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ScienceDirect
Procedia Engineering 108 (2015) 387 – 393
Procedia Engineering
www.elsevier.com/locate/procedia

7th Scientific-Technical Conference Material Problems in Civil Engineering (MATBUD'2015)

Methodology of cost parameter estimation for modern methods of construction based on wood

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Abstract

The modern building systems employ an unceasing development potential of latter building materials and systems. The composition of building structures (walls, roofs, floors, ...) is increasingly difficult due to combinations of various types of materials in order to ensure (create) the structures with the best parameters (thermo-technical, mechanical, user`s, ...). The production cost, determining the further application of building components on the market, definitely presents one from important parameters. Especially in the area of wooden constructions, there have been increasingly appearing new and new construction-material systems. To explore their structural and material characteristics, the standard analysis, calculations and test procedures are used. However, the determination of their quantities, when estimating the total cost, is problematic. The existing estimating databases providing at least information cost, don't involve the needed information. Thus, a potential customer is not able to confront the cost of such new construction systems with cost of other systems offered by various suppliers. The paper is focused on construction-technological analysis of the modern construction systems based on wood. Moreover, the proposed methodology of cost parameter estimation is presented. Estimation of Budgetary Index (BI) is based on a case study of a selected construction system based on wood, represented by ten wood houses with different shape and different size.

Peer-review under responsibility of organizing committee of the 7th Scientific-Technical Conference Material Problems in Civil Engineering

Keywords: construction cost; budgetary inder; modern methods of construction; wood construction

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Peer-review under responsibility of organizing committee of the 7th Scientific-Technical Conference Material Problems in Civil Engineering
doi:10.1016/j.proeng.2015.06.162

1. Introduction

Modern methods of construction (MMC) are known as those which provide an efficient product management process to provide more products of better quality in less time. The MMC offer an opportunity for increasing housing delivery and potentially reducing cost, thereby possibly slowing house price inflation. Decreased construction time, reduced whole life cost, increased quality through minimization of on-site operations and duration, less congestion on site, improved health and safety along with greater and increased sustainability are by Engstrom et al. [1], Gibb and Isack [2] and Blismas et al. [3] documented as the most distinguished benefit of MMC. With the increase in MMC, projects participants are embracing the drive toward off-site production, which is the manufacture of construction elements, components, modules and nearly complete buildings in a factory environment. According to Glass and Pepper [4], the use of off-site technologies has often thought to be a strategy to improve the overall performance of construction.

Huang et al. [5] indicate that given the stability, durability and renewability of wooden materials, as well as the targets for a greener, sustainable and low-carbon construction industry, a big potential to increase the use of wood in house construction has been identified. According to Liu et al. [6], wood as a building material is seen to have low impacts from the perspective of low water pollution, low green house gas emissions, low air pollution and low solid waste compared with concrete and steel. Roos et al. [7] described industrialized wood building methods as promising for various reasons as dry pre-fabrication increased quality, speed of on-site assembly, and requiring less personnel on site. In Slovakia, prefabricated wood-based building systems are the most preferred and expanded from all the MMC. The constant expansion of wood construction in architecture coincides with the development of new building materials and new building systems. One of the advantages of wood houses is the variability of structures and composition of the walls that can be designed as a low cost, low energy and passive models.

However, new building materials and modern methods of construction entail problems with absence of indexes for their precise cost estimation. Budgeting wood houses through individual calculation according to existing price-list items is often problematic. The cost estimator must set cost of construction according to general construction items that often misrepresent the true construction cost.

The current information technologies in construction cost estimation provide information of Budgetary Index (BI) relating to one unit of total building volume. These are effectively used in initial phase of any investment process to estimate the cost of upcoming construction project and to compare design variants of construction and requirements on investments. They are available several software tools utilizable by designers, contractors as well as by connoisseurs to estimate the construction cost or to determine the value of a finished structure. The Budgetary Index reflects the average cost of all building structures involved to one unit of total building volume (to 1 m^3 of the building). The Budgetary Indexes vary depending on building type and construction-material characteristics of building. In Slovakia, they are processed in accordance with the Decree no. 323/2010 Coll., about statistical classification of buildings. The aim of the study, presented in the paper, was to reveal the individual budgetary index of a specific group of wood-based houses characterized by open diffuse system.

2. The construction-technological analysis of the modern construction systems based on wood

Currently, there are available and preferred several wood-based construction systems. The systems differ by structures, composition of materials as well as by appearance.

