Periodica Polytechnica
Civil Engineering

OnlineFirst (2018) paper 11224
https://doi.org/10.3311/PPci.11224

RESEARCH ARTICLE

Quality Parameters Perception of Modern Methods of Construction Based on Wood in the Context of Sustainability

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Received 04 July 2017; Revised 02 October 2017; Accepted 23 January 2018

Abstract

Quality parameters are important for achieving sustainability and prosperity. A range of new and innovative construction systems is currently being developed, presented as modern methods of construction (MMC), which have an ambition to improve the performance parameters of buildings throughout their life cycle. As for the implementation of modern methods of construction in Slovakia, assembled buildings based on wood seem to be the most preferred construction system. In the study presented in the paper, we searched for already built and occupied wood-based family houses. The residents' attitudes towards such a type of buildings in the context with declared design and qualitative parameters of efficiency and sustainability are overlooked. The methodology of the research study is based on a socio-economic survey. Due to the large amounts of data collected through a questionnaire, only selected parts of the survey results are evaluated and discussed in the paper. The presented parts of the survey focus on two research questions. The first is aimed at determining the preferred parameters of wooden structures with future users and the second is aimed at evaluating the quality of buildings in view of users of existing wooden buildings. An expectations survey aims the determine the attitudes of users during their use of wooden buildings as one of the innovative technologies, MMC, and their view of the quality of construction and comfort while living in them.

Keywords

wooden buildings, modern methods of construction, quality, socio-economic survey

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1 Introduction

Modern methods of construction (MMC) based on wood are a response to the trend of sustainable and effective construction. Manufacturing and construction of wooden buildings, from the applied materials and production technologies point of view, definitely has a lower environmental impact compared to other traditionally preferred technologies in Slovakia (ceramic or silicate brickwork, monolithic reinforced concrete...). Smith and Timberlake [1] present MMC as technologies that provide effective procedures of construction preparation and execution, resulting in a larger volume of production with higher quality and reduced time of their procurement.

Generally, modern methods of construction are technologies which make use of structures or their components manufactured in a factory. Production of more or less completed components of building structures outside the construction site has a high potential to increase construction efficiency at the production stage of building components as well as in the process of their integration on the site. In Slovakia, where there is an increasing shortage of capacities in construction, especially of qualified human resources, it has developed into a real pressure on advancing construction work efficiency. As a result, in areas with until now preferred conventional, but not always effective construction methods, innovative and sustainable building solutions which are already created and applied exist.

The undoubted advantages of the MMC are shorter construction time, higher quality of produced elements, fewer errors in the construction process, or reduction of construction waste generation. Their ambition [2] is to enhance the construction efficiency through reducing construction time and improving the quality, sustainability and impact of a construction on the environment. As for modern methods of construction implementation in Slovakia, assembled buildings based on wood seem to be the most preferred construction system. According to Kupkovič, Kalamees and Selgel [3–5], efficiency is broadly understood as a successful production activity resulting from the application of a new technology or work organization. Piffko and Špaček [6] present efficiency as the ratio of invested cost (construction cost, service cost, effort made and time) to obtained benefits (quality and living comfort). Measuring efficiency presupposes establishing criteria and selecting their parameters [7]. According to Sosedová [8, 24, 25], a criterion or a parameter determines the degree, rule or standard, whereby it is possible to estimate the efficiency level, i.e. the extent to which the solution meets the requirements arising from the established criteria. The criteria for efficiency assess,ent may vary, because efficiency is a summary measure of all parameters affecting the results of any activity.

A similarly complicated set of criteria is also used for assessing sustainability of buildings. Currently, sustainability criteria, divided into three groups, economic, social and environmental, are used the most often in assessing buildings. These criteria are linked to each other; that is some criteria underlie others. This resulted in the occurrence of many different sustainability assessment systems [9–11,26]. There are several assessment systems for the evaluating building sustainability, namely LEED, BREEAM, DGNB or SBTooL, or standardized systems such as STN EN 15978, STN EN 15643-3, STN EN 15643-4 [16–18,23]. In Table 1, the use of selected criteria of assessment systems is analysed.

