Prospects for the multi-storey buildings construction using wooden structures

M Konovalov*, G Kozinets
St. Petersburg Polytechnical University named after Peter the Great, Politechnicheskaya str., 29, St. Petersburg, Russia

E-mail: mikhail.konovalov.94@gmail.com

Abstract. This article presents the multi-storey wooden construction development problem in Russia. The paper presents the work results on the possible mixed systems development for multi-storey buildings, where wood is embedded in the building structural system. In addition, the wood introduction effects are evaluated.

A 16-storey business center, with dimensions in terms of 22x44 meters was considered. As a result of the research for this object, a comparative analysis of a reference building made of monolithic reinforced concrete and four concepts, made entirely or partially of wood, was performed. According to the analysis results, strength, technical and economic indicators were calculated, and the conclusions and recommendations of advisory nature were made.

Introduction

Construction of multi-storey wooden houses is a promising direction for the construction industry development in Russia. Today, conventional high-rise reinforced concrete, is not surprising. Such buildings have already entered our lives long ago and have become a common practice in development, especially in “sleeping” districts and business centers. Another thing - a high-rise structure of 16 floors, made of wood.

Currently, the topic of wooden housing construction is only indicated in our country, but at the highest level are the following events:

• May 17, 2016 President of Russia Putin V.V. at the meeting of the State Council, instructed the Government to “develop a set of measures for the wooden housing development in the Russian Federation” [1];

• On March 15, 2018, the Government of Russia issued a decree “On the procedure for granting subsidies for the factory-made wooden houses purchase” [2].

But European countries are much further advanced in this topic implementation. According to statistics, the share of wooden housing is: in Finland - 40%, in Austria - 30%, in Sweden and Germany - 20% [3-5]. However, this circumstance makes it possible to significantly speed up the process of introducing into the Russian practice of wooden housing construction by the selection of technological solutions already existing in the world.

The scientific work relevance is related to the prospects for the wooden multi-storey buildings’ construction in Russia, especially in its remote areas, where there is a shortage of traditional materials: concrete, metal, etc. For such buildings construction it is supposed to use environmentally friendly materials, the processing of which practically does not occur emissions of carbon dioxide and other
harmful substances into the atmosphere. In addition, when choosing this technology for the buildings construction, weight reduction and reduction in the building structures volume, reduction of labor costs and construction rates are achieved.

The aim of the work is to adapt multi-storey wooden construction in Russia by the wooden elements use in the supporting frame of the building.

To achieve this goal, the following research objectives were formulated:

• to analyze the regulatory framework in Russia and the existing restrictions;
• to conduct a comparative analysis of the traditional building materials used and modern materials made of wood in the multi-storey building supporting elements;
• to develop conceptual solutions for office buildings where wood is sold in a mixed frame system and calculate the technical and economic indicators of these concepts.

The scientific novelty of the work is as follows:

• development of possible conceptual solutions for multi-storey public buildings, where wood is sold in a mixed frame system;
• the supporting structure model development of buildings with the wooden elements use in the software package;
• the wooden elements technical and economic efficiency determination use in the supporting structures in high-rise construction.

The practical significance of the work lies in the possibility of adapting this type of foreign construction from wood in Russia.

The progress of the work

To accomplish this goal, it was decided to develop five building concepts with the wooden elements use in the supporting frame of a multistory building and to make a subsequent comparison of these concepts with a reference sample made of monolithic reinforced concrete. The calculation of the components was carried out taking into account the regulatory documentation (SNiP, SP, GOST).

The design was calculated according to two limiting states (in the first and second groups), taking into account the loads unfavorable combinations.

The dimensions of wooden, concrete and steel columns were calculated taking into account the vertical loads from 50 kN to 2 MN. By changing the load, it was possible to assess the choice effect of the material for the columns in the building under consideration.

As a reference building, it was decided to take the business center building, see Figure 1. The service center is located at the address: St. Petersburg, Bogatyrsky Avenue, 3.

