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THE IMPACT OF LOGISTICS ON THE COST OF PREFABRICATED CONSTRUCTION

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Abstract: The aim of the paper is to emphasize the need for logistics planning in prefabricated construction in Slovakia. A construction contractor can achieve profit and efficiency of a construction project through well-managed resource logistics. Moreover, it helps to ensure the competitiveness of prefabricated construction compared to traditional on-site construction. In the case study of a wood-based family house, the construction cost and the transport cost are analysed in relation to available logistics chains. Three variants of wood-based construction systems are adopted in the study: the column-beam construction system, the construction system based on Structural Insulated Panels (SIPs) and the panel construction system. The results of the study found that the transport cost does not represent a large share of the total construction cost of the wood-based family house. This applies to all three variants of the construction system. A well-planned logistics of resources – people, materials, machines – can help to achieve an efficient and rational construction cost and construction time of a project. Thus, a client of a wood-based prefabricated building does not have to worry that the transport cost related to the transport of large, prefabricated components will make the construction of the building markedly more expensive.

1 Introduction

Currently, a continuous improvement of production efficiency is emphasized in construction. A proper type of construction material logistics and prefabricated components logistics in off-site construction can significantly contribute to enhance construction efficiency [1]. On the contrary, an inaccurately managed logistics may significantly increase construction cost. To remain competitive in the construction market, some manufacturers of prefabricated components for off-site construction, provide services only to a delimited distance from their factories. Otherwise, the logistics cost will increase to such an extent that the cost of a construction project will be significantly increased. Such a construction project accounts for a certain point of inefficiency and inefficient cost spending. In the long term, this can be reversed only if other monitored parameters of the construction project can guarantee economy and efficiency [2,3]. These parameters are such as for example use of prefabricated building components with a reduced carbon footprint in production, components with a reduced ability to emit pollutants into environment, components with a reduced overall environmental impact of production, etc. [4,5]. To ensure sustainability in construction, these parameters should be followed [6,7]. The life cycle environmental impact of prefabricated wood-based constructions can be assessed by the software Athena [8]. The off-site construction ranges manufacture and assembly of prefabricated components on various material bases such as wood, concrete, steel and their combinations. From logistics point of view, the planning of a nice flow of resources needs to be carried out for both framework construction products and finishing construction products (e.g., for prefabricated building façade systems) in all construction segments [9]. In order to be effective, the construction logistics could largely follow the example of other industries. The production of building components for direct assembly into a building is a characteristic feature of prefabrication. This develops the possibility of Just-in-time construction without need to store prefabricated construction products at the manufacturer and it also eliminates the storage of products in various intermediate warehouses within the supply chain. Over the last half century, many manufacturers in off-site construction have sought to achieve the "Zero Inventory (ZI)" production. The logistics processes are also affected by the Fourth industrial revolution. In particular, it concerns the automation of storage in order to facilitate storing and dispatching operations. The Zero-Warehousing Smart Manufacturing (ZWSM) production platform was developed in Hong Kong. This concerns the principle of avoiding traditional storage operations and reducing storage spaces to a minimum. The platform is based on the use of synchronization, unitization and the Internet of

Things (IoT) enabled infrastructures. The authors of the ZWSM applied the platform to a case study of a prefabricated construction project in Hong Kong, in which they pointed out the success of zero storage of prefabricated elements [10,11].

Loss of productivity through delays and interruptions of works on site is one from significant problems in the construction. This can be caused by collisions in workforce, material and machinery. Improvement of construction logistics efficiency, concerning the flow of material and products from factories to the place of installation on a construction site, is one from the central needs of the construction industry. To examine the efficiency of integrated construction supply chain logistics, a research study has been conducted in the United Kingdom [11]. The 4D Building Information Models (BIMs) were applied in the research. As the research results demonstrated, the 4D BIMs are not yet widely used in practice to plan and monitor supply chains during construction.

The flow of material to a construction site is characterized by two types of construction supplies. It is a supply of common piece materials and a supply of prefabricated components. The cost of delivery of building material in both on-site and off-site construction methods can be optimized with the help of appropriate logistics planning. In both types of construction, the plan of

a logistics system for efficient construction processes seems to be a problem. It is necessary to solve tasks with timely delivery and storage of material. The aim is to optimize the efficient use of resources and to reduce traffic related to construction tasks to a minimum. The adoption of CCC – Construction Consolidation Centre (Figure 1) is one of ways to achieve this goal [12].