The overview shows that although evaluation systems are more concerned with the quality of the indoor environment of buildings, standardized systems provide a comprehensive view of a building's operational quality. The quality of the indoor environment is assessed within the social sphere. In the social field, for example, thermal comfort, acoustic and visual comfort, level of daylight, indoor air quality or space adaptability are assessed. In the environmental field, concrete application of renewable sources of energy or water supply is assessed. Even the environmental parameters of building materials, waste generation (within manufacturing and construction) or the whole environmental impact of the building are also rated. Although the proportion of economic criteria has the lowest representation in assessment systems, those criteria influence the investors' "attitude" towards sustainability in building procurement the most. It can be concluded from the above that quality of construction is characterized by the extent to which a building is sustainable with emphasis on responsibility for society and environment [31]. A sustainable building must feature certain key characteristics, namely quality of all life cycle processes, such as optimization of environmental, economic and social parameters of quality [29, 30]. All sustainability arguments are beneficial for the demand for construction quality.

According to a survey conducted by the STEM/MARK agency in 2013, quality is the decisive factor when purchasing building materials for 82% of Slovaks, while 91% are willing

Table 1 The selected usage parameters of buildings in the context of sustainability systems

Selected criteria	Assessment systems							
	STN EN 15978	STN EN 15643-3	STN EN 15643-4	LEED	BREEAM	DGNB	SBToolCZ	CESBA Tool SK
applied building materials	●	○	○	○	○	○	●	○
visual comfort inside building	○	●	○	●	●	●	●	●
visual comfort of building exterior	○	●	○	●	●	●	●	○
spatial solution	○	●	○	○	○	○	●	○
housing quality	○	●	○	○	○	○	●	○
healthiness of building	○	●	○	●	●	●	●	○
investment cost on building procurement	○	○	●	○	○	○	●	○
service cost	○	○	●	●	●	●	●	●
acoustic comfort in building	○	●	○	●	●	●	●	●
lighting comfort in building	○	●	○	●	●	●	●	●
indoor air quality in building	○	●	○	●	●	●	●	●
construction quality	○	●	●	○	○	○	○	○
defects at the beginning of building use	○	●	●	○	○	○	○	○
defects during building use	○	●	●	○	○	○	○	○
construction time	●	●	●	○	○	○	○	○
thermal comfort in wintertime	○	●	○	●	●	●	●	●
thermal comfort in summertime	○	●	○	●	●	●	●	●

Note: ● - occurrence in assessment systems; ○ - absent in assessment systems to pay extra for it. This suggests that investors in procurement of housing prefer quality materials as a major factor, and therefore operational quality of a building [12, 22, 27]. The following study evaluates quality performance of buildings through their users, because they know the most objectively how to assess quality performance of their wooden buildings.

2 Research materials

Building constructions based on wood are also capable of becoming economically interesting in our regions, if they effectively manage design, technology, logistics, quality management system in manufacturing and construction. One of the advantages of wooden houses, according to Cellar [13, 14], is the variability of structures and composition of the walls, which can be designed as low cost, low energy and passive models. This system is designed to build multi-storey buildings, apartment buildings, office buildings and houses. According to Štefko and Hájek [15, 28] they can be divided into wooden buildings based on prefabricated panel constructions, columnar constructions, timbered constructions, skeleton and half-timbered constructions. According to the Association of Wood Processors of Slovak Republic, the most widely used structural systems of prefabricated wooden buildings used in Slovakia include panel constructions and columnar construction systems. Based on the aforementioned arguments, we have chosen panel wood houses as the subject of the investigation. The purpose of the investigation was to examine the overall quality of built wooden houses and to evaluate the occurrence of errors after moving in, during use of wooden buildings, and to assess the kinds and frequency of errors.

