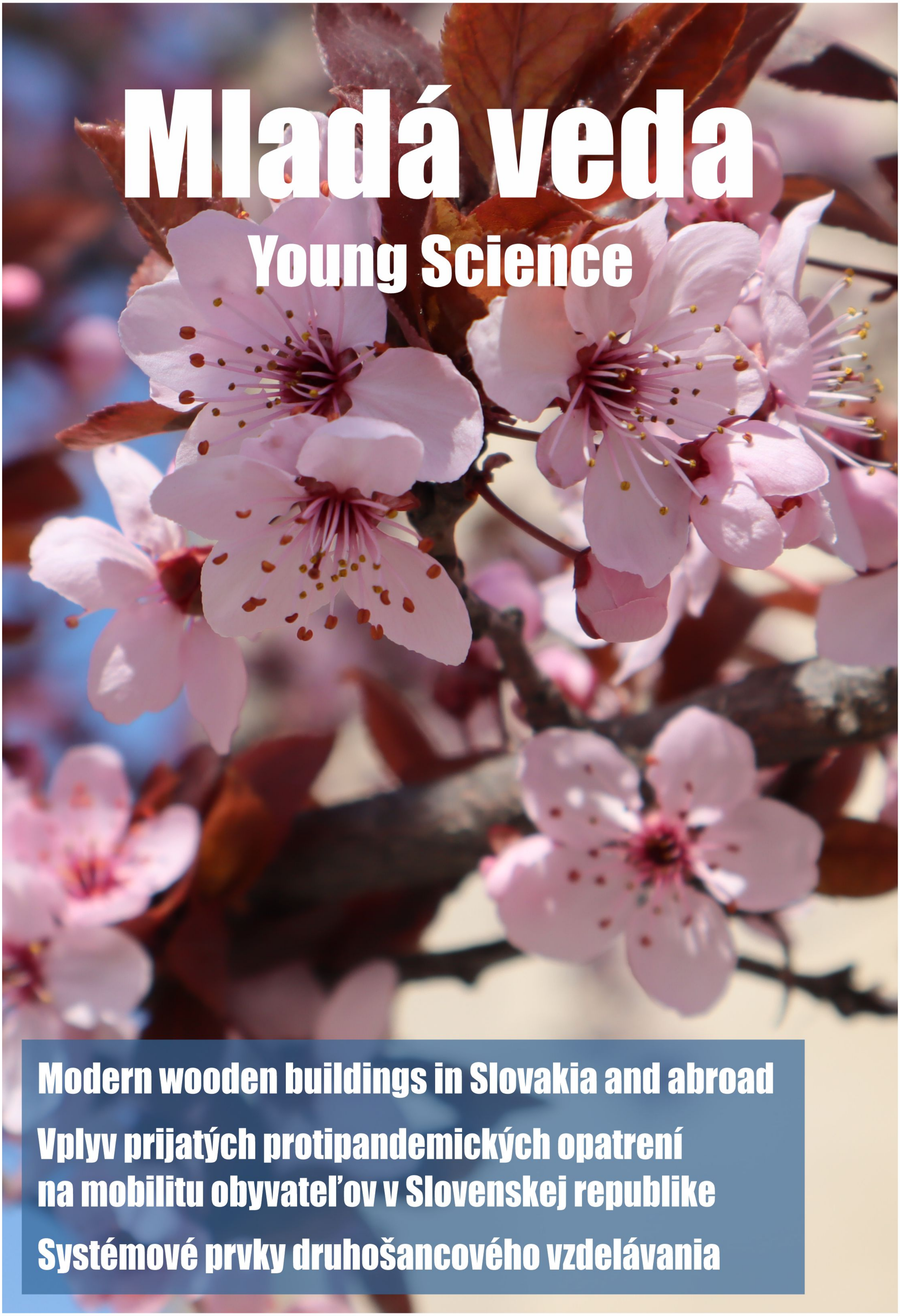
ISSN 1339-3189

1/2021



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Young Science

Modern wooden buildings in Slovakia and abroad

Vplyv prijatých protipandemických opatrení na mobilitu obyvateľov v Slovenskej republike

