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# Perception of User Criteria in the Context of Sustainability of Modern Methods of Construction Based on Wood

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**Abstract:** Recent developments in the construction industry have brought more efficient and sustainable technologies, technological procedures, and materials. An example of this are modern methods of construction, which offer larger production volumes with a higher quality and shorter procurement time. The goal of those methods is to improve construction sustainability through quality improvement, customer satisfaction, shortened construction time, and reduced environmental impact. The main goal of this research is to demonstrate, by means of theoretical assumptions, surveys, and analyses, the sustainability of modern methods of construction based on wood. The work focuses on identifying the user criteria for construction sustainability. Selected user criteria of construction sustainability are applied in a socio-economic survey whose purpose is to determine how users perceive the efficiency of selected construction systems. We evaluate certain user parameters in the context of sustainability by relying on the users of buildings (family houses) which have already been built and compare the results with declared design parameters.

**Keywords:** assessment; environment; modern methods of construction; socio-economic survey; sustainability; use phase; wood; wood construction

## 1. Introduction

In order to increase sustainability in construction, a whole host of construction problems is being addressed as part of global innovation and research activities in the field of construction (CIB—International Council for Research and Innovation in Building and Construction), supporting this goal through research programmes within so-called priority topics. One of the priority topics in construction, in both the European and global contexts, is sustainable construction [1–4]. The global trend in the construction market is such that construction sustainability is of increasingly crucial importance for the overall healthy functioning of the society and the whole environment [5,6].

Sustainable development in the construction industry is, nowadays, a much-debated subject, however, sustainability in this field of study still does not receive as much attention as it does in other fields [7]. Sustainability is viewed as a multi-dimensional system whose purpose is to improve people's quality of life. It does so by creating stronger community bonds, encouraging cooperation, and driving economic reform through increasing reliance on renewable resources [8]. Generally speaking, sustainable development [9,10] is a term used in numerous fields of economic and social life. A considerable number of researchers who are interested in those multiple dimensions of growth and development have now turned their attention to studying them from the point of view of sustainability [11–13]. Having said this, development sustainability is rather difficult to measure precisely. It is difficult to evaluate particular processes and phenomena in the society in terms of sustainability. The purpose of sustainability is not to limit development or reduce growth, but to search for such forms of social progress that will not be restrictive for the generations that will follow. It is about discovering a new kind of environmentally-friendly development that we can sustain longer, i.e., sustainable development [14,15]. The concepts of sustainability and sustainable development first appeared in the first half of the 1970s in a report produced by the Club of Rome in 1972. Unrestricted growth of any kind (due to production, consumption, pollution, etc.) is unsustainable if the environment only contains a limited amount of resources.

The term 'sustainable construction' lacks a clear definition and interpretation. However, it is possible to give a generalized formulation of the most commonly used characterisations of the criteria of what makes a building sustainable based on the following publications: Szekeres [16], Chen et al. [17], Smith and Timberlake [18], and Burwood and Jess [19]. Potential environmental (lower impact in terms of environment pollution), social (improving the sustainable functioning of society), and economic (reducing life cycle costs) advantages significantly influence most customers' decisions when choosing a wooden construction system. An assessment of the sustainability of a construction is a complex evaluation of a single life cycle period of the examined product or process [20,21]. As Lupíšek et al. [22], Yang et al. [23] and Napolano et al. [24] say, precise data on the properties of a building, building materials, and technologies, as well as other information on the building, is required to assess its life cycle. A life cycle consists of all stages, from the design process, through raw material mining, material production, transport to the construction site, construction itself, maintenance works, to demolition and removal of waste. Constructions use a considerable amount of resources during their life cycles and change landscapes. This has important consequences for the environment and people's health [25–27]. It is for this reason that we seek to reduce a construction's impact on the environment during its life cycle.

Modern methods of construction (MMC) of course follow this sustainability trend. The definition of MMC varies from country to country. In Asia, the terms "prefabrication" and "industrialized building systems" are favoured, the term "MMC" is favoured in the UK, and the term "off-site construction methods" is the most common in the US and Australia. MMC belong in two categories: the first is on-site MMC, and the second is off-site MMC. On-site MMC combine traditional materials with innovative manufacturing processes. On-site MMC are assembled directly onsite. Off-site MMC are made up of prefabricated panels or prefabricated modules. Parts of prefabricated constructions are manufactured in a factory, and completed parts are transported to the site and assembled there [18,28,29]. In general, modern methods of construction are technologies which use structures or parts of structures produced at factories [30]. Manufacturing finished parts of building structures at factories can improve construction efficiency during the phase of producing building components and during the phase of their onsite integration. MMC [18,31] are technologies that offer efficient processes in preparing and performing a construction, which leads to larger production volumes with a higher quality and reduced procurement time. MMC's main benefits are reduced construction time, elimination of errors during construction, lower energy intensity and lower production of waste. According to Burwood and Jess [19], MMC's goal is to improve efficiency in construction by shortening construction time, to enhance quality, sustainability, and to lower the impact of a building and a building process on the environment [32]. Lane [33] analyses the obstacles to more extensive use of modern methods of construction, characterising MMC as products and processes intended to boost business efficiency, quality, customer satisfaction, environmental impact, sustainability, and reliability in meeting deadlines. MMC are an examination of opportunities to improve the performance and effectiveness of the overall construction process. On Azman et al. [34] and Gibb [29], MMC are characterised by better productivity and quality, and also bring other advantages, such as shorter construction time, lower overall construction costs, better architectural appearance and durability, better protection of health and safety at work, reduced consumption of materials, less construction waste, and lower emissions, energy and water consumption. According to [32], MMC provide better products and processes. According to Burwood and Jess [19], MMC are viewed as construction methods that feature efficient product management processes to provide better products in larger quantities in a shorter period of time, using different methods and different materials. Their objective is to increase business efficiency, quality, customer satisfaction, sustainability, and reliability in meeting delivery deadlines and to reduce environmental impact [35].

