

Article

Time–Cost Analysis of Construction of Administrative Buildings Using Wood-Based Construction Systems

Alena Tažiková *, Zuzana Struková, Mária Kozlovská and Martin Škvarka

Institute of Technology, Economics and Management in Construction, Faculty of Civil Engineering, Technical University of Košice, 042 00 Košice, Slovakia; zuzana.strukova@tuke.sk (Z.S.); maria.kozlovska@tuke.sk (M.K.)

* Correspondence: alena.tazikova@tuke.sk (A.T.); Tel.: +421-055-602-4380

Abstract: Nowadays, wooden constructions should occupy an important place in the construction industry, mainly because they eliminate negative effects on the environment. Eco-friendly and sustainable buildings include, for example, buildings made of timber column structures and buildings made of cross-laminated timber (CLT) panels. Eco-friendly buildings based on wood are in the minority in Slovakia. The research question is what advantages and disadvantages can the construction of an administrative building from CLT panels include, not only for the construction investor, compared to a construction from a timber column structure? The main research method is the analysis of time and cost parameters of the construction of wooden buildings, with the aim of drawing attention to the characteristics of construction in the segment of administrative buildings in Slovakia. The synthesis of the resulting knowledge has proven the advantage of construction from CLT panels compared to timber column structures. The task of designers is to offer knowledge about the advantages and disadvantages of different types of constructions, to which the results of our study contribute. This study is based on a thorough time–cost analysis of the parameters of the CLT construction system and timber column structures, and it definitely fills the publishing gap in the given topic.

Keywords: cross-laminated timber; timber column structure; administrative building; time–cost analysis

Citation: Tažiková, A.; Struková, Z.; Kozlovská, M.; Škvarka, M.

Time–Cost Analysis of Construction of Administrative Buildings Using Wood-Based Construction Systems. *Appl. Sci.* **2024**, *14*, 11176. <https://doi.org/10.3390/app142311176>

Academic Editors: Sara Cattaneo and Manuela Alessandra Scamardo

Received: 5 November 2024

Revised: 26 November 2024

Accepted: 28 November 2024

Published: 29 November 2024



Copyright: © 2024 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

1. Introduction

In general, wooden structures are environmentally friendly constructions that are mainly beneficial because they are ecological, sustainable, and belong to dry construction techniques. Compared to traditional brick buildings, the implementation of wooden buildings is characterized by a shorter construction time. In the past, various types of wooden family houses were built in Slovakia to a considerable extent. However, at present, buildings made of traditional building materials hold their leading position. Modern types of wooden construction are not currently widespread enough to ensure sustainability in the construction industry. Considering the achievement of carbon neutrality, it would be desirable to switch from traditional materials to sustainable materials, to which wood clearly belongs. Currently, the range of construction systems for wooden buildings is much richer compared to the recent past. A rationally chosen composition of constructions and materials usually allows the implementation of wooden buildings in a low-energy, passive, or even zero-energy way. Cross-laminated timber (CLT) panels made of massive wooden elements represent the latest trend in the development of construction components for the construction of wooden buildings. They are characterized by high strength, stability, and precisely executed details. Cross-laminated timber is a massive timber product that is becoming increasingly popular as a viable structural option for tall and large structures [1]. Internationally, its use is growing rapidly [2]. To make it more

attractive in Slovakia, it is therefore important to analyze this construction method and strengthen its presentation with an emphasis on its sustainability. In order to compare the construction of CLT panels with another possible system for wooden construction, timber column construction was chosen. It is a similarly sustainable construction system for wooden buildings. These comparative analysis results, containing the advantages and disadvantages of the compared structural systems, can be used, for example, by investors when making decisions on the construction system of their buildings.

Many authors have dealt with various properties of CLT panels in their research, where, for example, they investigated the suitable types of wood [3–8], individual thicknesses of the glued layers, the method of gluing, and their properties (physical properties such as water absorption, thickness swelling, and delamination, and mechanical properties such as bond shear strength, flexural modulus, bending strength, and rolling shear strength) [9,10], use in high-seismicity areas [11], etc. The fire resistance of various types of wood used in CLT panels was also tested in several studies [2]. It has been proven that salvaged wood from natural disasters can also be used for the production of CLT panels, which shows a high degree of sustainability [12]. On the contrary, the researchers in [13] did not demonstrate the ability to ensure the air leakage of the CLT structure using a self-adhesive membrane to meet the stricter threshold values for air barrier assemblies.

Buildings contribute more than 40 percent to the total amount of global carbon emissions. In order to address both operational and embedded carbon, certain CLT panels have been developed with embedded insulating materials. These panels have great thermal resistance because of the embedded insulating portions, and they do away with the need for high-carbon materials such as steel and concrete [14].

Some studies dealt with innovative panels that combine nail-laminated timber (NLT) and CLT, creating a final product called nail-cross-laminated timber (NCLT) [15]. Some authors concluded in their studies that for structures with little static stress, such as floors, it is more economically advantageous to use lower-quality wood for gluing panels [16].

The development and use of CLT panels, especially abroad, partially replaced reinforced concrete and brick-in-concrete structures [17]. The CLT system is widely used in the construction of low-, medium-, and even high-rise residential and public buildings [18–20]. One of the aims of our study is to point out the need to expand the sustainable construction of wooden buildings in countries that include Slovakia, where monolithic concrete construction clearly dominates. This topic has been scarcely researched and published in Slovakia. The role of designers is to offer potential customers an analysis of the advantages and disadvantages of different designs and different types of constructions. The results of our study are a good resource for timber construction designers who consider such a task important. Our study is based on a rigorous time–cost analysis of the parameters of both the CLT structure and the timber column structure; thus, it fills a gap in the publications on the given topic.

Despite favorable production conditions, the low share of wooden buildings in the Slovak market remains. The main reasons include low consumer demand and several legislative restrictions [21–23]. The presented paper focuses on providing a comprehensive view of the construction of buildings from CLT panels. After collecting and studying knowledge from the literature in the field of CLT panels, it was possible to model and describe the implementation process of an administrative building designed and built using this construction system in our research. The main part of this research consists of a time and cost analysis of building implementation in two different variants of construction systems: (i) from CLT panels and (ii) the timber column structure.

The novelty of our study starts with the fact that Slovakia lacks several indicators for estimating the construction costs of wood-based administrative buildings. Our study offers these missing indicators. Moreover, we offer a proposal for a methodology to determine such indicators. The more indicators that become available (including from other countries), the more cost analyses will be possible among countries similar to Slovakia

under the same boundary conditions. We also consider this to be a continuation and extension of our research.

2. Materials and Methods

The cost and time analysis of both proposed variants, the construction from CLT panels as well as the timber column structure, was carried out using the design documents of an administrative building with a total built-up area of 312.2 m² (Figure 1). The virtual model of this building, processed in the Archicad 25 software, was part of these documents (Figure 2). The location of the building is proposed in the cadastral territory of one of the villages in Slovakia. The village of Jasenova in the region of Dolný Kubín is the actual location where the wooden-based office building is designed. The building, which is the subject of this study, consists of two above-ground floors. It is based on piles and is partly underground. Since the building is located on a sloping terrain, the perimeter load-bearing structures of the first underground floor and the first above-ground floor, located below ground level, are made of ceramic bricks. The ceiling structure between the underground floor and the first floor is designed as a 200 mm thick reinforced concrete slab. In the part of the building that does not have an underground floor, the floor structure of the first above-ground floor is designed as a 250 mm thick reinforced concrete slab. The structural parts of the object described above are identical for both variants of the structural system that are the subject of our analysis, i.e., both for the construction of CLT panels and for the timber column structure. The structural systems that are the subject of our time and cost analysis are presented in the following sections of this article.