Systémové prvky druhošancového vzdelávania

Mladá veda
Young Science

MEDZINÁRODNÝ VEDECKÝ ČASOPIS MLADÁ VEDA / YOUNG SCIENCE

Číslo 1, ročník 9., vydané v marci 2021
ISSN 1339-3189
Kontakt: info@mladaveda.sk, tel.: +421 908 546 716, www.mladaveda.sk
Fotografia na obálke: Jar v Prešove. © Branislav A. Švorc, foto.branisko.at

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Slovenská republika

Mladá veda
Young Science
ISSN 1339-3189

Vol. 9 (1), pp. 74-85

MODERN WOODEN BUILDINGS IN SLOVAKIA AND ABROAD. ASPECT OF SUSTAINABLE ARCHITECTURE & ACTUAL LEGISLATION

MODERNÉ DREVOSTAVBY NA SLOVENSKU I V ZAHRANIČÍ.
ASPEKT UDRŽATEĽNEJ ARCHITEKTÚRY A PLATNÁ LEGISLATÍVA

Peter Hanuliak, Peter Hartman [1]

Obaja autori pôsobia ako odborní asistenti na Stavebnej fakulte STU v Bratislave. V rámci svojej vedeckej činnosti sa venujú aplikovanému výskumu vplyvu tieniacich zariadení na nevizuálne účinky svetla na človeka. V pedagogickej praxi sa venujú najmä konštrukciám pozemných stavieb.

Both authors work as assistant professors at the Faculty of Civil Engineering STU in Bratislava. As part of their scientific work, they are engaged in applied research on the effect of shading devices on the non-visual effects of light on humans. In pedagogical practice, they focus mainly on the construction of buildings.

Abstract
Wood as a building material is on the rise again thanks to the current, evolving trend of sustainable architecture development. Its major advantage over other building materials is the combination of its mechanical, thermal and aesthetic properties. Together with good workability and the technology of making wooden prefabricated elements also makes it possible to ensure high accuracy, modulation and complexity of prefabricated elements. Prefabrication enables a significant acceleration of build-up processes thanks to immediate load-bearing capacity. Its environmental aspect associated with environmental friendliness is gaining prominence, especially today, as it is a renewable building material with a minimum of toxic substances. The article offers a critical view of the situation and possibilities of development of construction of wooden buildings in Slovakia from the perspective of current legislative restrictions and at the same time with regard to the ever-evolving trends and inspirations from abroad.
Key words: wooden building, sustainable architecture, high-rise building

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Abstrakt

Drevo ako stavebný materiál je aj vďaka súčasnému, rozvíjajúcemu sa trendu rozvoja udržateľnej architektúry opäť na vzostupe. Jeho najväčšími prednosťami a výhodami oproti iným stavebným materiálom je kombinácia jeho mechanických, tepelno-technických a estetických vlastností. Spolu s nimi vyniká jeho dobrá opracovateľnosť a technológia vyhotovenia drevených prvkov zároveň umožňujú zabezpečiť vysokú presnosť, moduláciu a komplexnosť prefabrikátov. To zároveň umožňuje významné urýchlenie výstavby už len z toho dôvodu, že drevo disponuje svojou únosnosťou okamžite. Do popredia, obzvlášť v dnešnej dobe, sa dostáva jeho environmentálna stránka spojená so šetrnosťou ku životnému prostrediu, nakoľko sa jedná o obnoviteľný stavebný materiál s minimom obsiahnutých toxických látok. Príspevok ponúka kritický pohľad na situáciu a možnosti rozvoja výstavby moderných drevostavieb na Slovensku z pohľadu súčasných legislatívnych obmedzení a zároveň s ohľadom na stále viac sa rozvíjajúci trend udržateľnej architektúry a inšpirácie zo zahraničia.