The stick-frame constructions consist of slender profiles. In the USA and Canada, it is the system known as “two by four”. In our country, the profiles 50 to 60 mm x 120 to 160 mm have expanded. Wind bracing and wall bracing is provided by large-scale sheathing material. The material is attached to sticks by nails or by clips. The cavities are filled with some thermal insulation material. Utilization of this system of slender profiles makes it possible to design and construct multi-storey buildings with high variability of ground plan solution.

The *wood frame constructions* are characterized by three-dimensional supporting system consisting of horizontal and vertical beam units. The construction is completed by sheet structural elements enclosing the internal space. The system is utilizable especially in industrial premises. It is possible to build constructions with large spans. The main building units involve improved laminated timber and metal connecting means. Filling components of external walls and indoor partitions are not bearing, but they can participate in providing the spatial rigidity of a structure. The bearing structures are created by solid sections of improved laminated timber of various shapes (square, rectangular, H-shaped) or of composed I-shaped sections.

The main elements of *a wood panel construction* are the bearing panels of external and indoor walls and partitions. The wood panel systems are produced in different degrees of prefabrication. The panels have several functions; bearing, dividing or fencing. They are manufactured in a factory and assembly in the site is really fast. This system is designed to build multi-storey buildings as well as flat houses. The panel is made up of a wood frame of 50 to 60 mm x 120 to 160 mm profiles and is covered on both sides by constructional boards with thermal insulation infill. Preparation for electrical and sanitary distributions in the panel is often made in the factory. Wooden panel houses consist of a wooden frame. It all starts at the factory where construction elements or panels (walls, ceilings and roof constructions) of the house are assembled from different timber materials (columns, beams, rafters). Panels are filled with insulating material (mineral wool or stone-wool), windows and exterior door are constructed, as well as complete or partial facade decoration and interior wall finishes are performed. After being constructed at the factory, panels are delivered to the construction site where the house is assembled on pre-built foundation.

A new product in the market is *a solid timber construction,* making use of benefits of assembled systems. It is characterized by full solid wood panels that are produced in a factory and are assembled into a building in the site. The panels are manufactured in the production line where timber is formatted to the required thickness. Walls consist of solid wood elements created by mechanical fusion without use of chemicals and adhesives. Such wood-based constructions are eco-friendly and are even utilizable for low-energy housing. The most distinguished benefit of the system is reduced construction time due to assembly without any wet processes. The components are produced in a factory with perfect accuracy, which accelerates the assembly process at the site. The system makes possible to design and construct buildings with good variability of disposition and architectural solutions.

Currently, *the assembled wood buildings from prefabricated modular panels* are the most advanced. Such wood buildings are often indistinguishable from masonry buildings. The system is popular especially due to fast construction. The panels are precisely manufactured in a factory and are delivered to the site. The construction system has excellent resistance to pests. The bearing structure of the panel consists of a wood frame that is filled by insulation material (thermal and acoustic) and covered by wood particle boards in external side and for example by plasterboards in internal side. In case of bonded sandwich panels, the self-blowing polystyrene board is installed between two oriented strand boards (OSB). The construction system from sandwich insulated panels is destined for low energy houses.

A flexible building system *Cross Laminated Timber* (CLT) is suitable to use in all assembly types (e.g. walls, floors and roofs). Gagnon [8] indicate that buildings with cross laminated timber have an impact in as much as it allows for a fundamentally new approach to solid wood as construction material. Made from industrial dried lumber stacked together at right angles and glued over their entire surface, it is an exceptionally strong product that retains its static strength and shape, and allows the transfer of loads on all sides. Panels are prefabricated based on the project design and arrive at the building site with windows and doors pre-cut. Sizes vary by manufacturer and include 3, 5, 7 or more layers. Panels are connected to each other with half –lapped, single or double splines made from engineered wood products, while metal brackets, hold-downs and plates are used to transfer forces.

Eco Home International presented a revolutionary building system STEKO. This unique system was invented in Switzerland in 1997. At the present time it is well known in Europe, Greenland and now it is reaching other countries, including the USA. It is designed for energy efficient and green houses. STEKO is a modular system of the most modern construction on a highly technical level. Exterior and interior walls are built from standardized, industrially produced wooden modules which are easy to assemble. Five layers of wood make up each module, with outer and inner vertical boards glued to horizontal-grain battens and vertical-grain studs. The modules are stacked on top of each other in staggered rows. Dowels projecting from the bottom of the blocks fit into holes in the top of the blocks below, preventing lateral movement. The resulting construction is both weather and load bearing. The planed timer finish means that internal walls can be left untreated, or drywall boards can be added and plastered. Electrical, heating and other services run within the spaces inside the blocks, which are then filled with cellulose insulation. External insulation can also be added, if desired. So, the basic elements of the STEKO building system are wooden modules which can be easily interconnected in rows and stacked. The modules are produced in various heights, lengths and with a variety of surface finishes. The system is faster to construct than regular timber-frame buildings, which saves time and money and lowers the labor cost. Walls are load bearing and space forming. Any glue, nails or other fasteners are needed directly at the site.