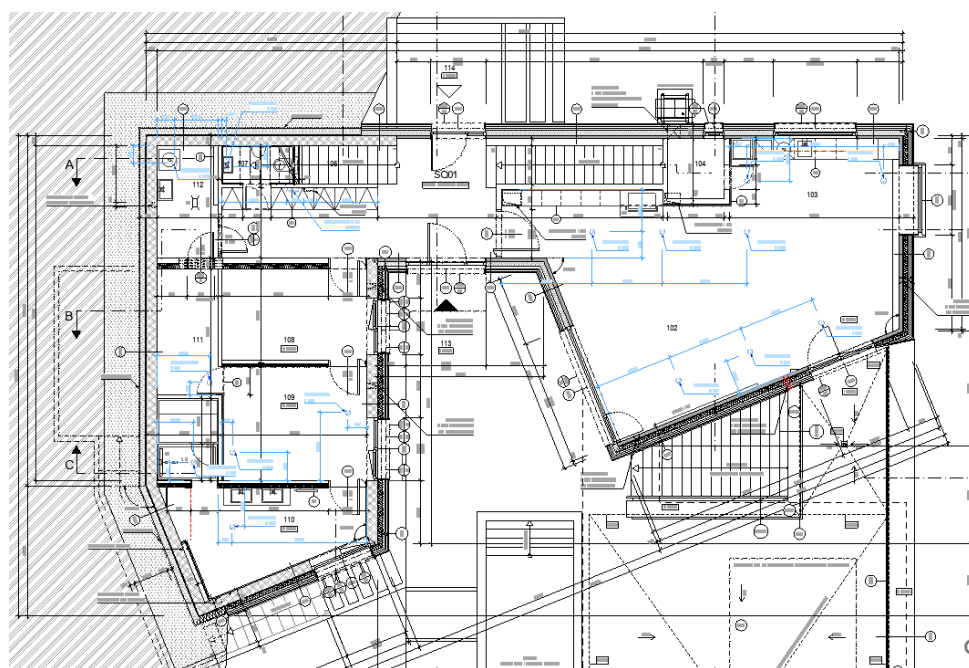


Figure 1. The ground plan of the building.

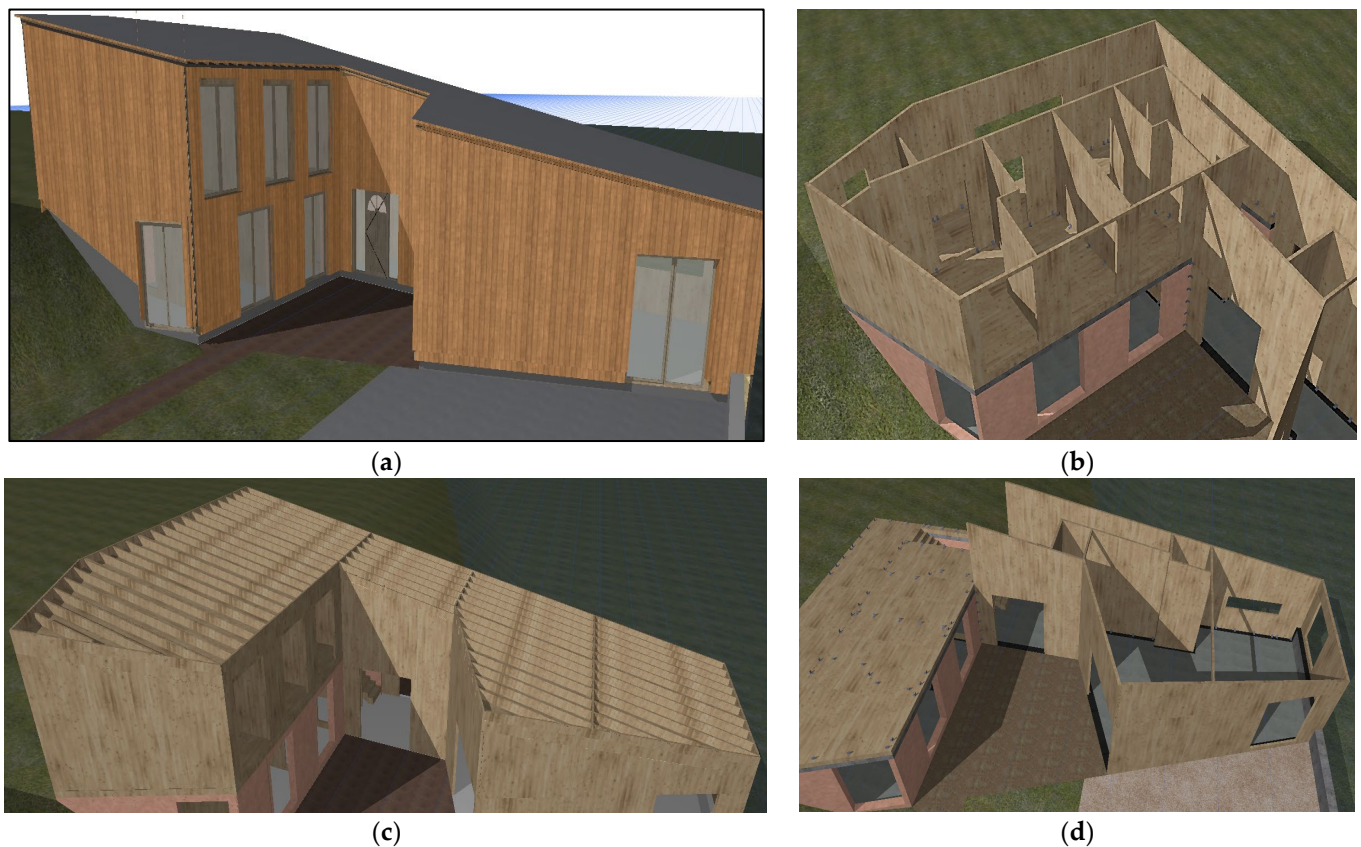


Figure 2. The virtual model of the building (a–d).

2.1. The Cross-Laminated Timber Construction System—Variant 1

In this variant, the perimeter load-bearing walls above ground level, the internal load-bearing walls, the ceiling structure, and the partitions are from wooden CLT panels. The roof structure is made of NOVATOP OPEN panels. The façade of the building is wooden with a lining of Siberian larch 27 mm thick, made on a wooding grating (Figure 3). On the CLT wall, the panels are vertical KVH prisms with a dimension of 50/140 mm; they are anchored at an axial distance of 620 mm. A 140 mm thick basalt thermal insulation is inserted between the prisms. The wall structure has additional thermal insulation using wood fiber boards of Steico Protect boards with a thickness of 60 mm. They are covered with a Delta Fassade facade sheet. In order to ensure the ventilation of the gap under the cladding and the possibility of fixing the wooden cladding, a wooden grate is designed. It consists of vertical slats and horizontal slats on top of the vertical slats. The dimension of the slats is 45/70 mm, and they are attached at an axial distance of 800 mm. Partitions are made of one-sided fair-face CLT panels (StoraEnso, Helsinki, Finland) 60 mm thick. From the side that is not fair-face, a grate made of CW 100 structural profiles is designed. A 100 mm thick mineral insulation is inserted into the grate. This space is primarily used for installations. On the top of the partitions, two layers of plasterboard are installed. The load-bearing ceiling consists of five-layer StoraEnso L-type CLT panels with a thickness of 140 mm (Figure 4). The floor is designed on the ceiling panels, the composition of which is as follows: thermal insulation 60 mm thick, separation PE sheet, cement screed 75 mm thick, and a footing layer of the floor in the form of gress tiles, a cast epoxy floor, or carpet.

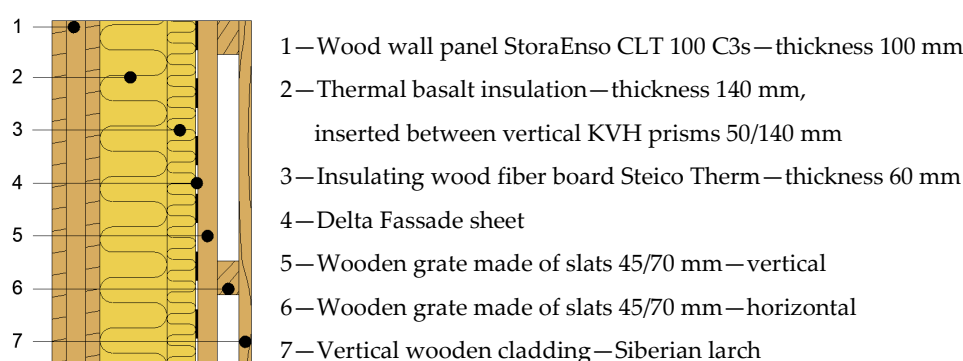


Figure 3. The composition of the perimeter walls made of CLT panels.