Kľúčové slová: drevostavba, udržateľná architektúra, výšková budova

Introduction

Wood as a building material is on the rise again thanks to the current, evolving trend of developing sustainable architecture. From the point of view of the consumed primary energy, the wooden structure is the least burdensome for the natural environment in comparison with silicate-based materials, which is advantageous if we evaluate the building in a complex way. The study [1] compared alternative construction systems of low-rise buildings with regard to its environmental impact during the initial phase of production of building materials and the final phase in the disposal of these materials. The environmental impact was up to 2.7 times higher in classic masonry buildings, compared to wooden buildings.

Wood is the only building material with the property of carbon sequestration, which means that it can absorb carbon in various forms into the biomass of wood and forest soil. As a result, forests reduce the concentration of CO_2 in the atmosphere and therefore wood shows a negative CO_2 balance, showed in Tab. 1.

Material	Amount of kg of CO_2 released / absorbed per m^3 of material
Concrete	333.6
Structural steel	12207
Glued laminated timber (GLULAM)	-714.4
Cross laminated timber (CLT)	-678.3

Table 1 – Comparison of CO2 released / absorbed balance for different materials [2]

The design of the 43-storey and 142 m high building has shown by calculation [3] that the use of a concrete reinforcing core and wooden CLT space elements can save up to 50,000 tonnes of CO2 emissions during construction, compared to a construction system consisting exclusively of reinforced concrete [4].

It is a fact that a large amount of wood is used for the construction of wooden buildings, which could be reflected in excessive deforestation during over-harvesting, but

Vol. 9 (1), pp. 74-85

under the assumption of prudent management of the forest stand, the amount of wood material will recover rapidly. Wood is a natural material, therefore, provided it is properly installed in the building and its treatment, the wooden structure creates and maintains a healthy microclimate and at the same time a positive psychological effect on the inhabitants.

In general, perhaps the biggest shortcomings of wooden structures are their inclination to wood-decaying fungi and insects, which is associated either with inappropriate design of wooden element, its incorrect installation in case of technological failure or use of improperly processed wooden material. In almost all cases, this disorder is associated with excessive moisture in the wood, which is its biggest weakness. It is natural for wood to work and swell with increasing humidity, but it is essential that the wood in general has the opportunity to dry, so it must not remain vapor-tight in the structure without the possibility of regulating its humidity and air volume, ideally transpiring wherever it is acceptable.

The design of wooden structures is based on two basic concepts, namely the creation of a diffusely closed structure or a diffusely open structure. For both concepts, the rule is that it is essential that building materials used in constructions of building´s envelope whose properties of diffusion resistance do not block the release of water vapor and have their values decreasing from interior to exterior. This allows moisture in the interior to escape to the outside and a suitable insulation design ensures that it does not condense in the space of the thermal insulation or even in the vicinity of the built-in wooden element. Otherwise, there is a high risk of mold creation and the fact that makes it worst is that it is often a hidden defect.

The sandwich system or solid wall support system is most commonly used. The current market offers a very wide range of products from treated building timber in order to achieve even better mechanical properties and at the same time to use the residual material as much as possible after the initial processing of grown wood. There is very wide range of products made of treated wood known as Engineered Wood Products (EWP). The most frequently used EWP are Glued Laminated Lumber (GLULAM) for beams and columns, Laminated Veneer Lumber (LVL) for sheathing and Cross Laminated Timber (CLT) for massive solid walls. EWPs generally achieve the highest quality thanks to their manufacturing technology, as parts that contain defects in the wood structure are removed in advance and the used wood has been slowly dried to the correct humidity beforehand. Despite the fact that the elements are composed of a large number of smaller parts, thanks to toothed edges, cross-laying of the slats and high-quality pressure bonding, these materials behave as one element. And such an element also excels in increased resistance to moisture.

Wooden constructions are characterized by the possibility of a high degree of prefabrication and system solution of elements not only within the rough construction. Very crucial is ensuring suitable connecting elements. These joinings must be designed to provide static stability, airtightness and thermal and acoustic insulation for appropriate indoor comfort. In addition to classic angles and strips, there is also a whole portfolio of sophisticated joints systems, Fig. 1.