![Reference building (Business Center).](image)
The calculation of the building and the elements sections selection was carried out using the Finishing Element Analysis System Lira-Sap 2012, and the calculation of the designed concepts using Autodesk Robot Structural 2017, Figure 2.

The investigated building is a 16-floor construction. However, only the upper floors were used for the comparative analysis: from the 8th to the 16th. The dimensions and type of columns, beams and floor slabs used in the basement and from the 1st to the 7th floors, inclusive, were used as in the reference building, the material is reinforced concrete.

Results
Based on the reference building and its components drawings, five alternative concepts were developed:

• **Concept No. 1** – all load-bearing components were made of wood, except for the central stiffness core, roof, basement elements and load-bearing elements from the 8th to the 16th floor.

  In this concept, wood is used in greater quantity than in other concepts that are preferable. The columns size compared to the reference building has become a little larger.

  In these calculations, the building was loaded with a wind component in addition to its own weight and payload.

• **Concept No. 2** - instead of wooden columns, I-section steel columns were used. The location remains the same as in concept No. 1. The remaining elements remain wooden.

  In this concept, the wooden columns were replaced with I-section steel columns, and the floors and beams remained the same as for Concept 1. The steel columns dimensions became much smaller than the columns in Concept 1.

  In addition to the fact that the columns turned out to be of a smaller section, their weight also decreased by about 20%. 

![Figure 2](image-url)
• **Concept No. 3** - in the right part of the building, the span was increased from 6 m to 12 meters. This allowed the steel beams inclusion in the left side of the building. For other beams, wood was used. Bearing elements are made of steel and wood.

In this concept, in the right part of the building a column was removed in the area of office premises requiring large space. Because of this, it was decided to replace the wooden beams with steel beams of the I-section, due to an increase in the span of 12 meters. But there is also a drawback: the I-section beam, it turned out a large section. And this means that this beam will hide the inter-floor space.

However, there are negative aspects to this concept. They consist in the fact that it is required to use the several different types of beams, and also it is required to increase on the right side of the building, due to the increase in the column cargo area.

• **Concept No. 4** - beams are made of steel, the remaining elements are made of wood.

In concept 4, the I-beam section steel beams were used instead of wooden beams.

Calculations showed that using steel beams, the columns load decreased, but not significantly, about 3% of the total load coming on the columns.

In the concepts’ development, it was decided to leave the central reinforcement core from reinforced concrete to impart additional rigidity to the building.

When developing concepts, two versions of beams and columns were applied: LVL and metal I-beams. The cross sections of all elements were calculated for standard fire resistance R90 and compared with the reference building for strength and technical and economic indicators for the specific building area.

When using the wooden elements in the building supporting frame – the wooden building small specific weight is achieved, which allows the use of a smaller foundation. But on the other hand, light structure can be a problem when designing tall buildings. In many cases, it is necessary to provide the lightweight frame of the building with additional weight or to strengthen it additionally to prevent the building from tipping over. Therefore, it was decided to compare the masses of different concepts. It is worth noting that the building upper parts masses (from the 8th to the 16th floor) were compared.

The building and the roof core weight are the same for the concepts and the reference building. The floors and walls weight has the greatest difference in relation to the total weight of the building. There was also a significant percentage difference between the beams. However, the effect on total weight is negligible.

In a comparative analysis of weight characteristics, the easiest is concept 4, where the beams are made of steel and the rest of the elements are made of wood. Concept 4 is 49.36% of the weight of the reference building, i.e. 51.64% lighter, and it turns out that this option is two times lighter than the reference building.

The rest of the concept is not much harder. The most difficult concept was concept 1 and is 51.13% of the reference building weight and just heavier than concept 4 by 1.77% or 90 tons.

As stated earlier, a lighter building requires less foundation.