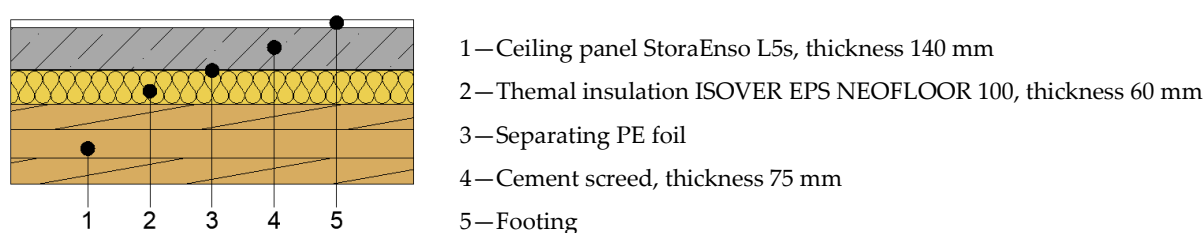


Figure 4. The composition of ceiling structures made of CLT panels.

2.2. The Timber Column Structure—Variant 2

In this variant, the perimeter walls are formed by a timber column structure made of 60/160 mm profiles made of C24 spruce wood. They are designed at a maximum axial distance of 625 mm (Figure 5). Nobasil MPS mineral wool thermal insulation (160 mm thick) is inserted between the columns. From the exterior side, the same composition of the facade as in the previous variant of the structural system is proposed. It therefore consists of insulation from a 60 mm thick fiberboard, a facade sheet, a wooden grid made of 45/70 mm slats installed at an axial distance of 800 mm, and a wooden lining made of Siberian larch, 27 mm thick. From the interior side, the structure is lined with oriented strand boards (OSBs). A grate made of CD profiles is installed on the boards. On the grate, plasterboards with a thickness of 12.5 mm are attached. They form the surface of the structure from the interior side. The partitions are formed by a column structure made of 50/100 mm wooden profiles anchored at a maximum axial distance of 625 mm. The filling between the columns is made of 100 mm thick mineral wool. On both sides of the partition, there is a lining made of OSBs, on which plasterboards forming the top of the partition are further installed. The load-bearing structure of the ceiling consists of a 200 mm thick reinforced concrete slab. The surface treatment of the lower side of the ceiling structure is designed as 10 mm thick gypsum plaster. The composition of the floor is the same as in variant 1. In this variant, the load-bearing structure of the lean-to roof is proposed from wooden truss girders installed on the load-bearing walls of the building (Figure 6). The thermal insulation of the roof is in the form of a 400 mm thick blown cellulose layer. The other composition of the roof deck is the same as in the CLT variant. The following layers of the roof deck are gradually installed on the wooden trusses: Delta Vent S safety high-diffusion foil, 60 × 40 mm contra-lats, double wooden cladding with 24 mm thick boards, and a roof covering made of colored aluminum folded sheet metal.

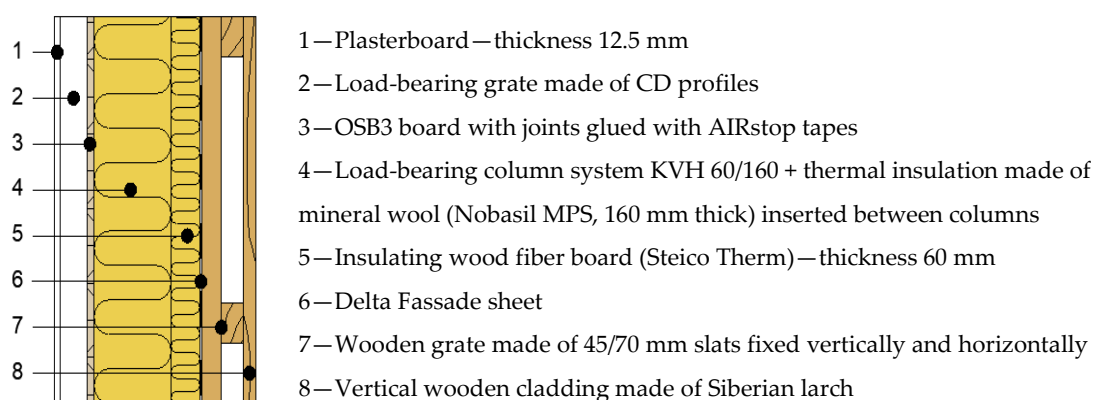


Figure 5. The composition of the perimeter walls made of a timber column structure.

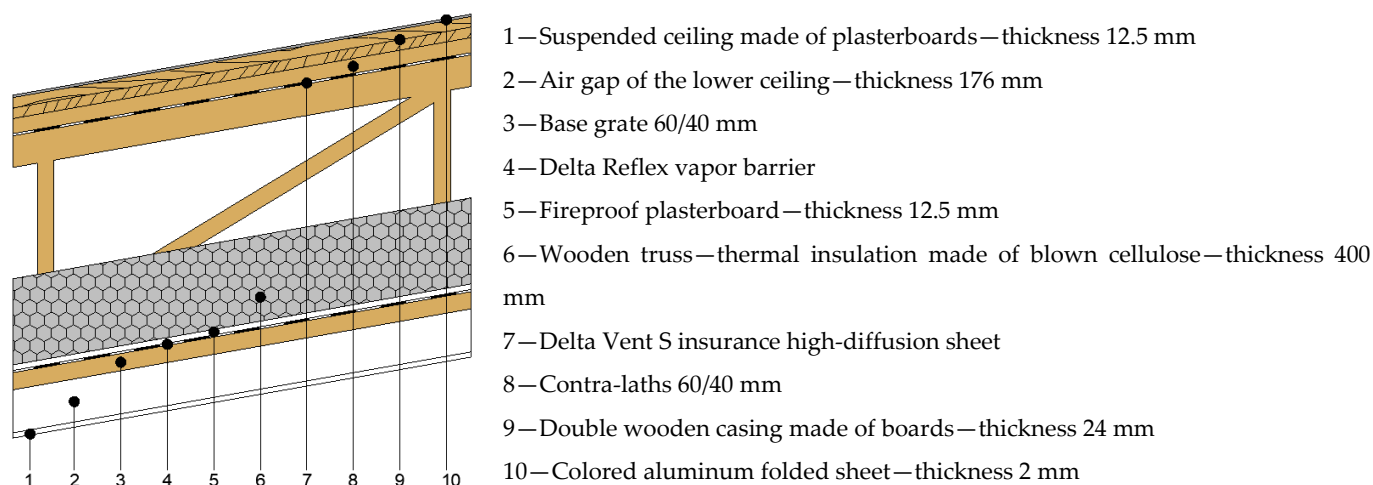


Figure 6. The composition of the roof structure.

2.3. The Cost Analysis

For the analysis of the building construction costs implemented in two variants of the construction system, two different construction budgets were individually estimated for both construction systems. The national budgeting software CenKros 4 was used to estimate the construction budgets. This budgeting software is the most widely used budgeting software in Slovakia.

2.3.1. The Analysis of Construction Costs in the Variant of the Building Made of CLT Panels

When estimating the budget of the building in question in the variant from the CLT system, we were guided by the methodology of pricing panels in production, which includes a certain standardization. It is possible to design and manufacture panels in various shapes and sizes not exceeding 16 m in length and 2.95 m in width, but if the standard dimensions are not observed, the cut-off material, as waste, is included in the price of the panel. The standard widths of the panels in the factory are 2450 mm, 2750 mm, and 2950 mm, and for an additional fee, they can be 3250 mm and 3450 mm. The minimum length of the panels is 8 m and this is graduated in 10 cm increments up to 16 m. In the case of non-compliance with the standard production dimensions, the next larger standard panel dimension is charged. It is necessary to check the optimal selection of panels from which individual structural parts are cut, so that waste is not produced and costs are not increased.

Individual elements in the structural system of the building are laid out into panels of standard dimensions, so-called master panels, so that the smallest amount of waste is generated. Since the panels are cut with a milling machine with a diameter of 50 mm, it was necessary to add a cutting gap of 50 mm to the dimensions of the panels. As standard, cutouts larger than 1.2 m² are delivered to the building together with the panels. Smaller cutouts are counted as waste that is not supplied to the building. Figure 7 visualizes the cutting of the perimeter elements of the building structure: First Floor 08, First Floor 10, First Floor 15, and First Floor 17 from a panel of standard dimensions—2.45 × 15.5 m.