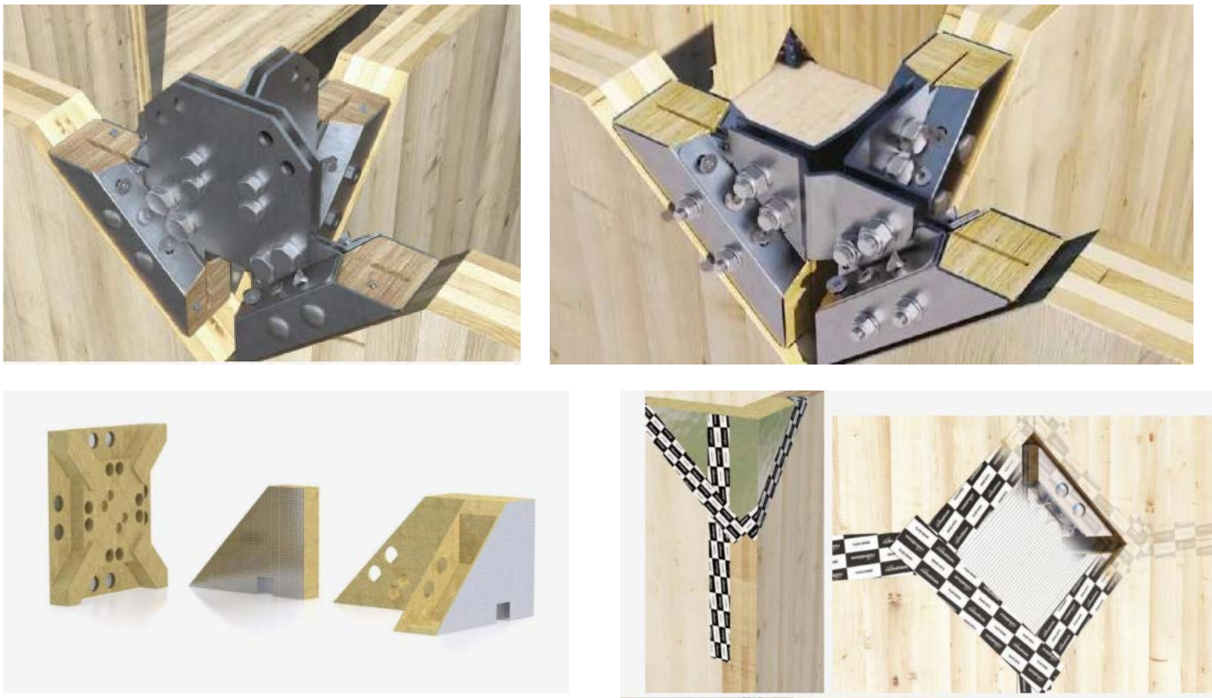

Figure 1 – Example of innovative joining system X-RAD (Rothoblaas) [5]

The design of wooden buildings and their fire protection is based on basic legislative regulations, namely the Decree of the Ministry of Interior of the Slovak Republic no. 94/2004 Coll. and standards STN 92 0201-1 to 4 and STN EN 13501-1.

Despite the fact that natural wood is a combustible material, it is necessary to distinguish two different parameters. One is flammability and the other is fire resistance. Solid wood is flammable, but it can still provide the required fire resistance from the area where there is no fire, provided that the elements have a sufficient thickness. This is based on fire tests, when a wooden structure made of solid wood burns to a depth of approximately 0.5 mm to 0.7 mm per minute. This fact is used, for example, in the design of log buildings and wooden structures from combustible structural elements, where the fire resistance of a building element, such as a wooden column, is increased by enlarging the dimensions of the column on each side, beyond the static calculation requirements. Alternatively, there can be used fire protection layers in the form of fire protection cladding or fire protection coating.