A variety of materials is used in MMC, with wood, steel, and concrete being the most common. Selection of basic building materials is a crucial part of every project and is usually based on professional judgment, taking account of the importance of economic, environmental, functional, aesthetic, and health-related criteria [36]. Modern methods of construction based on wood involve efficient, economic, and sustainable solutions. As for the use of modern methods of construction in Slovakia (Central Europe), assembled buildings based on wood seem to be the most common construction systems [37]. In addition to the benefits of modern methods of construction mentioned above, one of the significant merits of modern wood constructions is the fact that this is a so-called dry construction process, so assembly of buildings is also possible during winter months [38,39]. The elimination of wet processes also eliminates failures and defects caused by the impact of technological moisture [40,41]. A wooden building can be used immediately after completion, so the investment starts to appreciate immediately. Quality wooden buildings can optimise interior moisture and can naturally optimise the parameters of the internal environment [42–46]. Since their construction solution consists of sandwich structures, they also have good acoustic and thermal-technical properties [47–49]. A sandwich structure, made up of layers of materials of varying density, also ensures necessary fire protection [50]. Aesthetic properties are also one of the advantages of buildings made from wooden structures. Natural texture, colour, and scent are pleasing to human senses. In addition to the fact that wood is a renewable resource, modern wooden buildings bring a significant environmental benefit as opposed to a heavy ceramic or silicate structure [51–54].

Despite the clear benefits associated with using construction systems based on wood, more extensive use of wooden buildings in Central Europe is limited by poor awareness among both potential customers and users. Countries where wooden buildings have a strong tradition, known for their proactive approach to innovations (Scandinavian countries), started to address these problems decades ago. It resulted in the introduction of modern construction solutions which significantly contributed to improved construction efficiency.

The main objective of our research is to demonstrate, on the basis of theoretical premises and performed surveys and analyses, the efficiency of modern methods of construction based on wood. We evaluate user parameters of assembled wooden buildings (family houses) during their use phase in terms of efficiency and sustainability.

## 2. Materials and Methods

On the one hand, use of a construction is limited by its architectural, construction, technical, and material solutions, and by the future user's idea of construction time, quality, and costs on the other. In the context of sustainable construction, there is a host of other environmental, social, and economic criteria showing the extent to which a construction affects its users' health, or even the society's health.

The method of collecting primary information was a socio-economic survey focused on the user parameters of MMC in terms of sustainability. Before the survey, we selected criteria and outlined the methodology for collecting and interpreting findings. Information was collected in the form of a questionnaire completed in person and in the form of an electronic on-line questionnaire. Selected quantitative and qualitative statistical indicators, an empirical comparison, and percentage analyses were used to evaluate and interpret our results. The questionnaire survey and the controlled interviews focused on the user parameters of assembled wooden buildings (family houses).

A total of 126 answers were collected using the questionnaire. The individual answers to the questionnaire correspond to the number of constructions, as one representative (homeowner) filled in the questionnaire for each construction and their answers included the opinions of the other users of the given construction.

Of the total number of respondents, 79% were men and 21% were women. Of the respondents most were of higher and secondary education. A total of 4.8% of respondents were in the 18–25 age group, 27.8% were in the 26–35 age group, 44.4%, were in the 36–50 age group, 20.7% were in the 51–65 age group, and 2.3% were in the over 66 age group. The initial statistical analysis did not reveal a significant impact of age and education of the respondents in terms of answering questions. Therefore, the impact of age categories and education was not taken into account.

Most respondents were from the Western Slovakia region, 36.5% of the total number, 28.57% were from Eastern Slovakia, and 15.09% were from Central Slovakia (Central Europe). A total of 19.84% of the respondents were from regions in the Czech Republic (Central Europe).

The methodology proposal and selection of scientific methods were based on the objectives and theses of the VEGA research project. This research relies on the following scientific methods: analysis, synthesis, induction, deduction, analogy, comparison, generalisation, specification (definition), verification, scientific elements, model and algorithm, and on the following statistical methods: Spearman's correlation coefficient and Student's *t*-test.

The analysis, synthesis, induction, deduction, generalisation, and specification (definition) methods are used in the analytical part of the work, in determining the user criteria of construction efficiency in terms of sustainability, and in the methodology for collecting documentation in the form of a socio-economic survey focused on wooden buildings' user parameters.