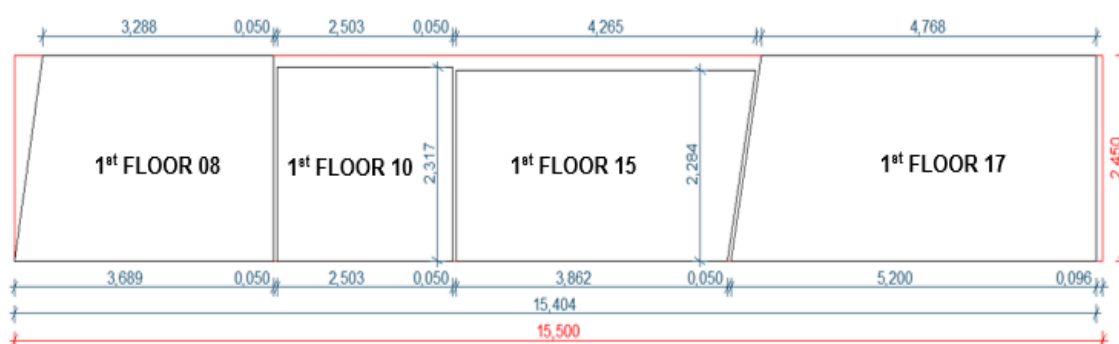


Figure 7. The cutting plan of CLT panels to minimize cost and waste.

2.3.2. The Analysis of Construction Costs in the Variant of the Building Made of a Timber Column Structure

When estimating the budget of the construction in question in the variant of the timber column structure, we followed the traditional budgeting methodology according to database items and the measurement units of individual structures. Database items consist of items of the basic costing formula. The formula contains the following items: direct materials, direct wages, direct machinery, manufacturing overhead, general expenses, and profit. This is how we estimated the construction costs of the building construction in the variant of the timber column structure.

2.4. The Analysis of Construction Time

For the construction time analysis, construction schedules in the form of Gantt Charts were made for both structural system variants. MS Project is a software tool for planning, managing, and tracking projects. In our study, the MS Project Professional 2021 software was used for the development of construction schedules for the construction of the administrative building in question, in both variants of the structural system—the CLT construction system and the timber column structure.

3. Results

Below are the results of the construction time and construction cost analysis of the implementation of the building in question in both variant solutions in terms of the construction system used.

3.1. Results of the Cost Analysis—The CLT Construction System

In the case of the CLT panel construction variant, a significant item is the construction of the building's framework and partitions, with a resulting budget of EUR 94,555.90. Although the construction costs of the framework made of CLT panels are high, since the surfaces of all wall panels are finished on one side, as well as the lower surface of the ceiling and roof panels, the costs of making plasterboard ceilings and dry linings are reduced. Drywalls for the installation of media pipes and electrical distribution are constructed from only one side, which reduces their quantity by half. Construction costs for

the drywalls for pipes and distribution installations are EUR 9922.48, excluding the insulating material. The assembly costs of wall panels, including dry linings for pipes and distribution installation, are EUR 68,009.21. The cost of suspended ceilings with one-sided surface treatment, including assembly, is EUR 13,711.55. Construction costs related to the construction of the roof from NOVATOP OPEN panels represent the amount of EUR 22,755.98 in the budget (Figure 8). The panels have a final surface treatment on one side. In this variant, the staircase is designed as a saddle staircase made of CLT panels and is assembled directly on the construction site. The load-bearing system of the staircase will be cut from the waste material generated when cutting the 100 mm thick CLT panel for the internal load-bearing walls.

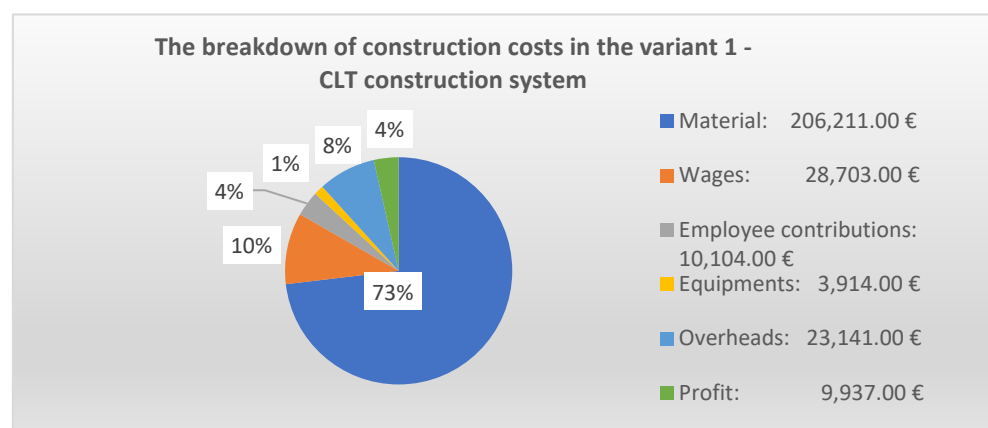


Figure 8. The breakdown of the construction costs of the building in variant 1, the “CLT construction system”, based on the calculation formula.

The construction costs of the staircase, including materials, amount to EUR 1813.83.

3.2. Results of the Cost Analysis—The Timber Column Structure

Compared to the variant made of the CLT construction system, the construction costs of the framework and partitions in the case of the timber column structure are significantly lower. The construction costs of the perimeter wall in the case of the timber column structure are EUR 16,694.49, and the construction costs of the partitions in this variant are EUR 10,613.46. The cost of the building material is included. The construction costs of the cladding of the perimeter walls from the interior side and the cladding of the partitions on both sides made of OSBs and plasterboards are EUR 19,940.35. Thus, the total construction costs of the timber column structure of the walls and partitions, including linings made of OSBs and plasterboards, are EUR 47,248.30. As for the assembly of the roof trusses, the construction costs are calculated to be EUR 6692.44, including the cost of materials. On the interior side, the suspended ceiling made of plasterboards is proposed. The construction costs of the plasterboard lower ceiling are EUR 14,046.31. The total construction costs for the construction of the roof structure from trusses and the plasterboard suspended ceiling are EUR 20,738.75. Compared to the construction of the roof made of NOVATOP OPEN panels, proposed in the variant “CLT construction system”, the construction of timber trusses and the plasterboard suspended ceiling is cheaper by EUR 2017.23. In this variant, the load-bearing ceiling structure is designed as a reinforced concrete ceiling slab, and the construction costs are EUR 8608.87. The construction costs of the ceiling coating made of gypsum plaster are EUR 1447.31. Thus, the total construction costs of the ceiling, including the plaster coating, are EUR 10,056.18. Compared to the ceiling made of CLT panels, where the construction costs of the ceiling are EUR 13,711.55, the construction costs of the ceiling in the variant of the timber column structure are lower (Figure 9). In the variant of the timber column structure, a staircase made of spruce wood is proposed. It is manufactured as a whole prefabricated component in the factory and is only placed on the construction

site. The construction cost of the staircase, including its installation on the construction site, is EUR 1830.52, which is very similar to the previous “CLT building system” variant.

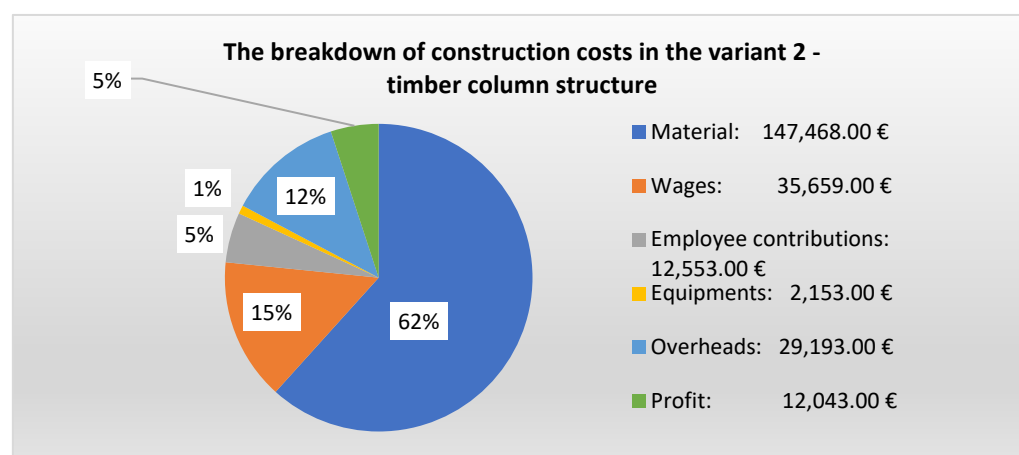


Figure 9. The breakdown of the construction costs of the building in variant 2, the “timber column structure”, based on the calculation formula.