It is ironic that an untreated solid wooden column can withstand a fire much better than a non-combustible steel column, which permanently loses its yield strength when the temperature exceeds 500 ° C, causing a sudden loss of strength. In practice, this means that in the event of a fire, the steel column, without fire protection cladding, painting or concreting, will permanently lose its load-bearing capacity and risk the collapse of the entire structure or the part it supports. Actually it is worse, because of using of highly flammable materials in interiors, a temperature of 500 ° C and more can actually occur in a fire after 5-6 minutes. Even if the structure does not collapse, the steel element must be replaced. On the other hand, a wooden column can withstand fire when oversized, and if it retains dimensions for static requirements, it can continue to be used if its fire resistance is additionally increased. Wooden structure meets the problem with the speed of fire spreading over the surface and the spaces of joints and cavities (in sandwich element). The presence and spreading of fire in a hollow cavity is one of the most frequent problems reported abroad, especially when the cavity is hidden or continuously ongoing. In this case, the fire may spread very quickly, especially if there is a chimney effect allowed. To prevent the spreading of fire through the cavities, the cavities must be continuously divided and filled with non-combustible material, such as mineral wool especially in the presence of electric wiring.

The individual fire compartmentations must be separated each other by a fire door or fire seal or fire dumper to prevent spreading fire into another fire zone.

Normative requirements in terms of fire safety in Slovakia have always been very strict compared to foreign countries and despite the advantageous properties of wood-based building elements and proximity to the woodworking industry, our legislation allowed a maximum of 3 above-ground floors for wooden buildings for housing and accommodation and 2 above-ground floors for production buildings. The significant release of these criteria came only with the revision of the standard STN 92 0201-2 Fire safety of buildings. Common provisions. Part 2: Building structures from 2017.

The most significant change in the standard is the possibility of classifying a flammable component (type D3) into the category of a mixed component (type D2) if the required conditions are met. If the construction is carried out from mixed structural elements (type D2), then the construction of up to 5 above-ground floors for residential buildings is permitted.

Type D2 components do not increase the intensity of the fire during the required fire resistance. It is because building materials or components with a reaction to fire class other than A1 or A2 are enclosed with building materials or components with a reaction to fire class A1 or A2 so that at the required fire resistance time they do not ignite and do not release heat. Combustible materials and components enclosed within components of types D1 and D2 shall not reach the flash point during the required fire resistance time; if this is not clearly determined, a flash point of 180 ° C is considered [6].

If the wooden structure is made as a sandwich structure, all cavities must be filled with a non-combustible material, without the possibility of settling or falling out, which can withstand a temperature of min. 1000 °C, which is also met, for example, by stone wool. A standard example of a security element that can be applied for reaction to fire class A1, A2 is fireproof plasterboard. In order for the structural unit to be considered as mixed, it is necessary that the exterior surface treatment of the perimeter wall also meets the criterion of the reaction to fire class A1, A2, which precludes the use of flammable material for thermal insulation or cladding.

If the previous fire protection requirements are met, the building assembly can be considered as mixed type. According to the revision of the standard, it is possible to implement wooden buildings for housing and accommodation with up to five floors, resp. non-production buildings with a fire height of up to 12 m.

The examples of high-rise buildings.

In addition to the inclination to moisture problems and the risk of fire, it is necessary to take into account the specific static risk of high-rise wooden buildings, namely the verification of the maximum deflection caused by horizontal forces (Fig. 2).

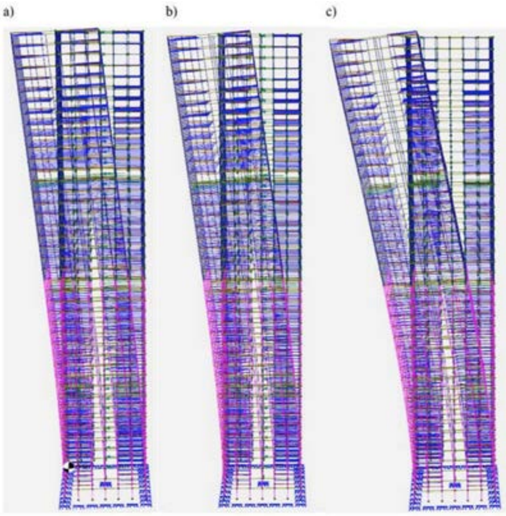

Figure 2 - Maximum deflections of the structure caused by horizontal forces [4]

A study of a high-rise building [4] showed that if all non-load-bearing elements, i.e. partitions and façade elements are made of wooden elements, then the increase in maximum deflection is almost 17% greater than in the case of complex reinforced concrete construction. And if wood-based load-bearing elements are also used in the system in combination with a reinforcing reinforced concrete core, the maximum deflection can increase by up to 68%. Given our current legislation, we need to look abroad for high-rise wooden buildings, but there is no need to go far, as a wooden high-rise building known as HolzHochhaus or Hoho Wien (fig 3.) has already grown in the new, developing city district of Vienna in neighboring Austria.