Panel construction system is the main off-site construction method based on wood. Structural elements are panels (wall, ceil, roof, gable, partition wall) produced in different stages of completion in the production hall (Fig. 2) and subsequently transported to the construction site where they are assembled to the structure. Build-up process is characterized by speed and precision. A panel generally consists of a wooden frame of profiled timber, covered on both sides with large-scale plates and filled with thermal insulation material (Fig. 1). During manufacturing, panels are incorporated into preparation for installation.

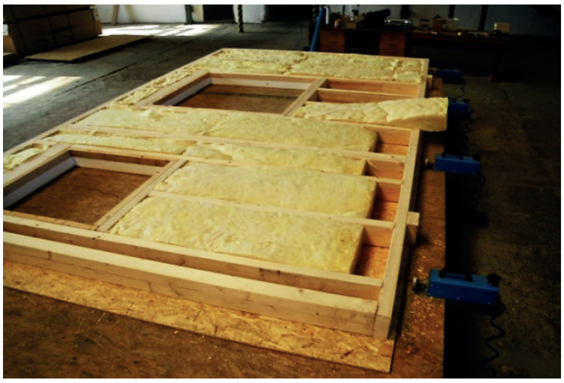

Fig. 1 An example of a prefabricated sandwich wood panel [19].

Fig. 2 A production hall for sandwich wall panels [20].

Fig. 3 Construction of a panel construction system [21].

A prefabricated construction panel system fully utilizes construction, manufacturing and assembly advantages of their production to achieve efficiency of the entire construction process. The key moment in increasing the efficiency and degree of prefabrication is a panel's finalization. A panel system has an enormous potential to increasing efficiency in the design, production and construction phase. Manufacturing can be automated, thus increasing the quality of production, and workmanship is achieved by means of a construction's re-application. The bearing system of prefabricated wooden houses is completed within a few days of starting the construction (Fig. 3). Other finishing and plumbing work takes place after the assembly of the individual elements.

3 Research methodology

The research methodology is based on a socio-economic survey. The research subject is represented by already occupied wooden family houses, and the subject matter of the survey consists of the residents' feelings in the context of the extent of fulfilling the initially declared use parameters. The results should confirm or refute the initially declared parameters of wooden buildings from the selected sustainability criteria point of view.

The socio-economic survey was conducted by means of a questionnaire, while quantitative methods of evaluation (in the form of multiple choice or scaling) as well as qualitative methods (through open responses during personal contact with respondents) were used. Since wood-based family houses are the most common in the whole segment of wooden buildings in Slovakia, the respondents were owners or users of already occupied wood-based family houses. The questionnaire contains more than 50 questions divided into five parts: information on the respondent, the origin of the references on wooden building, data on the building, selected parameters of customer efficiency in the context of building sustainability, advantages/disadvantages – a summary of respondent experiences. Answers to the questions combined methods using choice, scaling and open responses.

The survey ran from the beginning of 2015 and, given the still ongoing research activities in this segment of construction, more data will be obtained in the future. The respondents (owners of wooden buildings) were identified with the help of companies specializing in manufacturing and construction of assembled wooden buildings in Slovakia. This fact should contribute to impartiality; the respondents did not feel any "pressure" from the building contractor's side. Due to the large amount of data collected through the questionnaire, only parts of the survey results concerning quality are evaluated and discussed. The presented parts of the survey focus on two research questions. The first is aimed at determining preferences regarding the parameters of wooden structures with future users, and the second is aimed at evaluating the quality of the buildings according to the users of existing wooden buildings.

The first part of the survey focuses on the priority of the selected criteria for users before to the procurement of a wooden building. The views of users were divided according to the construction system of the wooden building in which they live. To assess the significance of the selected parameters, the method of weighted average was used. The method uses the distribution of the respondents' opinions, ranging from completely no significance (-2 weight), little significance (-1 weight), moderately significant (0 weight), very significant (+1 weight) to highly significant (+2 weight). In the survey, these aspects were evaluated: time of construction, investment cost of building procurement, operating costs of the building, quality and comfort of living, ecological aspects, reference on companies and construction technology.