3.3. Estimation of Unit Cost Indicator

One of the aims of our study is to estimate the values of the unit cost indicator (UCI) for buildings made of CLT panels. The unit cost indicators for the CLT construction system are not yet available in the existing register of UCIs. The register of UCIs contains a list of average unit costs for different types of construction. The UCIs are used for estimating the construction costs in the phase of design study creation. In the construction procurement process, designers are able to determine and present to investors an approximate cost estimate for various types of construction.

Below are the resulting values of UCI for both variants of the wooden construction system. The UCI represents either construction costs per 1 m² of the built-up area of the building (Table 1) or construction costs per 1 m³ of the built-up volume of the building (Table 2). For comparison, the UCI was also calculated for the variant of the timber column structure with a roof made of trusses. However, it is important to note that the values of TEI are estimated for the condition of the above-described constructions, while VAT is not included.

Table 1. The unit cost indicator per built-up area.

Variant of the Construction System of Administrative Building	Construction Costs [EUR]	Built-Up Area [m ²]	Unit Cost Indicator per 1 m ² of Build-Up Area [EUR/m ²]
Variant no. 1—CLT construction system	282,010	171.68	1642.65
Variant no. 2—Timber column structure	239,069	171.68	1392.53

Table 2. The unit cost indicator per built-up volume.

Variant of the Construction System of Administrative Building	Construction Costs [EUR]	Built-Up Volume [m ³]	Unit Cost Indicator per 1 m ³ of Build-Up Volume [EUR/m ³]
Variant no. 1—CLT construction system	282,010	1072.97	262.83
Variant no. 2—Timber column structure	239,069	1072.97	222.81

3.4. The Results of the Time Analysis

The proposed variants of the administrative building can be compared from several points of view. In the first case, the variants of structural systems are compared on the basis of construction time demands. The results are shown in Table 3, where the construction time of individual construction stages is listed. The construction time includes week-end days when no work is done. In addition, the corresponding time differences between the two construction systems are listed.

Table 3. The construction time of the CLT construction system and the timber column structure.

Construction Stage	Construction Time: CLT Construction System [day]	Construction Time: Timber Column Structure [day]	Difference [day]
Total construction time (entire building)	73	88	−15
Waterproofing	9	9	0
Wooden load-bearing structures and partitions	13	26	−13
Roof construction	9	14	−5
Window and door installation	6	6	0
External thermal insulation composite system and wooden façade assembly	20	16	−4
Plastering, wall layer construction, and floor screeding	7	11	−4
Plasterboard suspended ceilings and partitions, ceramic tiling, and footings	23	31	−8
Paintings and coatings, cleaning of the building	4	4	0

Based on the graphic representation of the construction time of individual construction stages, it can be clearly stated that the time differences in the compared variants are the biggest during the construction of the load-bearing structure of the building and the finishes of ceilings, walls, and floors (Figure 10). In total, the construction of the administrative building may be shortened by 15 days if the CLT construction variant is selected. However, the difference in the construction time of both variants is not significant. The reason for the smaller difference is the size of the administrative building. If it were the construction of a larger area and with more floors, effective planning and the division of the construction into different work units would lead to the difference in the construction time being greater.

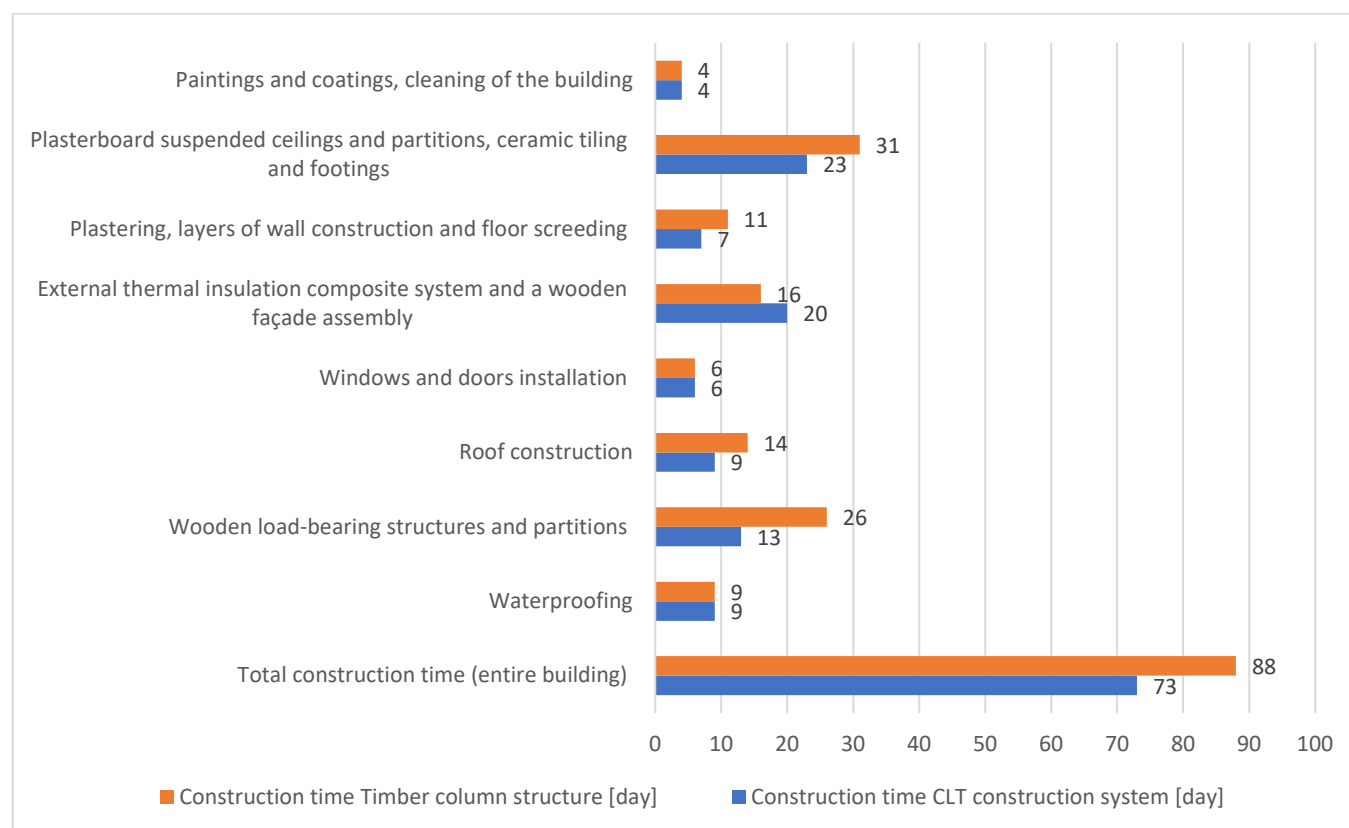


Figure 10. Comparison of CLT construction and timber column structure in terms of construction time.

3.5. Multi-Criteria Analysis of Variant Proposals for the Construction of the Administrative Building

In the final part of this study, a multi-criteria analysis of variant proposals for the construction of the administrative building was carried out. Several technological, technical, economic, energy, and functional aspects were considered. The criteria shown in Table 4 were included in the analysis. The purpose of this comparative analysis is to determine which of the proposed building construction variants is comprehensively more appropriate and efficient. The criteria were set based on the most frequent requests of investors. They were obtained as a result of structured interviews with contractors of wooden constructions. Two wooden construction suppliers participated in the structured interviews. One deals with the implementation of timber constructions from CLT panels, and the other is a supplier of timber column structures. Both have been operating in the construction market in Slovakia for a long time, since 2005 and 2007, respectively. They have more than 20 employees, and each has already implemented more than 100 timber constructions.

Table 4. The list of criteria included in the multi-criteria analysis.

Signature Criterion Set Based on Investors' Requirements	
A	Construction time
B	Difficulty of construction implementation
C	Flexibility during construction
D	Availability of specific materials and specialized contractors on the market
E	Structural strength
F	Lifespan
G	Fire resistance

H	Earthquake resistance
I	Energy efficiency
J	Total CO ₂ emissions
K	Environmental quality during construction use

A short description of each criterion from Table 4:

A—Construction time—time needed to implement the construction.