Figure 3 - HoHo Wien - view and illustration of material solution of construction system [7-8]

Mladá veda
Young Science
ISSN 1339-3189
Vol. 9 (1), pp. 74-85

This building project is considered one of the most important construction projects in Europe, as the dominant of sustainable architecture with a gold LEED certificate, also due to the maximum use of renewable materials and thus the reduction of waste and CO_2 emissions. The building consists of a complex of 3 towers that support each other, while the tallest tower has 24 floors with a total height of 84 meters. This multifunctional complex is used for accommodation, administration, business premises and services. In terms of material and construction solution, the building is composed of approximately 75% wooden based materials, which is complemented by a reinforced concrete stiffening core. With its cladding, the building ensures a high standard for energy savings and interior comfort. Insulating triple glazing with a heat transfer coefficient U_g = 0.50 W/m^{2}K with a warm edge spacer with a value of Ψ_g = 0.033 W/mK and a total solar energy transmittance only g = 0.49 was used for the glazing. That provides to a large surface area of 6000 m^2 a passive protection against excessive sunlight. The total window transition coefficient reached U_w = 0.78 W/m^{2}K. Due to the effects of wind and to increase acoustic properties a laminated safety glass on the exterior side and from the interior side a standard safety glass was used. The glazing were pre-installed in wall CLT panels and delivered directly to the construction site. The perimeter walls consist of CLT panels with a thickness of 140 mm and thermal insulation from mineral wool with a thickness of 200 mm. The resulting heat transfer coefficient through the opaque parts of the perimeter wall is approximately U = 0.18 W/m^{2}K.