Analogy, comparison, verification, and algorithm are used in the collection and evaluation of the performed surveys. In the practical part of the work, the above scientific methods are accompanied by a statistical data analysis using the statistical method of Student's *t*-test.

### 2.1. Selection of Wood Construction User Parameters in the Context of Efficiency and Sustainability

Several evaluation and standardisation systems were used to select user parameters: STN EN 15978, 15643-3, 15643-4, LEED, BREEAM, DGNB, and SBTooL [55–59]. These standards comprehensively evaluate sustainability of constructions in terms of design and execution (Table 1). The above evaluation systems are analysed in more detail in the theoretical part of this work. In the next part of the research, the parameters listed in Table 1 were incorporated into a socio-economic research focused on examining the extent to which the results matched the declared user parameters of prefabricated wooden constructions in use. Due to the various classifications of criteria and parameters in the individual evaluation systems, even the selected parameters are impossible to match to a single set of criteria.

**Table 1.** Selection of user parameters in the context of sustainability systems.

| Sustainability of Buildings | | |
|---|---|---|
| **Parameters Assessed in the Environmental Field** | **Parameters Assessed in the Social Field** | **Parameters Assessed in the Economic Field** |
| √ Materials used for construction [1,7] | √ Visual comfort in the construction's interior [2,4,5,6,7,8]<br>√ Visual comfort of the construction's exterior [2,4,5,6,7]<br>√ Layout [2,7]<br>√ Quality of living in the construction [2,7]<br>√ Construction health safety [2,4,5,6,7] | √ Investment cost of building procurement [3,7]<br>√ Operating costs [3,4,5,6,7,8] |
| √ Acoustic comfort in the construction [2,4,5,6,7,8]<br>√ Lighting comfort in the construction [2,4,5,6,7,8]<br>√ Air quality in the construction's [2,4,5,6,7,8] | √ Overall construction build quality [2,3]<br>√ Occurrence of defects at the beginning of the construction's use [2,3]<br>√ Occurrence of defects during the construction's use [2,3] | |
| √ Construction time [1,2,3]<br>√ Thermal comfort in the winter period [2,4,5,6,7,8]<br>√ Thermal comfort in the summer period [2,4,5,6,7,8] | | |

Note: Evaluation systems—[1] STN EN 15978, [2] STN EN 15643-3, [3] STN EN 15643-4, [4] LEED, [5] BREEAM, [6] DGNB, [7] SBToolCZ, [8] CESBA Tool SK.

### 2.2. Socio-Economic Survey Methodology and the Structure of Parameters

The research methodology is based on a socio-economic survey. The subject of our study were already-completed wooden constructions of family houses, and the object of the study were user opinions, both in the context of meeting user sustainability criteria. The results should confirm or refute the wood construction parameters in terms of selected sustainability criteria.

The socio-economic survey was conducted in the form of a structured questionnaire using quantitative (in the form of multiple choice or scaling) and qualitative evaluation methods (in the form of open answers during a personal contact with respondents). Users of wooden constructions were identified and then contacted to collect data with the help of companies specialising in the production and execution of prefabricated constructions based on wood. This fact should contribute to the questioner's impartiality so that the respondent does not feel pressure from the construction's supplier.

The questionnaire contains over 50 questions divided into five parts: the respondent's details, the origin of references to the wooden construction, construction details, selected parameters of efficiency in the context of the construction's sustainability, and advantages/disadvantages—user experience summary. The answers to the questions combined selection methods, scaling, and open answers (Table 2). Table 2 presents a selected part of the survey focused on studying the selected sustainability parameters of constructions in use.

**Table 2.** The structure of the questionnaire for the perception of wood buildings by users.

| **Part 4: Examination of Selected Sustainability Parameters** | | |
|---|---|---|
| **Questions** | | **Type of Answer** |
| √ Wood construction build quality<br>√ Occurrence of defects at the beginning of the construction's use (after moving in) | | Multiple choice (a scale of 0 to 5) |
| √ Types of defects and their occurrence at the beginning of the construction's use (after moving in) | | Open (details to be added) |
| √ Occurrence of defects during the construction's use | | Multiple choice (a scale of 0 to 5) |
| √ Types of defects and their occurrence during the construction's use | | Open (details to be added) |
| √ Visual comfort in the construction's interior<br>√ Visual comfort of the construction's exterior<br>√ Construction's functionality<br>√ Layout<br>√ Quality of living<br>√ Materials used | √ Thermal comfort in the summer period<br>√ Thermal comfort in the winter period<br>√ Acoustic comfort<br>√ Lighting comfort<br>√ Air quality<br>√ Health safety | Multiple choice (a scale of 1 to 5) |

The listed user parameters were a basis for measuring the sustainability of constructions or construction systems based on wood and will reveal any shortcomings in the individual sustainability criteria for constructions in this segment of modern constructions.