B—Difficulty of construction implementation—this criterion reflects work with large-format elements, easier joining of panels or wooden frames, handling, and high dimensional accuracy.

C—Flexibility during construction—this criterion reflects how quickly it is possible to implement, for example, a structural change during construction, if such a requirement arises.

D—Availability of specific materials and specialized contractors on the market—this criterion reflects that assembly workers have more experience with the construction of more conventional timber column structures than with CLT panels.

E—Structural strength—this criterion reflects the fact that CLT panel manufacturers state higher strength values compared to timber column structures.

F—Lifespan—this criterion reflects the fact that CLT panel manufacturers state longer lifespans compared to more conventional timber column structures.

G—Fire resistance—this criterion reflects the fact that CLT panel manufacturers state higher values of fire resistance compared to more conventional timber column structures.

H—Earthquake resistance—this criterion reflects the fact that CLT panel manufacturers state higher values of earthquake resistance compared to more conventional timber column structures.

I—Energy efficiency—this criterion reflects the amount of energy consumption during the construction phase.

J—Total CO₂ emissions—this criterion reflects the amount of CO₂ emissions during construction.

K—Environmental quality during construction use—this criterion reflects, for example, the difficulty of surface treatment during use, internal humidity, climate, joint design, air tightness, etc.

Since the authors of this study are convinced, based on their own and others' experiences, that the criteria related to structural properties are more important for clients than the criteria related to structural properties, the criterion weight of 60% was assigned to this group of criteria.

The remaining weight from the total amount of criteria weight, i.e., 40%, was assigned to the group of criteria related to construction implementation. Similarly, 100% of the criteria weight was also distributed at the next decomposition level of the significance tree. The conjunction of the weight of the criterion and the weight of the respective decomposition levels was the calculated weight of the criterion at the end of the branch of the significance tree. The resulting weights of all criteria that are included in the analysis are presented in red in the diagram in Figure 11. The criteria in the green rectangles are perceived as the most significant when deciding on the optimal variant of the construction system from a client's point of view. These criteria are the construction time, the lifespan of the building, and the quality of the environment during the use of the building.

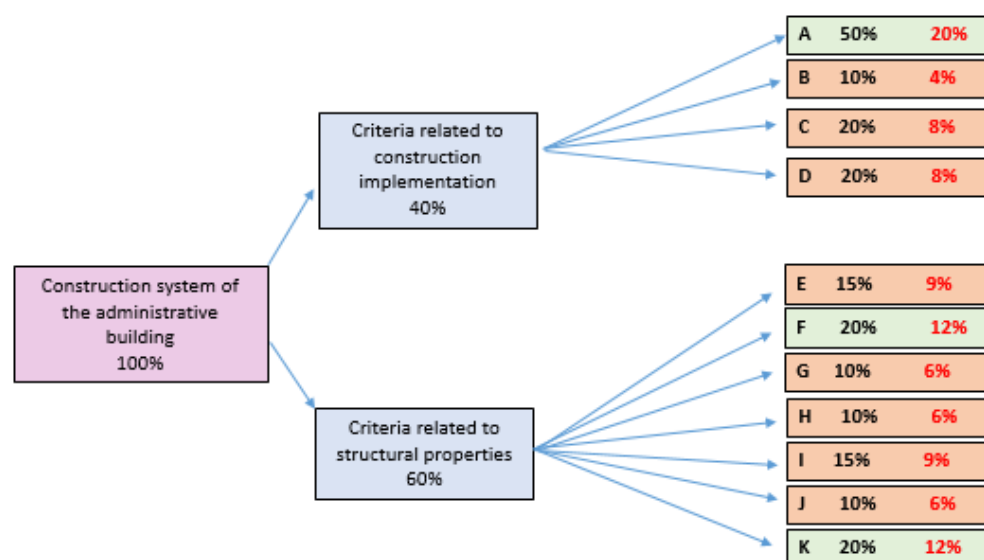


Figure 11. The significance tree for the criteria implied in this research.

The weights of the individual criteria, determined by the Tree of Significance method, are shown in Table 5 together with the assigned grades. In both variants of the construction system, a grade of 1 or 2 was assigned to all comparative criteria. A grade of 1 means that the variant is better from the point of view of the given criterion, and conversely, a grade of 2 means that the variant is worse from the point of view of the given criterion. From this method of evaluation, the more suitable variant is the one with the smallest number in the sum. In the last column, for both variants, the relevant construction cost resulting from the cost analysis is presented. It is also crucial in determining a more effective variant. The last line shows the basic variant, in which it is indicated which value is more advantageous for each criterion. Since grades were added to the variants in the manner of 1 = better and 2 = worse, concerning the compared criteria, the basic variant line has a grade of 1 for each criterion. The evaluation of the criteria was carried out based on values and data obtained from the manufacturers of both structural systems, as well as based on estimated construction costs and estimated construction times.

Table 5. The determined criteria and grades awarded to both construction systems.

Criterion	A	B	C	D	E	F	G	H	I	J	K	Cost [EUR]
Criterion weight	0.20	0.04	0.08	0.08	0.09	0.12	0.06	0.06	0.09	0.06	0.12	
Grade												
CLT construction system	1	1	2	2	1	1	1	1	1	1	1	282,010.00
Timber column structure	2	2	1	1	2	2	2	2	2	2	2	239,069.00
Type of criteria	Smaller number = better option											
Basic variant	1	1	1	1	1	1	1	1	1	1	1	

Then, the value of the base variant (value = 1) for each criterion was divided by the corresponding grade assigned to the given variant. This is how the index coefficient was calculated, which is listed in Table 6 instead of the grade. Thereafter, the total utility for each variant was calculated. The total utility value was calculated by adding the products of the relevant index coefficient of the criterion and the weight of the given criterion. The calculation example is as follows (Table 5). The weight of Criterion A (construction time) is 0.20. The grade for CLT construction is 1.00 (because the construction time is shorter, it is more beneficial). The grade for the timber column structure is 2.00 (because the construction time is longer, it is more disadvantageous).

The value of the basic variant (value = 1) for each criterion was divided by the corresponding grade assigned to the given variant, thus calculating the index coefficient (Table 6). The weight of Criterion A (construction cost) is 0.20. The basic variant (value = 1): the grade (for CLT construction, it is 1.00) = $1:1=1$ index coefficient. The basic variant (value = 1): the grade (for the timber column structure, it is 2.00) = $1:2=0.5$ index coefficient. First, the product of the criterion weight and the index coefficient is calculated. Then, the total utility is obtained as the sum of these two products.

Table 6. The total utility.

Criterion	A	B	C	D	E	F	G	H	I	J	K	Total Utility
Criterion weight	0.20	0.04	0.08	0.08	0.09	0.12	0.06	0.06	0.09	0.06	0.12	
Index coefficient												
CLT construction system	1	1	0.5	0.5	1	1	1	1	1	1	1.00	0.92
Timber column structure	0.5	0.5	1	1	0.5	0.5	0.5	0.5	0.5	0.5	0.50	0.58

In order to obtain a definitive result of the comparison of the proposed variants for the construction of a wooden administrative building, the efficiency rate was calculated (Table 7). The efficiency rate is obtained by dividing the total utility value by the construction cost of the respective variants. As a result, a higher value means a more efficient variant. In our study, this is the CLT construction system.

Table 7. The efficiency rates.

Type of Construction	Total Utility	Cost [EUR]	Efficiency Rate
CLT construction system	0.92	282,010.00	3.262×10^{-6}
Timber column structure	0.58	239,069.00	2.426×10^{-6}

4. Discussion

In addition to in Slovakia, wood-based constructions still face many prejudices globally, with masonry and concrete construction methods still being preferred [24,25]. This makes the goal of increasing sustainability in the construction sector impossible. In addition to our study, many other studies have argued that it is inevitable to constantly publish justifications for construction systems based on wood so that they can come to the fore [26]. In the next phase of our research, we want to focus on the driving forces that can help increase the share of wood-based constructions, as presented for example by Lindblad et al. [26].

The type of research that we offer in our study is intended to encourage designers and investors to consider the alternative of wood-based building construction, which will ultimately ensure a greener and more sustainable construction industry. Like our research, many other researchers claim that it is necessary to improve the ecological aspect of construction [25–27].