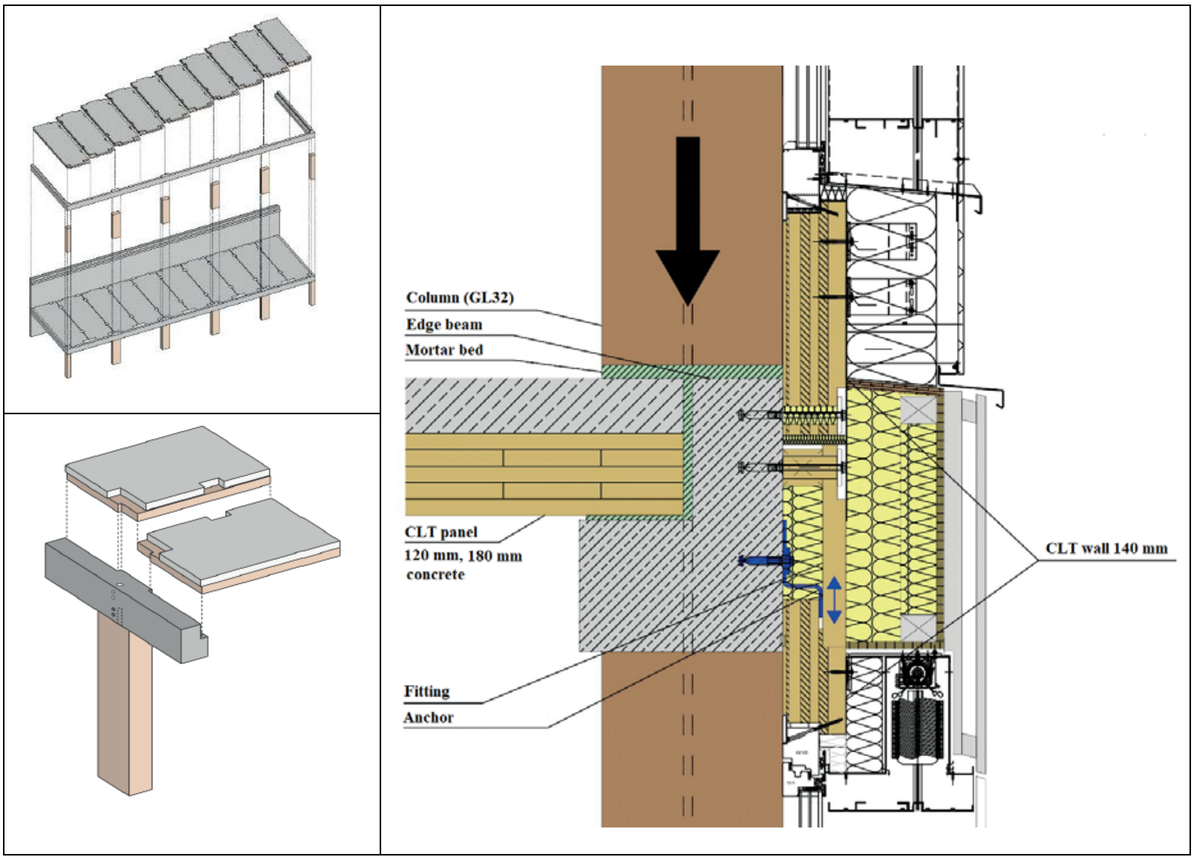

Figure 4 - Design solution for connection of horizontal and vertical load-bearing elements [8]

From the perspective of fire safety, this construction was a great challenge and prejudices against wooden constructions could not be neglected, especially when it is a high-rise construction. For evacuation, a safe escape through a reinforced concrete core with vertical communications and ventilated shafts is ensured. Apart from the side of the protected escape route, this core is also lined with solid wood. The ceiling structures are designed as a hybrid element consisting of a 180 mm solid wooden CLT panel coupled with a 120 mm thick layer of concrete. The ceilings and walls in the interiors are made from solid wood, uncovered, thus enabling the full use of the potential of wood to regulate the indoor microclimate and to provide aesthetic and psychological impression. For this construction, a systematic construction detail was developed for the connection of prefabricated elements of a wood-concrete composite ceiling, a wooden column, a beam and a wall panel without a metal connection due to the exclusion of welding work on the construction site (Fig. 4).

Fire tests were performed during the design stage of the building, which showed that the carbon layer, which forms on the surface of solid wood elements of CLT panels, will provide the required fire resistance and stability of the component for 115 minutes [9], exceeding the requirements of 90 minutes, valid in Austria.The surface treatment of the façade from exterior consists of fiber-cement panels, which for safety reasons have replaced the original architectural idea imitating the bark of a tree. The total construction cost exceeded 75 million euros, which is higher than expected for a wooden structure, but this project is becoming a pioneer of a new direction and its potential in sustainable architecture, precisely because of its global goals of minimizing CO_2 emissions.

Another example is the Mjøstårnet building or the Mjøsa Tower, just a few meters higher. Mjøsa Tower is an 18-storey and 85.4 m high high-rise building built in 2019 in the Norwegian city of Brummundda. It is a multifunctional building with a hotel, offices and residential apartments. The environmental impact has been reduced to a minimum due to the availability of material within 3.6 km of the construction site.

Figure 5 - Mjøsa Tower Design and actual view [10]

Mladá veda
Young Science
ISSN 1339-3189

Vol. 9 (1), pp. 74-85

The building is founded on a bedrock using piles. It is interesting that the 2nd to 11th floors are made of prefabricated wooden sandwich panels. These are filled with stone wool. The surface of the ceilings is covered with a diffusion foil as protection against external conditions and with additional 50 mm thick layer of concrete screed.

Figure 6 - View of prefabricated sandwich ceiling panels [11]

From the 12th to the 18th floor a 300 mm thick concrete floors were used, made of a prefabricated part, which serves as a formwork and a concrete grout. They have an aggravating effect in order to alleviate the already mentioned deflection due to horizontal forces and also help to ensure acoustic comfort in the apartments. The maximum calculated deflection of the upper floor is 140 mm. The floor of the last residential floor is at a height of 68 m above the ground. The elevator shafts and the staircase are made of CLT panels, which however, do not primarily fulfill the function of reinforcing the whole structure of building. The reinforcement of the building is provided by massive frame structures and diagonal stiffeners, which carry the horizontal load from the wind. The individual elements were first assembled on the ground and then the structural units were lifted to a height of 4 floors.