The selected datasets were evaluated using the weight average method according to Equation (1) for determining the sustainability rate by means of the evaluated criteria. The weight average method uses the number of answers and a division of opinions into 'confirmation' (+) and 'refutation' (−) of constructions' sustainability by means of the evaluated criteria. The following evaluation weights of sustainability rates were determined for the comparison evaluation:

Dissatisfaction (weight −2)
Partial satisfaction (weight −1)
Neutral evaluation (weight 0)
Partial satisfaction (weight +1)
Satisfaction (weight +2)

The mean value of the individual parameters is calculated:

$$\overline{x_i} = \frac{\sum_{j=1}^{5} W_j \times f_{ij}}{\sum_{j=1}^{5} f_{ij}} \quad (1)$$

where $W_j$ is a weight in the satisfaction rate (−2, −1, 0, +1, +2).

$F_{ij}$ is the corresponding frequency of the satisfaction rate j of parameter i, and where $\sum_{j=1}^{5} f_{ij}$ is the total number of respondents.

The value $\overline{x_i}$ of the individual parameters represents the evaluation rate of the construction's sustainability, i.e., the resulting degree of meeting the sustainability requirements in wooden constructions which have already been built. The (+) values confirm the fulfilment of a parameter from the user's point of view and the (−) values refute the fulfilment of the evaluated parameters. Based on the evaluated criteria, we determined the so-called sustainability indicator of a technology (Sustainability Indicator—SI) which represents the sum of the selected evaluated sustainability criteria of a given technology according to Equation (2). The analysis of user efficiency by means of the selected sustainability criteria points towards differences in the comparison of the individual construction systems. Of those 105 analysed constructions, 45 were panel construction systems, 35 were column construction systems, and 23 were log construction systems.

The Sustainability Indicator (SI) was calculated based on the following formula:

$$SI = \sum_{i=1}^{n} CS\ [-] \tag{2}$$

where CS = the value of the sustainability criterion i [−].

## 3. Results

The respondents' previous housing significantly affects the comparison with current wooden construction housing. The majority of respondents (60.3%) mentioned a block of flats as their previous housing, 27.8% of respondents mentioned a traditional masonry family house, and 11.9% of respondents even mentioned a wooden construction as their previous housing. It follows from the findings that the respondents can compare traditional housing with living in a wooden construction based on their experience with other housing construction solutions.

Of those 126 wooden constructions, the largest group, with 45 houses (35.7% of the total number), were full-wall sandwich panel construction systems, the second largest group were column construction systems with 35 houses (27.8%), and the third largest category were log construction systems with 23 buildings (18.25%). Other construction systems of wooden constructions were panel construction systems with small-format panels with 10 buildings (7.9%), half-timbered construction systems with seven buildings (5.5%), panel construction systems from full-wall CLT panels (3.97%), and modular (cellular) construction systems with one construction.

Perhaps the most required parameter, in terms of legislation and users, is currently a building's energy standard, which does not only affect overall efficiency, but also its internal comfort during use. For this reason, the energy standard of the examined wooden constructions was also surveyed. Exactly one half of the analysed wooden constructions were built with a low-energy standard. Groups of energy saving constructions (14.29%), ultra-low-energy constructions (14.28%), and constructions with a passive standard (15.87%) were all more or less equally large. The smallest groups were constructions which meet the current legislative requirements (4.76%) and constructions without a specified energy standard due to the users' lack of knowledge of their energy standard (0.8%).

The periods of use of the individual wooden constructions shown in Figure 1 were also surveyed. Constructions with a period of use of one year were the largest group. Groups with a period of use between two and five years and over 10 years were more or less equally large. The period of use of the individual wooden constructions is sufficiently long for an objective evaluation of the constructions by their users.

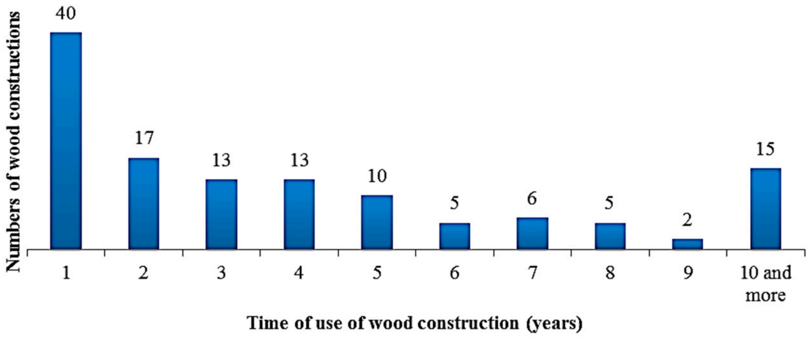



**Figure 1.** The number of assessed wood buildings in years of use.

In the next part of the research, we analysed the first three largest groups of wood construction systems. The groups of on-site technologies (wood constructions carried out on-site) consist of:

- Column construction system (Figures 2 and 3)
- Log construction system (traditional construction system) (Figures 4 and 5).

Off-site technologies (prefabricated wooden constructions) consist of:

- Panel construction system from full-wall sandwich panels (Figures 6 and 7).

(**a**) (**b**)

**Figure 2.** An example of a traditional log construction. (**a**) Construction process; (**b**) Traditional log construction [60].

