the weld according to the material of the seam and the material of the structures.

This approach greatly simplifies and accelerates the work of designers. The variability of chapiters joints due to the complexity of the project is high, therefore, with a traditional approach without families or with a poorly parameterized family, joints would take a long time to create, with possible errors. Using standard sizes of one family, “chapiters” are quickly arranged, and if changes are made to the project, it is enough to replace the current standard size of “chapiters” with another.

4.3. Foundation joint

We created the foundation joint family based on the functionality of the chapiters family. Fundamentally, the family of foundation units differs from chapiter that the racks were connected at the same level only from above relative to the plate, therefore the variability of standard sizes is lower compared to chapiter and depends only on the number of racks. The connection to the foundation slab is made using anchor bolts, which is additionally added to the family.

For the project, we created four standard sizes of the foundation joint family. They differ in the number of pillars connected to the joint, precisely from 1 to 4, and in the dimensions of the plate, depending on the number of pillars in the joint. (Fig. 6).

We also checked the welds connecting the plates and columns, as well as checked the anchor bolts for shearing and pulling out.

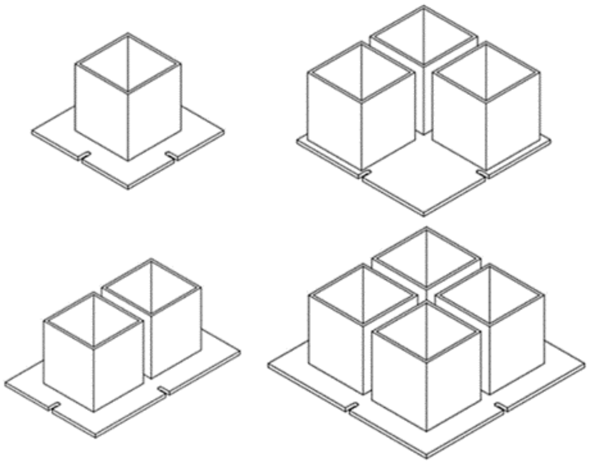

Fig. 6. Standard dimensions of foundation joint (figure by Kozhemiako E.A.)

4.4. Paperwork

After creating a full-fledged model of the building from modules, elements connecting the modules to each other, walls and floor slabs of the staircase and elevator, it is necessary to obtain documentation from the model.

The use of information modeling greatly simplifies the creation of drawings under the following conditions:

1. Accuracy of the model: correctly placed elements, correctly assigned properties of the elements.

2. Completeness of the information model: the model must be fully implemented

3. Sufficient detail of the model elements. The model should not be overloaded with unnecessary elements that will not be displayed or will be displayed only for joint drawings, and there should not be a strong geometric simplification.

4. Availability of templates and families of annotations that comply with the standards and rules of design documentation.

Since the model in the project is created accurately, comprehensively, with sufficient detail for documentation, the drawings of the load–bearing elements are automatically constructed correctly. Designer only need to manually enter dimensions, tags and general notes.

4.5. Creation and calculation of specifications

Availability of material and geometry parameters in family elements and specifications (BOM) creation tools in Revit allow automating BOM generation.

Specifications in Autodesk Revit are a table that defines element filters during installation and lists the properties of a given element. In specifications, fields (columns) are properties of an element, and users can set fields with formulas that will use the properties of the element and calculate another parameter. Templates with ready-made specifications already exist in the public domain. Thus, to automate criteria, it is necessary to assign properties to elements, fill them out correctly and apply the necessary filters on elements in the characteristics.

Each element was assigned an element grade, material, section and other data necessary for specifications within families of modules.