If a pile foundation is applied, it is possible to use fewer piles, or make smaller piles. This allows to spend less material, less energy, on the foundation construction, which makes the foundation of a lighter building - cheaper, less labor intensive and environmentally friendly. It is also interesting to consider this option in the areas with weak soils, for example, in St. Petersburg, where waterlogged, boggy, and clay soils predominate.

In addition to comparing the weight characteristics, the concepts load-bearing structural elements dimensions analysis with respect to the applied loads was made. The analysis showed that the required dimensions of the supporting elements made of wood in all cases are larger in relation to structures made of traditional materials made of steel and concrete. But at the same time, wooden elements perform their functions with the same efficiency, while maintaining the bearing capacity when exposed to fire. The fire resistance characteristics of wooden beams comply with the regulations.

When designing, the most effective strength, as well as technical and economic indicators for wooden structures is a span of 6 meters.
The use of wooden floors instead of concrete is almost a prerequisite. After all, if wooden beams and wooden columns can be replaced with analogues, then with overlapping, such a replacement will only increase the mass of the structure as a whole. Otherwise, the beams and columns dimensions become too large.

For the office buildings where large spans are required, it may be better to use steel beams instead of wooden beams. This is due to the fact that the beam’s cross section becomes very large. Wooden beams are better suited for buildings where the spans may be smaller, such as residential buildings.

The bearing elements strength characteristics analysis showed that the wood bearing components required dimensions in all cases exceed the dimensions of structures made of traditional materials: steel and concrete. But, at the same time, wooden elements do not worse perform their functions, withstanding a given load and retaining the carrying capacity when exposed to fire.

As shown by the technical and economic indicators calculations, the most expensive option in all cases is the monolithic reinforced concrete construction. The cheapest option is the construction of a combined supporting frame, where wooden columns are combined with steel girders. But the construction costs of wooden elements occupy an intermediate place (Figure 3).

![Comparison of concepts with reference building](image)

**Figure 3.** The calculation results’ analysis.

**Summary**

Summarizing the above-mentioned, it is possible to draw the following conclusion. The most promising direction in the multi-storey wooden construction development is the use of a combined supporting frame, a combination of wooden columns with steel floor beams. However, in this case, further study of the problems associated with the combination of various materials during the supporting structures construction is required.

In addition to this, the main problem in the wooden buildings with a reinforced concrete rigidity core design is the difference in vertical displacements. In this case, it is necessary to use structural joints that perceive displacement data, or provide measures to reduce this difference in displacements.

Nevertheless, the main advantage of this type of construction is the possibility of building these buildings with a shortage of traditional materials. And this will reduce the additional costs of delivering...
and constructing buildings from traditional materials in distant areas. Therefore, it is recommended to use this option of construction for the areas with a shortage of steel and concrete.

In concluding research on this type of construction, it is worth paying special attention to the fact that the engineers who will probably be able to implement these projects do not forget about the problems encountered when combining the load-bearing elements from various materials. This should be borne in mind at the initial stages of the project to all participants: the customer, architects, engineers and builders.

References
[1] Introduction on http://kremlin.ru // List of instructions following a meeting of the State Council // Official network resources of the President of Russia // Pr-1138GS, p.2 g), 2017.
[2] Information on http://m.government.ru // On the procedure for granting subsidies for the purchase of factory-made wooden houses // Official network resources of the President of Russia, 2018.
[3] Schegolev E V 2017 Ecological Construction with the Use of Wood as the Main Building Material (Scientific Bulletin of the Voronezh State University of Architecture and Civil Engineering: Publishing House of the Voronezh State University of Architecture and Civil Engineering) 3 142-149.
[4] Shirmanov V V 2014 Construction of Environmentally Friendly, Energy-Efficient, Pre-Fabricated Wooden Buildings (Building materials, equipment, technologies of the XXI century) 8 38-40.
[5] Belichenko M Yu, Akhmetova L R, Drozdov V A 2016 Construction of Multi-Storey Buildings Based on Wood (Problems of Modern Science and Innovation) 12 31-37.