(**a**) (**b**)

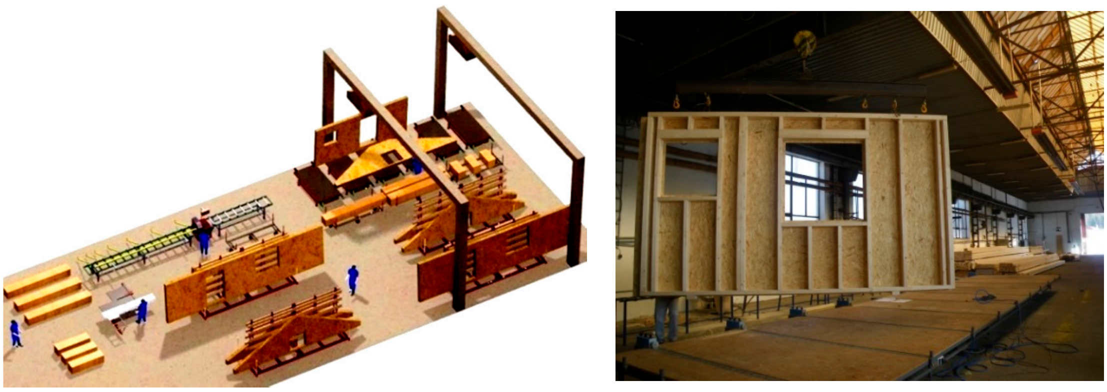
**Figure 3.** An example of a modern log construction. (**a**) Construction process; (**b**) Modern log construction [61].

(**a**) (**b**)

**Figure 4.** An example of a column construction system (**a**) Construction process—1st floor (**b**) Construction process—2nd floor [62].

(**a**) (**b**)

**Figure 5.** Construction process of details a column construction system (**a**) Inserting thermal insulation for walls (**b**) Performing the installation of wiring in the walls [62].



(**a**) (**b**)

**Figure 6.** Production hall with sandwich panels (**a**) Manufacturing process (**b**) Wood sandwich panel [63].

(**a**) (**b**)

**Figure 7.** An example of a panel construction (**a**) Construction process; (**b**) Panel construction [64].

*Analysis of the Sustainability of Assembled Constructions Based on Wood*

In this chapter we analyse selected sustainability parameters focused on the user evaluation of existing wooden constructions in terms of environmental and social sustainability parameters. Based on the selected evaluated criteria, we determined the so-called sustainability indicator of a construction system (Sustainability Indicator—SI) which represents a sustainability rate, i.e., the benefit gained by the users of the individual wood construction systems.

The analysis has shown positive assessment by the users within the perception of selected sustainability criteria. Even the weight analysis (Figure 8) did not refute fulfilling the originally-declared parameters of the used constructions (none of the criteria have a negative value). Thus, the selected user criteria confirm the efficiency of wooden constructions. However, we may state, based on the results, that the satisfaction of users of wooden constructions with the 'acoustic comfort' and 'thermal comfort' criteria in the summer is lower by half compared to other criteria. This indicates a 'problem' wooden constructions have with the acoustic spread of sound and thermal comfort in the summer period. The users can technically address thermal comfort (e.g., through recuperation or cooling). The evaluation rate of the individual criteria points towards a difference within the individual construction systems, where the panel construction system of wooden constructions based on sandwich panels received a better evaluation with respect to almost every criterion. The column construction system received the second best evaluation and the log construction system was last.

Based on the results of the individual criteria evaluation, a sustainability indicator was determined, representing the sum of the selected evaluated sustainability criteria of a given technology. The resulting indicator of the construction system from full wall sandwich panels is 20.18, which is almost 15% higher than in the case of the column construction (17.29) and almost 27% higher than the indicator of the log construction system (14.87).

The results imply (Figure 9) the greatest potential in terms of the evaluated sustainability criteria in the case of the panel construction system, evaluated by means of the users of the analysed wooden constructions.

For the sake of comparing datasets from the individual construction systems with one another, and for the sake of evaluating the degree of statistical significance between the individual criteria, we performed a statistical analysis using Student's *t*-test at the significance level $p < 0.05$. The results of the comparison are summarised in Table 3.