Industrial prefabrication of structural wood products, such as cross-laminated timber panels, enabled the use of wood in large-scale constructions, including, e.g., the construction of administrative buildings, the construction of which we have dealt with in our other studies [28–30].

The infrequent occurrence of the construction of wood-based administrative buildings causes dependence on concrete, as well as reliance on customary methods of constructing administrative buildings [31–33].

Efforts to prevent unwanted climate changes force the construction industry to reduce greenhouse gas emissions. Due to the use of renewable resources, the construction of wood-based office buildings might be an interesting alternative for the construction

industry to promote sustainable development, combined with the aesthetic benefits and advantages of wood that are perceived by many customers [25].

In various comparisons, Slovakia ranks last in the number of wooden buildings implemented. When we look at EU countries, the share of wood-based buildings is significantly higher than in Slovakia (Scandinavia—70%, Germany—50%, Austria—45%, Czech Republic—20%, and Slovakia—10%). While the height of a wooden building is limited to 12 m in Slovakia, the situation is different in other countries of the world. A lot depends on the building regulations of individual countries. For example, in Australia, the maximum permitted height of a wooden building is 25 m. Tall wooden buildings are also found in northern Europe. In Norway, the Mjøstårnet wooden building was built in 2020, which has eighteen floors and a height of 81 m. In Sweden, the wooden skyscraper Sara Kulturhu is 75 m high and has 20 floors. In the Netherlands, a 21-storey timber building called Haut Amsterdam has been built, achieving the highest sustainability rating of BREEAM Outstanding. The HoHo Wien building was built in Austria in 2019. It has 24 floors and is 84 m high. The development and use of CLT panels, especially abroad, partially replaced reinforced concrete and brick-in-concrete structures [17]. The CLT system is widely used in the construction of low-, medium-, and even high-rise residential and public buildings [18–20].

The procurement of wooden buildings is the subject of green public procurement. According to the Commission of the European Parliament (year 2008), green public procurement (GPP) is “a process in which public authorities seek to procure goods with a reduced environmental impact throughout their life cycle compared to goods with the same primary function that would otherwise be procured.” [34]. Some authors have conducted a systematic review of life cycle assessment (LCA) in the building procurement phase. In construction, GPP is more than LCA and the evaluation of tenders. In the topic of GPP, it is necessary to include the Conceptual Framework, which includes: LCA—Life Cycle Assessment, CBA—Cost/Benefit Analysis, MEAT—Most economically advantageous tender, and the EMS—Environmental Management System [35].

Limited awareness of green public procurement among decision-makers in the public sector can hinder their implementation. This situation is prevalent in the construction industry. Developing clear and consistent GPP criteria across product categories is an ongoing effort. There is a growing body of literature evaluating the concept of green public procurement [36–39]. In the area of wooden buildings, Slovakia lags behind in terms of the number of wooden buildings. Our paper contributes to the spread of the need to implement wooden constructions of administrative buildings in Slovakia, thus contributing to the assigning of green public procurement.

Previous studies have found that wood-based constructions struggle with insufficient awareness; our contribution offers an opportunity to overcome this struggle. The results of our research are useful to industry professionals, society, and building owners in adopting wood as a major construction material. This study may also increase the acceptance of the construction of taller buildings using wooden structures in the Slovak construction industry.

The results of our research can be used for comparison with the results of cost analyses of wooden buildings in other countries, especially when it comes to countries similar to Slovakia, with similar research conditions such as a similar population, GDP, and land area, or post-communist countries and countries with a green state policy, etc.

5. Conclusions

The growing interest in sustainable construction methods brings various wood-based construction techniques to the fore. This requires an analysis of these techniques from different perspectives. In Slovakia, however, the trend of traditional construction from concrete and from piece masonry elements still prevails, which is not entirely satisfactory. This has resulted from the traditional beliefs of small investors in Slovakia and little trust in wood-based construction methods. This paper has examined the construction cost and

construction time parameters of an office building constructed using two wood-based construction methods: CLT panels and a timber column structural system. The goal was to analyze the parameters of two sustainable construction methods and evaluate their benefits and challenges. In addition, the goal is to demonstrate to potential investors the need to redirect to the given type of construction. The analysis found that construction costs could be what discourages potential investors from building with CLT panels, for example. The growing number of constructions based on wood including, those from CLT panels, can significantly contribute to the sustainability of the construction industry, which the Slovak construction industry requires. The synthesis of the acquired knowledge, as well as the determined efficiency rate, proved the advantage of building with CLT panels compared to the timber column structure. In our study dealing with varying structural proposals for the construction of an administrative building, the efficiency rate of different structural solutions was determined. As a result, it was found that the CLT construction has an efficiency rate of 3.262×10^{-6} and represents a more efficient variant than the timber column structure with a value of 2.426×10^{-6} .

The task of designers is to offer an analysis of the advantages and disadvantages of various types of constructions; the results of our study can be useful for some of these analyses.

There are various myths and prejudices and it is difficult to break them down. Our study will help to explain the facts and how to answer these prejudices. Similarly, our study can be used by other countries similar to Slovakia, where these prejudices also persist, as we have mentioned in the comments above. The cost of the material for wooden buildings is comparable to the cost of conventional construction. Based on the results of our multi-criteria comparison, constructions made of CLT panels are more advantageous than a timber column structure.

In an exemplary way, future research and the promotion of construction from CLT panels in Slovakia, both in the segment of family houses and in the segment of administrative buildings, can force the introduction of budgeting items of the CLT panel construction technique into the national construction budgeting software CenKros 4. This will contribute to a simpler calculation of costs for this construction system. Even in this way, it is possible to contribute to the simplification of the process of construction process preparation.

Even nowadays, there is a lack of available cost and time analyses of various construction methods that would make it easier for investors to decide on a specific construction technique or construction system in the decision-making process. This lack will mostly cause the investor to eventually be forced to opt for traditional construction techniques, as he does not have enough time and resources to carry out these analyses by himself. Our research complements the missing time–cost analysis of two wood-based sustainable construction systems.

Moreover, our research study on construction methods that apply wood as the main structural material contributes to sustainability in the construction industry. The findings of our study guide investors who can then improve their choice of construction technique in the phase of construction intention.

Through a case study of an administrative building, factors that can influence the choice of a wood-based construction method for the construction of taller buildings in Slovakia were investigated in this research.