The second part of the survey focuses on the overall construction quality of built wooden houses, and on evaluating the occurrence of errors after moving in and during use of wooden buildings, assessed by scaling from 1 to 5 (1 – negative, 5 – positive). The kinds and number of errors were also assessed.

4 Results and discussion

Up until now, more than thirty wooden buildings have been explored through the aforementioned survey. The sample largely consisted of panel construction systems. The results from 25 wood-based family houses represented by panel construction systems are presented.

The period of use for the surveyed buildings was from 1 year to 8 years. The age distribution of the wooden houses constitutes a sufficiently long time for a genuine evaluation of the buildings from users' side. The evaluation involved the customers' requirements and demand for fulfilling the use parameters. As for the previous type of living before living in the examined wood-based house, 64% of respondents lived in a panel flat-building (reinforced concrete panel construction system), 28% of respondents lived in a traditional brick house, and even 8% respondents had already lived in a wooden house.

In the survey, these criteria were evaluated: time of construction, investment cost of building procurement, operating costs of the building, quality and comfort of living, ecological aspects and construction technology. The mean of each parameter represents the significance criterion, i.e. how significantly users prefer the selected criteria (Fig. 4).

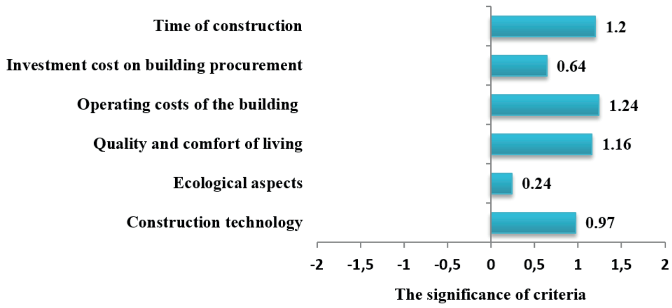

Fig. 4 Assessing the significance of the selected criteria of wooden buildings

According to Figure 4, users attach the greatest significance to operating costs of the building and time of construction. Less significance was observed for quality and comfort of living and construction technology. The users placed the least significance on ecological aspects and investment cost of building procurement. As we mentioned above, quality is an important factor, as confirmed by our findings in which quality was also assessed as an important aspect in the users' rating.

The second part of the survey focused on the overall quality of wooden houses and on an evaluation of the occurrence of errors after moving in and during use of wooden buildings (Table 2).

For a better comparison with the first part of the research, the evaluation of qualitative criteria through users was transformed to a scale of -2 to +2. The comparison showed that quality parameters were among the three most important parameters in terms of significance criteria with the degree of significance 1.16. A more detailed analysis of the quality criteria has shown an even higher level of satisfaction among users of prefabricated wooden buildings with quality (Fig.5). The parameters of the overall quality satisfaction rate reached a value of up to 1.8. An interesting fact is also found in connection with the occurrence of errors. While the level of user satisfaction after moving into the building was to 1.8, after a period of use (the period of use of buildings is within 1–8 years, which is an average of 4 years) it fell to 1.28.

Table 2 The assessment of the selected parameters of wooden houses conducted by their users

Building/ Parameter	Evaluation of the overall quality (the construction of wooden houses)	Evaluation of users satisfaction with errors occurs after move in to the wooden houses	Evaluation of users satisfaction with appearance of errors during uses the wooden houses	Type errors	
				at the beginning of use of wooden houses (after moving in)	during uses the wooden houses
1	5	4	5	re-install the windows and doors	x
2	5	5	5	x	x
3	5	4	4	roof	roof
4	4	5	4	x	small cracks by using magnesium boards for thermal insulation of buildings
5	5	4	4	small cracks in plaster	small cracks in plaster
6	5	4	4	small cracks in plaster	small cracks in plaster
7	5	5	5	x	x
8	5	5	5	x	x
9	5	5	5	x	x
10	5	5	4	x	small cracks at a joint structures
11	5	5	4	x	unstuck tile in the kitchen
12	4	5	4	x	small cracks in plaster
13	4	5	4	x	small cracks in plaster
14	5	5	5	x	-
15	5	5	3	x	windows, doors, shower
16	5	5	5	x	-
17	5	5	4	x	failure of the lock entrance doors, wood moldings apostasy on the edge of the roof and walls
18	5	5	5	x	-
19	5	5	5	x	-
20	5	5	5	x	-
21	4	4	3	subsidence of insulation in the wall	crackling wood ,cracks on the facade, the transmission of noise when going to the upper floor
22	5	5	4	x	small cracks in plaster
23	5	5	4	x	cracks in plasterboard
24	4	5	3	sanitary	cracks in plasterboard
25	5	5	4	x	boiler failure