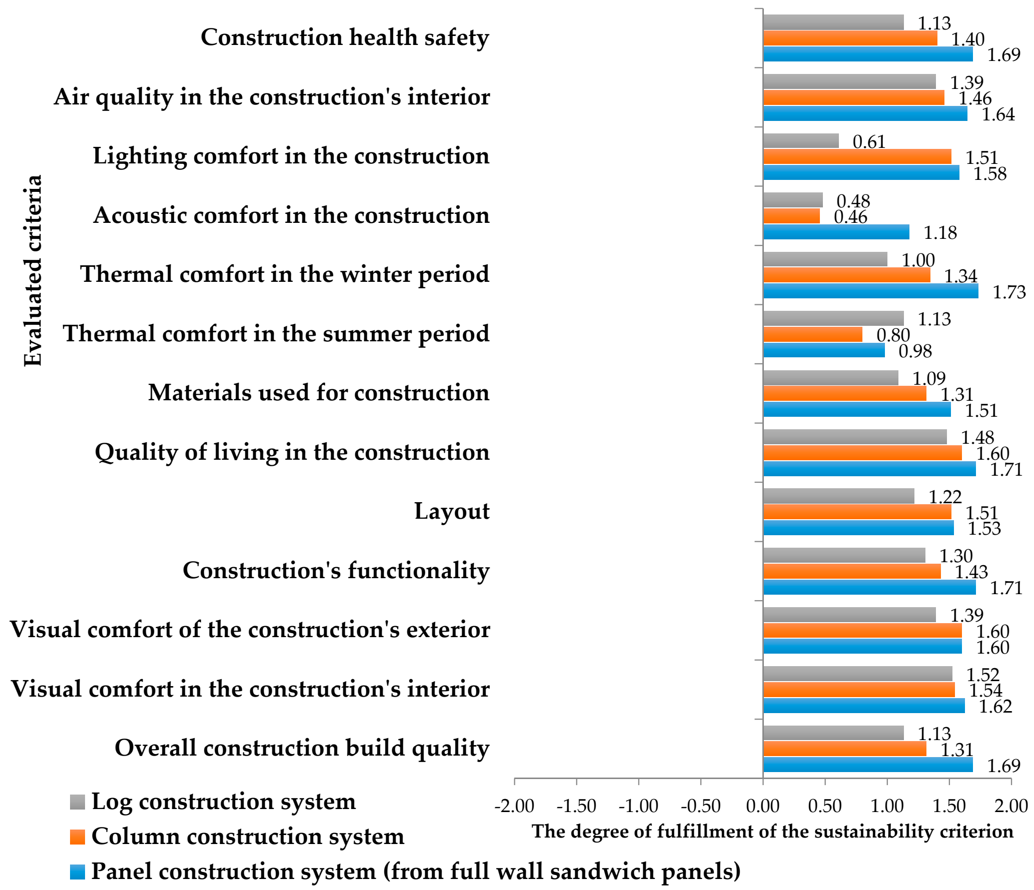



**Figure 8.** Assessing the sustainability of wooden buildings by their users.

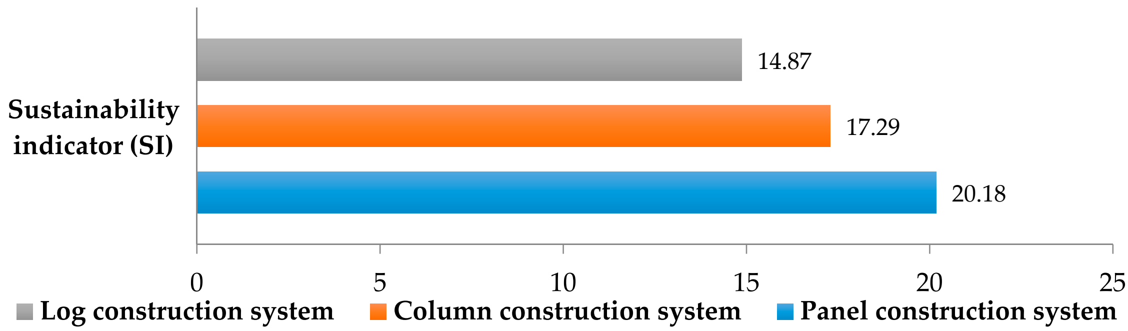



**Figure 9.** The sustainability indicator of construction systems.

**Table 3.** Mutual comparison of construction systems in individual evaluated criteria by *t*-test.

| ($p < 0.05$) | Panel Construction System vs. Column Construction System | | Panel Construction System vs. Log Construction System | | Column Construction System vs. Log Construction System | |
|---|---|---|---|---|---|---|
| | ***p* Values** | | ***p* Values** | | ***p* Values** | |
| Overall construction build quality | 0.0160 | * | 0.0034 | ** | 0.2591 | ns |
| The occurrence of errors at the beginning of the construction use (after moving in) | 0.0099 | ** | 0.0354 | * | 0.3702 | ns |
| The occurrence of errors during the use of the building | 0.1219 | ns | 0.1818 | ns | 0.3761 | ns |
| Visual comfort in the construction's interior | 0.3105 | ns | 0.2943 | ns | 0.4650 | ns |
| Visual comfort of the construction's exterior | 0.5000 | ns | 0.1564 | ns | 0.2020 | ns |
| Construction's functionality | 0.0454 | * | 0.0109 | ns | 0.3188 | ns |
| Layout | 0.4440 | ns | 0.0571 | ns | 0.0885 | ns |

**Table 3.** *Cont.*

| ($p < 0.05$) | Panel Construction System vs. Column Construction System | | Panel Construction System vs. Log Construction System | | Column Construction System vs. Log Construction System | |
|---|---|---|---|---|---|---|
| | *p* Values | | *p* Values | | *p* Values | |
| Quality of living in the construction | 0.2276 | ns | 0.1083 | ns | 0.3096 | ns |
| Materials used for construction | 0.1364 | ns | 0.0527 | ns | 0.2312 | ns |
| Thermal comfort in the summer period | 0.2111 | ns | 0.2665 | ns | 0.1201 | ns |
| Thermal comfort in the winter period | 0.0045 | ** | 0.0004 | *** | 0.1071 | ns |
| Acoustic comfort in the construction | $p < 0.0001$ | *** | 0.0006 | *** | 0.4650 | ns |
| Lighting comfort in the construction | 0.3347 | ns | $p < 0.0001$ | *** | 0.0002 | *** |
| Air quality in the construction's interior | 0.0956 | ns | 0.1039 | ns | 0.3837 | ns |
| Construction health safety | 0.0603 | ns | 0.0129 | * | 0.1914 | ns |

Note: ns—no significant, *, **, ***—significant.