3. Material and methods

In order to reveal the individual Budgetary Index of a specific group of wood-based houses characterized by open diffuse system, ten different projects of such type wood house have been used. All the houses (H1 to H10) are without underground floor and are founded through concrete strip foundation or concrete foundation plate. They are different in terms of shape and gross floor area and are single deck or double deck. The construction system of all houses is the same (Fig. 1). It consists of wood frame structure filled by thermal mineral insulation based on stone wool. From the interior side, the envelope is composed of OSB, mineral insulation and plasterboard front wall. The exterior envelope consists of special fiberboard, mineral plate and diffuse open plaster in face. All the frame structure creates the open diffusion system. Regarding other structures, partitions are from plasterboard, roof is designed as a truss frame structure with heavy concrete covering. Construction systems of the truss are different from point of roof shape. There are four variants: gabled, desk, hipped and tent. In case of double deck house, the ceiling consists of wood bearing frame, which is filled by thermal insulation based on mineral wool. From the bottom, the ceiling is enveloped by plasterboard and from the top by OSB and fiberboard. The specific material of the open diffusion system is represented by the fiberboard. It is produced by wet process, without any glue and is considered as environmentally friendly material. This fact is reflected in cost of the entire construction system of these houses.

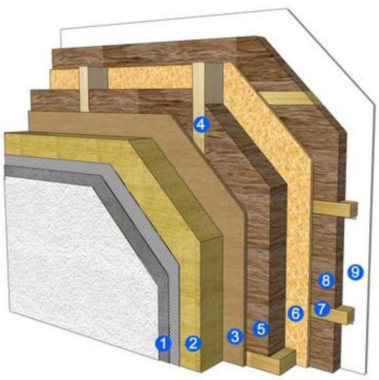

Fig. 1. The construction system of the houses
1 - diffuse open plaster, 2 – mineral plate, 3 - diffuse open fiberboard, 4 – frame structure,
5 – mineral stone insulation, 6 - OSB, 7- frame for insulation, 8 - mineral insulation, 9 – plasterboard.

In order to reveal the Budgetary Index relevant to the mentioned type of wood house, the construction cost of all ten houses were individually estimated. Then, the average value of ten Budgetary Indexes pertaining to ten houses, presents the Resulting Budgetary Index of any wood house characterized by the same construction system and similar construction and material characteristics.

4. Results and discussion

When estimating construction cost of individual houses, the cost were aggregated into four groups: foundation cost, bearing construction system cost, roofing cost and finishing works cost. To calculate the building volume (BV) of a house, the formula (1) was used:

$$BV = Vf + Vus + Vts + Vr \qquad [m^3] \tag{1}$$

where:
BV – the building volume of a house [m^3]
Vf – the volume of foundation structures [m^3]
Vus – the volume of understructure [m^3]
Vts – the volume of top structure [m^3]
Vr – the volume of roofing [m^3]

The Budgetary Index (BI) is calculated as follows:

$$\mathrm{BI} = \frac{CCt}{\mathrm{BV}} \qquad [\mathrm{EUR/m^3}] \tag{2}$$

where:
CCt - total construction cost of a house [EUR]
BV – the building volume of a house [m^3]

The results of construction cost estimation and Budgetary Indexes as well as Resulting Budgetary Index determination are presented in Table 1.

Table 1. The results of the Resulting Budgetary Index (BI) determination.

Family house	Type of construction			Construction cost (CCt) [EUR]					Building volume (BV) [m3]	Budgetary index (BI) [EUR/m^3]
	Number of floors	Foundation	Roof	Foundation	Bearing construction system	Roofing	Finishing works	Total		
H1	1	strip	gabled	7 356	11 820	14 076	50 496	83 748	459	182
H2	1	plate	desk	11 100	12 168	12 932	42 400	78 600	485	162
H3	1	plate	desk	5 280	14 384	12 930	55 774	88 368	434	204
H4	1	strip	desk	9 300	16 440	15 744	52 236	93 720	499	188
H5	1	strip	gabled	9 120	14 484	15 978	51 474	91 056	506	180
H6	1	strip	gabled	7 854	12 984	14 076	47 682	82 596	467	177
H7	1	strip	hipped	10 320	13 008	17 670	59 682	10 0680	599	168
H8	1	strip	hipped	10 506	11 664	17 352	57 678	97 200	590	165
H9	2	strip	tent	4 884	18 300	13 224	51 552	87 960	574	153
H10	2	strip	hipped	14 880	37 344	40 920	107 976	201 120	1087	185
						Resulting Budgetary Index (RBI) as the average value				176

According to the methodology, the Resulting Budgetary Index (RBI) of wood house characterized by open diffusion system has achieved the value of 176 EUR/m^3.