Author Contributions: Conceptualization, A.T., Z.S. and M.Š.; methodology, A.T., Z.S. and M.Š.; software, M.Š.; validation, Z.S. and A.T.; formal analysis, Z.S. and A.T.; investigation, A.T. and Z.S.; resources, A.T.; data curation, Z.S.; writing—original draft preparation, A.T. and Z.S.; writing—review and editing, A.T. and Z.S.; visualization, M.Š.; supervision, M.K.; project administration, A.T.; Z.S.; M.K.; funding acquisition, M.K. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the research project VEGA 1/0336/22 of the Scientific Grant Agency, the Ministry of Education, Science, and Research, and Sport of the Slovak Republic. This paper presents partial research results of a project of the Slovak Research and Development Agency under contract no. APVV-22-0576: “Research of digital technologies and building information modelling tools for designing and evaluating the sustainability parameters of building structures in the context of decarbonization and circular construction”.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The original contributions presented in this study are included in the article. Further inquiries can be directed to the corresponding author.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Fakhrzarej, M.; Daneshvar, H.; Chui, Y.H. Numerical parametric study of cross-laminated timber diaphragms under in-plane loading. *Con. Build. Mat.* **2024**, *429*, 136387.
2. van der Westhuyzen, S.; Walls, R.; de Koker, N. Fire tests of South African cross-laminated timber wall panels: Fire ratings, charring rates, and delamination. *J. S. Afr. Inst. Civ. Eng.* **2020**, *62*, 33–41.
3. Zhang, Y.N.; Nehdi, M.L.; Gao, X.H.; Zhang, L.V. Flexural Performance of Novel Nail-Cross-Laminated Timber Composite Panels. *Appl. Sci.* **2020**, *10*, 5983.
4. Muñiz, F.; Tenorio, C.; Moya, R.; Navarro-Mora, A. CLT Fabricated with Gmelina arborea and Tectona grandis Wood from Fast-Growth Forest Plantations: Physical and Mechanical Properties. *J. Renew. Mat.* **2022**, *10*, 1–17.
5. He, M.J.; Sun, X.F.; Li, Z.; Feng, W. Bending, shear, and compressive properties of three- and five-layer cross-laminated timber fabricated with black spruce. *J. Wood Sci.* **2020**, *66*, 1–17. <https://doi.org/10.1186/s10086-020-01886-z>.
6. Srivaro, S.; Leelatanon, S.; Setkit, M.; Matan, N.; Khongtong, S.; Jantawee, S.; Tomad, J. Effects of manufacturing parameters on properties of rubberwood-cross laminated timber manufactured via hot pressing. *J. Buil. Eng.* **2021**, *44*, 102703.
7. Baño, V.; Godoy, D.; Figueredo, D.; Vega, A. Characterization and Structural Performance in Bending of CLT Panels Made from Small-Diameter Logs of Loblolly/Slash Pine. *Materials* **2018**, *11*, 2436.
8. Liang, Y.W.; Taoum, A.; Kotlarewski, N.; Chan, A.; Holloway, D. Behavior of Cross-Laminated Timber Panels Made from Fibre-Managed Eucalyptus nitens under Short-Term Serviceability Loads. *Buildings* **2023**, *13*, 245.
9. Das, S.; Gasparik, M.; Sethy, A.K.; Niemz, P.; Lagana, R.; Kytka, T.; Svitak, M.; Kamboj, G. Suitability of Aspen (*Populus tremula* L.) For Cross-Laminated Timber (CLT). *Wood Resear.* **2023**, *68*, 502–520.
10. Asgari, H.; Tannert, T.; Loss, C. Block tear-out resistance of CLT panels with single large-diameter connectors. *Europ. J. Wood W. Prod.* **2022**, *80*, 805–816.
11. Aljuhmani, A.G.; Alwashali, H.; Ogasawara, A.; Atsuzawa, E.; Maeda, M.; Seki, M. Experimental investigation on the effect of openings on the in-plane shear strength and stiffness of cross-laminated timber panels. *Eng. Struc.* **2021**, *254*, 113786.
12. Ma, Y.; Wang, X.; Begael, M.; Dai, Q.; Dickinson, Y.; Xie, X.; Ross, R.J. Flexural and shear performance of CLT panels made from salvaged beetle-killed white spruce. *Const. Build. Mat.* **2021**, *302*, 124381.
13. Cochon, N.; Richman, R. Towards quantifying the air leakage through cross-laminated timber. *Cas. Stud. Constr. Mat.* **2024**, *20*, e02748.
14. Salonvaara, M.; Desjarlais, A. Impact of Insulation Strategies of Cross-Laminated Timber Assemblies on Energy Use, Peak Demand, and Carbon Emissions. *Buildings* **2024**, *14*, 1089.
15. Hosseinzadeh, S.; Mohebbi, B.; Elyasi, M. Bending performances and rolling shear strength of nail-cross-laminated timber. *Wood Mat. Sci. Eng.* **2022**, *17*, 113–120.
16. Markovic, N.; Marjanovic, M.; Cvetkovic, R. Design approach for cost-effective hybrid CLT floors. *Gradevinar* **2022**, *74*, 301–311.
17. Huang, Y.; Hu, J.; Peng, H.; Chen, J.; Wang, Y.; Zhu, R.; Yu, W.; Zhang, Y. A new type of engineered wood product: Cross-laminated-thick veneers. *Cas. Stud. Constr. Mat.* **2024**, *20*, e02753.
18. D’Amico, B.; Pomponi, F.; Hart, J. Global potential for material substitution in building construction: The case of cross laminated timber. *J. Clean. Prod.* **2021**, *279*, 123487.
19. De Geetere, L.; Ingelaere, B.; Djickmans, A. New acoustic solutions for cross laminated timber based buildings. *J. Acoust. Soc. Am.* **2017**, *141*, 3714.
20. Zhang, T.T.; Sun, Q.; Sun, X.M.; Shi, J.W.; Ding, Z.P.; Wang, J.H. Research status and localization prospects of cross-laminated timber. *For. Mach. Woodwork. Equip.* **2017**, *45*, 4–7.
21. Kaputa, V.; Olsiakova, M.; Matova, H.; Drlickova, E. Do preferences for wood-framed houses’ attributes change over time? In Proceedings of Digitalisation and Circular Economy: Forestry and Forestry Based Industry Implications, Varna, Bulgaria, 11–13 September 2019.
22. Potkany, M.; Skultetyova, M.; Schmidtova, J.; Hajduchova, I. Customer Preferences for Wood-based Houses in Slovakia. *BioResources* **2021**, *16*, 7798–7815.

23. Potkany, M.; Skultetyova, M. Research into Customer Preferences of Potential Buyers of Simple Wood-based Houses for the Purpose of Using the Target Costing. *Op. Eng.* **2019**, *9*, 390–396.
24. Lazarevic, D.; Kautto, P.; Antikainen, R. Finland's wood-frame multi-storey construction innovation system: Analysing motors of creative destruction. *For. Pol. Econ.* **2020**, *110*, 101861.
25. Jussila, J.; Nagy, E.; Lähinen, K.; Hurmekoski, E.; Häyrynen, L.; Mark-Herbert, C.; Roos, A.; Toivonen, R.; Toppinen, A. Wooden multi-storey construction market development—Systematic literature review within a global scope with insights on the Nordic region. *Silva Fenn.* **2022**, *56*, 10609.
26. Lindblad, F.; Schauerte, T.; Johansson, J. Identifying Market Mobility Barriers for Wooden Single-Family House Producers to Enter the Multi-Family Segment. In Proceedings of the Forest Products Society Annual Convention—Forest Products: Key to a Sustainable Future, Madison, WI, USA, 11–14 June 2018.
27. Irland, L.C. Developing markets for certified wood products: Greening the supply chain for construction materials. *J. Ind. Ecol.* **2007**, *11*, 201–216.
28. Hurmekoski, E. Long-Term Outlook for Wood Construction in Europe. Dissertationes Forestales. Academic Dissertation, Faculty of Science and Forestry, University of Eastern Finland, Kuopio, Finland, 2016. <https://doi.org/10.14214/df.211>.
29. Hurmekoski, E.; Jonsson, R.; Nord, T. Context, drivers, and future potential for wood-frame multi-story construction in Europe. *Technol. Forecast. Soc. Chang.* **2015**, *99*, 181–196.
30. Hurmekoski, E.; Pykäläinen, J.; Hetemäki, L. Long-term targets for green building: Explorative Delphi backcasting study on wood-frame multi-story construction in Finland. *J. Clean. Prod.* **2018**, *172*, 3644–3654.
31. Nordin, F.; Öberg, C.; Kollberg, B.; Nord, T. Building a new supply chain position: An exploratory study of companies in the timber housing industry. *Constr. Manag. Econ.* **2010**, *28*, 1071–1083.
32. Riala, M.; Ilola, L. Multi-storey timber construction and bioeconomy—Barriers and opportunities. *Scand. J. Forest. Res.* **2014**, *29*, 367–377.
33. Vihemäki, H.; Ludvig, A.; Toivonen, R.; Toppinen, A.; Weiss, G. Institutional and policy frameworks shaping the wooden multi-storey construction markets: A comparative case study on Austria and Finland. *Wood Mater. Sci. Eng.* **2019**, *14*, 312–324.
34. Krieger, B.; Zipperer, V. Does green public procurement trigger environmental innovations? *Res. Policy* **2022**, *51*, 104516.
35. Zajeer Ahmed, M.; O'Donoghue, C.; McGetrick, P. Green public procurement in construction: A systematic review. *Clean. Respons. Consum.* **2024**, *15*, 100234.
36. Edquist, C.; Zabala-Iturriagoitia, J.M. Functional procurement for innovation, welfare, and the environment. *Sci. Publ. Policy* **2020**, *47*, 595–603.
37. Hall, P.; Löfgren, K. Greening the street-level procurer: Challenges in the strongly decentralized Swedish system. *J. Consum. Policy* **2016**, *39*, 467–483.
38. Rainville, A. Stimulating a more Circular economy through public procurement: Roles and dynamics of intermediation. *Res. Policy* **2021**, *50*, 104193.
39. Ye, M.; Ma, Y.; Liu, J. Why do public sectors perform high-level green public procurement practice? A new insight with fsQCA approach. *J. Environ. Plann. Manag.* **2021**, *65*, 2719–2747.

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.