The results imply a significant difference mainly in comparing the off-site and on-site technologies. Statistically significant dependencies were found in comparing the panel and column constructions in terms of these criteria: overall quality of construction design ($p = 0.0160$), occurrence of faults when the construction starts to be used (after moving in) ($p = 0.0099$), construction functionality (limitations of the design system in terms of function) ($p = 0.0454$), thermal comfort in winter ($p = 0.0045$), and acoustic comfort in the construction ($p < 0.0001$).

By comparing the panel and log constructions, we found statistically significant differences in terms of these criteria: overall quality of construction design ($p = 0.0034$), occurrence of faults when the construction starts to be used (after moving in) ($p = 0.0354$), thermal comfort in winter ($p = 0.0004$), acoustic comfort in the construction ($p < 0.0006$), lighting comfort in the construction ($p < 0.0001$) and the construction's health safety (occurrence of pests, molds, and other factors that affect the health status of exposed persons) ($p = 0.0129$).

By comparing the on-site construction systems, i.e., the column and log construction systems, we observed a statistically significant difference in terms of only one of the selected criteria, lighting comfort in the construction ($p = 0.0002$), which follows from the fact that log construction systems have generally smaller windows compared to other construction systems, which ultimately results in reduced lighting conditions in the building. The comparison of the construction systems using a statistical analysis showed differences in the construction systems in terms of the evaluated criteria, particularly between the off-site and on-site construction systems. These differences can be attributed mainly to the different designs of the construction systems themselves in terms of producing the main components on-site and off-site, which affects design quality, construction time, and construction costs.

## 4. Discussion

Pifko et al. [65], the authors of the extensive publication entitled 'Efektívne bývanie' (Efficient Housing), described efficient housing concepts regarding energy savings in relation to constructions' energy standards. These authors, based on their research, analyses, and case studies, state that if we build an unnecessarily large house, we will pay too much for the construction, heating and maintenance will be too expensive, and it is possible that we will not feel good in such a house. If we build a house which consumes more energy for heating, hot water, and thermal comfort in the summer than necessary, every year we will spend too much on the house's operation, while damaging the environment [3,66,67]. Additionally, if we build a house where we will not feel good, all investment will, in fact, be wasted [6,68]. We agree with these claims in our views supported by our research involving a socio-economic efficiency survey in the context of sustainability. Pifko et al. [65] also describe the housing quality that can be achieved using suitable construction materials, such as wood. As wood is a natural material and provides many benefits, ultimately helping to create a good microclimate inside buildings, in addition to offering social benefits in the form of inducing a good and balanced psychological state in users of wood constructions [27,49,55]. These benefits then act in combination with the economic and environmental aspects of housing [56,58]. The environmental and social area can also be attributed to the interactions between a construction and its user in the context of use [18,49,65]. We also support the claims on interactions between users and the constructions in which they live, given the experience we gained from our survey. Since a person spends 90 percent of their life in buildings, it is important to study these interactions between people and buildings [18,19]. Additionally, the more urgent the housing need, as the population growth curve is ever steeper, with the growing trend of relocation and urbanisation, the more important these problems of efficiency and sustainability evaluation in the use phase become. The current phenomenon of population migration from less-developed countries to more-developed ones, which raises the problem of growing demand and shortage of quality and decent housing, also certainly contributes to the relocation trend [1–3].

Several research works dedicated to various regions of the Czech Republic (Central Europe) examined using a unified methodology of research at Mendel University in Brno were concerned with similar problems of monitoring user experience with wood constructions [69–71]. These works were not focused in as much detail as ours on the aspects of efficiency in the context of sustainability. These works focused primarily on user experience with construction use in terms of advantages and disadvantages of wood constructions of various construction specifications. They found in their surveys that users in the Czech Republic prefer a frame or a column wood construction type completed on-site. We had similar findings in our survey, although users in Slovakia prefer a prefabricated panel construction system from full-wall sandwich panels (a so-called off-site construction system) as the most commonly used construction system. A comparison of these works' results with ours showed that we had arrived at similar findings, i.e., that wood constructions completed on-site are more susceptible to failures than constructions completed by means of off-site construction systems, which was caused either by low quality or by the impact of weather conditions during construction. Ultimately, deficiencies and defects directly affect users' attitudes towards wood constructions in the context of basic sustainability and efficiency requirements [27,38,55,72,73].