5. Advantages of BIM in the design of modular buildings

A modular building is a system of standard elements interconnected into

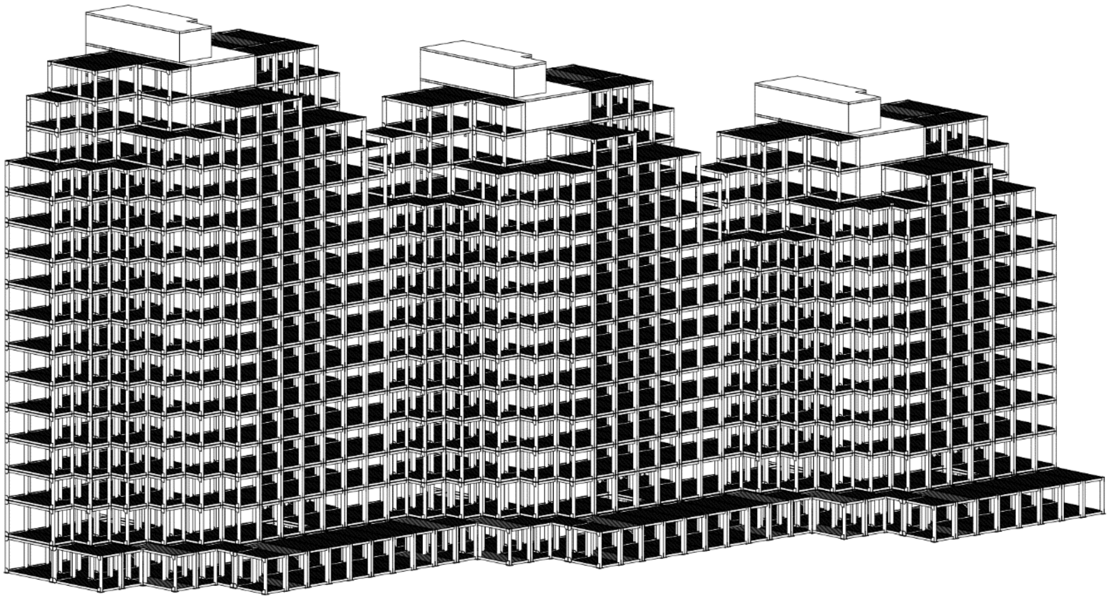

Fig. 7. Information model of load-bearing structures of a modular building (figure by Karimullin I.S.)

a single building. It is enough to develop standard modules and components, and the building can be assembled using identical elements. An information model is created in the same way: a typical floor is created from a set of families of modules and connections, which is then copied floor by floor. Thus, the most time–consuming part of running an information model is creating elaborate, parameterized families of modules and connections. In the future, these standard solutions can be used repeatedly for various projects and, if necessary, modified, which is the main advantage of using an information model.

The second advantage of using an information model is the constant coordination of the work of architects and designers. In the design of a modular building, many decisions must be made early in the project [2]. Since the modular building model immediately includes modules and load-bearing structures, the designer can immediately visually assess the adequacy of the building's structural design and make comments and changes (Fig. 7).

Other benefits at various stages of project development:

Correctly filled in parameters of load-bearing structures of modules allow users to automate the creation of specifications and eliminate errors in specification calculations.

Material take-off is calculated automatically and it is possible to evaluate it already at the preliminary design stage

It is easy to use for conceptual design architects

The number of errors in the project associated with the human factor is reduced to a minimum

Speed up drawing creation

Simplify the visualization process for architects – the model can be directly loaded into the required software.

6. Conclusion

Information modeling significantly speeds up the design of a modular building and improves the quality of project development.

Carrying out a project in BIM ensures, starting from the preliminary design stage, effective coordination of the work of architects and designers, since the load-bearing structures of the building are immediately visible in the model.

The use of modular construction technology in combination with BIM design can be a major breakthrough in modern construction. Information modeling allows engineers to take into account the design features of modular buildings correctly, which increases the speed of the design process without losing the quality of the development of design solutions. Families and a high degree of parameterization make it possible to consider the standardization of the elements of a modular building, greatly simplify making changes, automate the calculation of specifications and the creation of correctly designed drawings.

At the same time, one of the main features of modular construction is the high speed of building construction due to the high unification of elements. As a result, the combination of BIM and modular construction allows one to increase the speed of building construction by an order of magnitude, improve the quality of project development and makes it possible to implement more complex projects made of modules in the future. These advantages can be used both for the construction of social housing and housing for resettlement, and for non-standard projects of office and residential buildings.

It is worth noting that to achieve this result, a software package with a flexible family editor is required, which Russian CAD systems cannot provide currently.

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