Figure 7 - View of the lifting of 4 storey heigh structural elements [11]

Fire protection measures prescribe the resistance of the primary load-bearing system for at least 120 minutes and for the secondary system (ceilings) the requirement stands for a resistance of 90 minutes. The fire resistance was calculated and verified and the admitted wooden elements made of glued laminated wood were considered. In 2016, fire tests of

Vol. 9 (1), pp. 74-85

laminated wood columns were performed according to ISO standards. After 90 minutes after the burners had stopped, the columns continued to char, and after several hours the temperature gradually decreased and the burning stopped. This proves that the massive columns from the laminated wood are able to extinguish themselves and thus prevent the collapse of the building. Uncovered wooden elements on escape routes are treated with fire-retardant paint, with the exception of exposed walls on the staircase, which are covered with plasterboard. The building is equipped with a sprinkler system and there are fire shutters on the facade to prevent the fire from spreading upwards. Ceiling panels are designed to withstand the impact load from a fall of a higher ceiling panel.

Figure 8 - View of the fire test of the sample with activated fire strips, on the left and the placement of the strips in the slots between the beam, the column and the connecting elements, on the right [10]

It is questionable, using a more critical view, how the building as a whole will behave, if a fire break out on a random floor in the middle of the building and wooden elements, pre-exposed to the fire will be then rapidly cooled and soaked with water by the sprinkler activation. There is no doubt that reinforced concrete structures have better resistance to these influences and their ability to recover from fire, if not fatal, but on the other hand, also a building made of non-combustible materials can end in destruction after fire, whether caused directly by fire or controlled demolition. There is also a certain advantage in the case of wooden constructions that less waste remains after its collapse, which is also not negligible. Regardless of the material selection for the supporting structure, the most common cause of fire is human failure and the presence of flammable materials in his living or working space that spread the fire further, so it is important how complex the investor's intention is and how to the inhabitants behave.

Conclusions

The development of sustainable architecture abroad indicates a clear new trend in the construction of modern high-rise wooden buildings. The environmental situation in Slovakia and abroad requires a change in people's thinking about the environment. In the field of construction and energy, it is an effort to minimize energy demand and reduce emissions. There is a proven benefit from the increasing incorporation of wood materials, as an alternative solution, for other construction materials that have a significantly worse impact on the environment. The described high-rise wooden buildings and many others, which were not mentioned here, are proof that this way of thinking has found a firm support abroad and will continue to develop. When designing buildings, it is always necessary to think about the safety of users, as well as investment costs and their return. However, taking into account the potential benefits that the development of wooden buildings brings, it would be appropriate to be inspired by many years of experience from foreign architects. Countries such as Norway, Sweden and neighboring Austria have been implementing significantly taller wooden buildings for decades and have found a way to realize these works and ideas into their own form. In our current situation, that view of the matter is absent and strictly rejected. The development of building materials and their surface treatments, as well as the confirmed tests performed, should pave the way for the possibility of finding compromises. The revision of the STN 92 0201-2 standard from 2017 indicates that it is necessary to support the development of the construction of wooden buildings also in connection with sustainable architecture. Changing the current limit on the number of floors from 3 to a potential 5 floors, subject to strict conditions, is a big step forward compared to the past. Unfortunately the price of additional 2 floors is relatively high, evoked by the necessary fire protection cladding or coatings and filling of cavities with non-combustible material. In addition, these interventions largely suppress the already mentioned benefits that wood can add to the interior: the visual quality and maintaining healthy microclimate.

This article was recommended for publication in a scientific journal Young Science by:
doc. Dr. Ing. arch. Roman Rabenseifer

Acknowledgment: This paper was supported by projects APVV-18-0174, APVV-16-0126 and VEGA 1/0050/18

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