There are several internationally-recognised evaluation systems for evaluating construction sustainability or efficiency in the context of construction sustainability used to award sustainable construction certifications on the basis of an individual assessment. The American LEED, British BREEAM, German DGN, and the internationally-recognised SBTooL are among the best-known and most respected evaluation systems [74–78]. Sustainable building or construction certifications (so-called green certificates) are commonly required in Western Europe. As part of the market competition to offer the best quality properties, this trend is gradually being embraced by investors, developers, and users (tenants) in Central Europe (Slovakia and the Czech Republic) [68,79–82]. The positive impact of environmental assessments of construction projects will be reflected in operating costs and energy savings and, moreover, in the quality of the interior environment, applied technologies, materials, and other criteria [83–85]. Obtaining a building certification can be considered during any design, construction, or use phase [78,86]. The period of project documentation preparation is the most appropriate time to consider it [87]. However, certifications do differ, so choosing a certification system is an important step. There are certifications which are more difficult to attain and are more valuable. The more well-known certification a building is awarded, the better public image it has, gaining a competitive advantage [68,88]. The above evaluation systems comprehensively assess buildings' sustainability in terms of design and execution by assessing predefined criteria and aspects through an independent assessor or a certification body [89,90]. The methodologies of these [16,17,86], and other internationally-recognised evaluation systems and standards, formed [55,56,59] a basis for our definition of comprehensive efficiency criteria in the context of sustainability. We then selected the criteria to be adjusted to an evaluation by users of existing constructions, as they can rely on their experience with the acquisition process and use of constructions to realistically evaluate the specified criteria in the areas evaluated in our scientific research work. Our scientific research work progressively evaluates existing constructions by means of users, themselves, using our methodologies and analyses, which is what makes it innovative. The most commonly used sustainability evaluation tools are based primarily on buildings' quality assessments [16,17,86]. The evaluated criteria used in these tools may, therefore, be influenced by assessors [91]. In addition to these matters, there are also various performance categories and criteria of these systems, although they are based on similar key sustainability principles [92,93]. These differences among them are impossible to align at the moment, as the evaluation systems are not designed according to unified directives or standards and are, in a certain way, subject to conditions specific to the countries where they were introduced.

There are also evaluation systems applied in constructions' efficiency and sustainability evaluation that are based on the principle of evaluating existing buildings already in use. For example, the system called the Living Building Challenge (LBC) [94] employs a philosophy similar to ours, but their evaluation does not include evaluation by actual users, unlike in our case. An LBC certification is awarded based on actual project performance (instead of modelled or anticipated performance) according to basic sustainability criteria. The system judges buildings during their operation, typically after one year of use. The system also allows performing audits in the project preparation and execution phases, which can reveal possible defects or deficiencies in a project or a construction. By eliminating deficiencies and by proposing an improved design, it is possible to achieve more efficient and, crucially, more sustainable housing for future users.

## 5. Conclusions

The central part of the work dedicated to a user survey of wood construction sustainability was divided into two parts: an identification, selection, and specification of sustainability criteria for constructions based on wood, and an elaboration of methodology for evaluating sustainability of modern methods of construction based on wood by means of a socio-economic survey. The subject of the socio-economic survey consisted of already-completed wood constructions of family houses in use, while the object of the study consisted of user opinions in the context of matching the originally-declared user parameters. It follows from the comparison of construction systems in the context of selected sustainability parameters that panel constructions based on wood are perceived as more sustainable. Based on the resulting evaluation of users and conclusions, we state that the panel construction system, representing off-site technologies, is more positively evaluated in terms of selected sustainability criteria when compared with instances of on-site technologies. Of these technologies, a column construction system is more sustainable than a log construction system, but the difference is not as great as that between a panel construction system and a column construction system. Of the above on-site technologies, a column construction system is a more 'modern' technology than a log one, which tends to be closer to traditional construction technologies based on wood. It is also interesting that, from the point of view of sustainability, we would expect a better rating for log constructions, which are the most suitable environmentally. However, it is precisely the sustainability indicator, which also took account of other sustainability criteria, which revealed their shortcomings, especially regarding construction use, comfort, and quality.

Our evaluation approach was based on the perception of selected sustainability criteria for existing building sites by their users, since users are capable of providing the best feedback on the basis of experience with acquiring their constructions. Based on these approaches to the addressed problems, it was possible to analyse the strengths and weaknesses of assembled constructions based on wood, as they may benefit construction practices and businesses in the given construction segment. The work brings a whole host of findings arising from the conclusions of the conducted surveys and analyses, potentially helping to raise awareness of wood constructions in terms of the benefits they offer in the context of construction sustainability, not least the contribution that modern construction methods based on wood offer in terms of improving the efficiency in the construction industry. The elaboration of the methodology for evaluating sustainability and efficiency in selected phases of constructions' life cycles is a contribution, as it can be used in the future to evaluate various types of construction systems and their comparisons from the above perspectives. The work provides a methodology for designing a set of evaluation criteria allowing an evaluation of the use phase of constructions from the users' perspective in the context of the basic sustainability principles. We may state, based on the findings, that modern construction systems offer a healthy and ecological housing alternative.

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