Based on the data, presented in Table 1 and on the basis of other derived data, which are not presented in the paper by reason of limited extent, here are the following conclusions:

- Although the range of the building volumes (BV) of ten different houses is relatively large, the values of Budgetary Indexes (BI) of these houses are similar (see Fig. 2). This suggests that individual Budgetary Indexes of the houses are only slightly affected by the size of the house (± 12.5%).

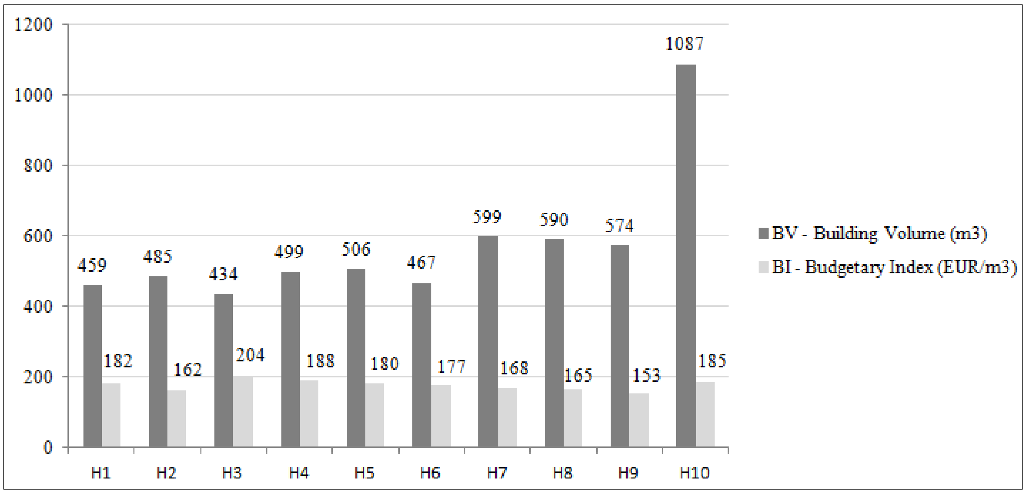

Fig. 2. Range of Building Volumes (BV) and Budgetary Indexes (BI).

- Foundation structure participate in the total construction cost of a house at least (9%), wood bearing construction system and roofing almost equally (16% and 17%) and the finishing works include the biggest part of the construction cost of a house (58%) (see Fig. 3).

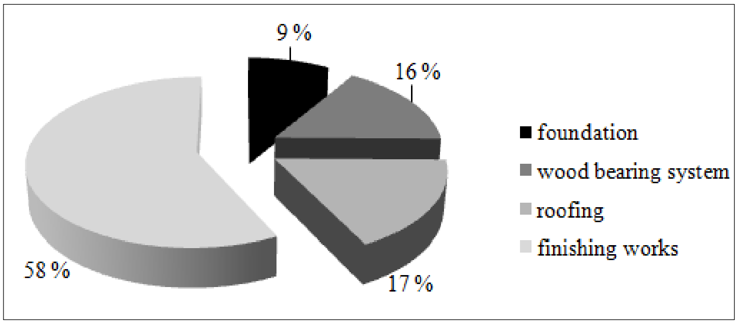

Fig. 3. Share of construction structure groups on the total construction cost of a house.

5. Conclusion

Nowadays, in the area of wooden constructions, there have been increasingly appearing new and new materials and new construction systems. In the first part of the paper the construction-technological analysis of the modern construction systems based on wood is presented. The proposed methodology of the cost parameter estimation is presented. Estimation of Budgetary Index (BI) is based on the case study of selected construction system based on wood, which is represented by ten different wood houses.

Wood houses with an open diffuse system represent a special group of wood houses with added environmental value. Regarding this type of wood houses, the big expansion in our construction market is expected. Several environmentally-friendly materials (natural insulation, wet-processed fiberboard) are applied in the system. Due to big variety of materials as well as of shapes and measures of a house, the cost estimating according to available standards is difficult. Based on the projects of ten different houses pertaining to the mentioned group, the Resulting Budgetary Index of such type of houses was determined. The Resulting Budgetary Index, determined by the presented study, serves to estimate the construction cost of any wood house, with various shape and measures, but based on this construction system (open diffuse system).

Acknowledgements

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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