Note: scaling from 1 to 5: 1 – negative, 5 – positive, x - the user does not defect

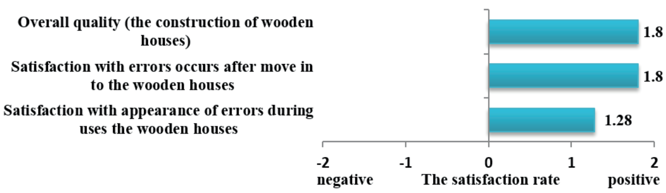

Fig. 5 Assessing the satisfaction of selected criteria of wooden buildings

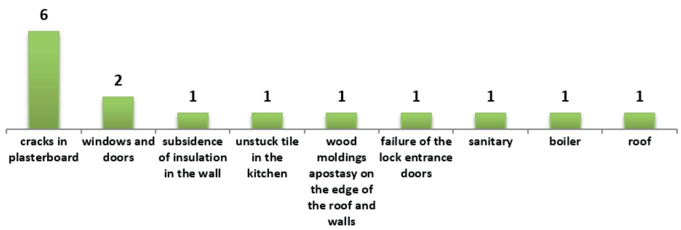

Fig. 6 The kinds and number of errors

On the basis of the facts mentioned above, it is also very important to identify the specific errors in wooden houses. This is necessary for process improvement in production and construction of other buildings. Figure 6 presents the specific errors detected and their number in the analysed buildings.

Users, after moving in, were generally satisfied with the occurrence of defects after moving in, because faults occurred only rarely in the six cases. Errors were not important and concerned only minor defects on the plaster, while one case involved an error on roofing and plumbing. Only one case was related to the construction of wooden houses – it concerned the subsidence of thermal insulation in the wall of wooden houses. Fourteen defects occurred during use, but only three cases concerned the construction of wooden houses. Errors related to the construction system included cracked wood, cracks on the facade, the transmission of noise when going to the upper floor. Other errors were not serious and concerned mainly small cracks in the plaster and cracks in drywall joints. Errors related to minor cracks and faults in relation to drywall are also commonly found in other traditional construction systems. Despite finding some errors, on the basis of the qualitative research through personal interviews with users, the users were generally satisfied with the quality of wood construction.

5 Conclusions

The research focused on the analysis of buildings' sustainability parameters and an evaluation of the user's criterion for quality buildings based on wood, both of which demonstrate fulfilment of the declared parameters of the design of wood buildings as perceived by actual users. The analysis focused on two research questions. The first is aimed at determining the preferences of parameters of wooden structures for future users, and the second is aimed at evaluating the quality of buildings as viewed by users of existing wooden buildings. According to the results, future users give the greatest significance on operating costs of the building and quality and comfort of living. Rating of current users shows the overall satisfaction with quality of wooden houses as one of the innovative MMC technology. A more detailed analysis of quality criteria demonstrated even greater level of significance user satisfaction wooden prefabricated buildings with the quality. The parameters of the overall quality satisfaction rate reached a value of up to 1.8 (on a scale of -2, 2). An interesting fact is also found in connection with the occurrence of errors. While the level of user satisfaction after moving into the building was to 1.8, after a period of use it fell to 1.28. The research indicates some defects, which can be eliminated through process and product innovation in future production of modern methods of construction based on wood.

Acknowledgement

The article presents a partial research result of project VEGA - 1/0677/14 „Research of construction efficiency improvement through MMC technologies"

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