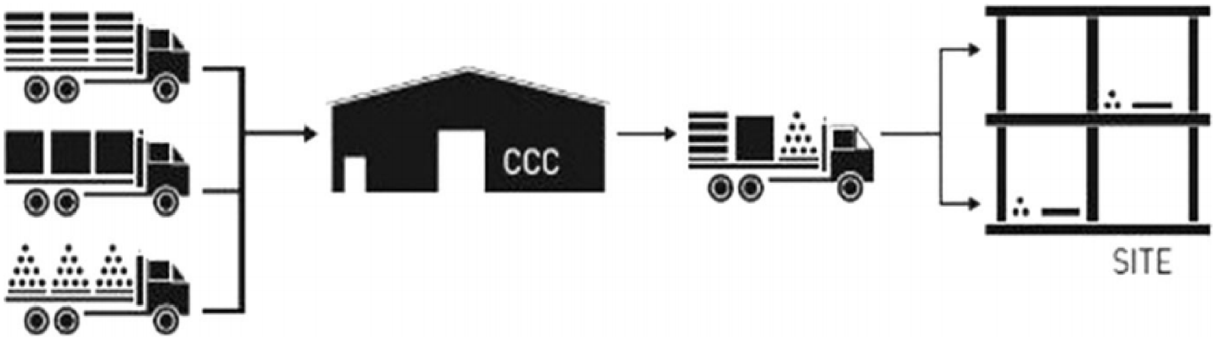

Figure 1 Principles of a construction consolidation center (CCC), adapted from Lundesjo (2015) [12]

The Construction Consolidation Centre (CCC) is a distribution facility that can be used in the process of managing project logistics, channelling material deliveries to a large, single construction site or to several different construction sites (Figure). It facilitates the efficient flow of materials through the supply chain, reduces waste and other problems such as goods flow congestion. Building materials are delivered from suppliers to CCC where they are stored until the delivery to the construction site is required [12].

To understand the importance of logistics in construction projects, the concept of the logistics in construction should be accordingly defined. The logistics is defined as planning, execution and control of the procurement, transport and placement of material, human and other resources to achieve the objectives of a construction project. The transfer of prefabricated components from the manufacturing plant to the construction site is a simple illustration of logistics for construction sites supply. When prefabricated panels are delivered to assembly site, a lifting equipment will be needed to install the prefabricated components directly from the vehicle, i.e., cantilevered construction. Prefabricated panels represent the material, a lifting crane is the equipment and there is also a crew of workers who will assemble the panels. The logistics allows getting all three components of resources to the same place at the same time. Moreover, the logistics has a significant impact on profitability. If the crane is not in the place when it is to be, the crews cannot start assembly works. They receive their hourly wage despite the fact the crane is not ready for assembly and assembly cannot begin [13]. In addition, as far as construction process, the delay of one activity makes it impossible to start the next one. Thus, the construction readiness for the following crews will not be maintained. If execution of some critical path activity (CPM – Critical Path Method) is delayed along of poor logistics and wrong organization (Figure 2), the construction time of the whole project will be extended [14].

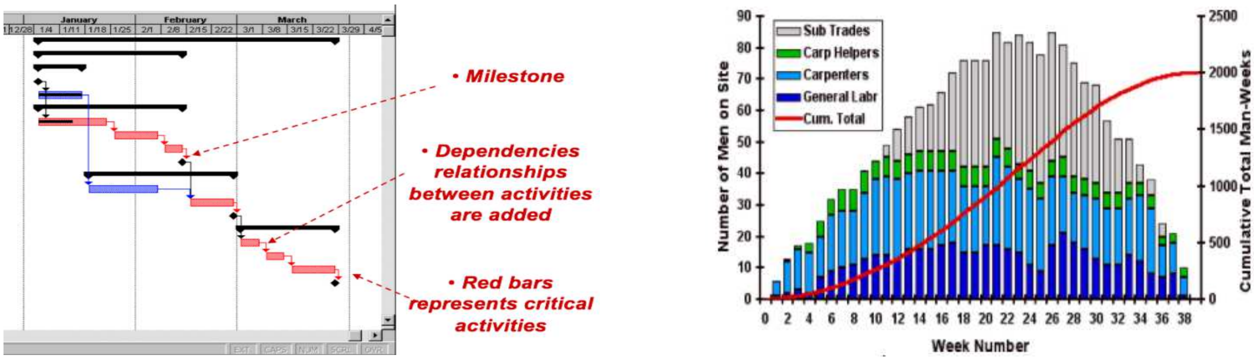

Figure 2 CPM [14] and Histogram of human resources and S-curve [15]

If prefabricated panels are installed late, the following professions can also be delayed, for example, partitions assembly, electrical installations, air conditioning, installation of floors and other trades. In the preliminary phase of a construction project, the general contractor must make a construction schedule for each stage of the project. The time plan must contain an overall list of materials, equipment and tools needed for each stage of the project. This involves planning the flow of resources with the help of histograms of workers, equipment, and materials (Figure 2). Advance planning helps ensure the right materials are in place every day so that construction teams can work without any interruption. Logistic planning also means that materials are stored in adequate quantities, are easy to locate and easy to handle.

2 Methodology

A carefully planned logistics of production resources can ensure the efficiency and economy of construction process. The presented study deals with the construction of wood-based family house. The impact of transport cost on the total construction cost is examined. The transport cost is one of the factors that must never be neglected in issues of optimization of construction from prefabricated components. Many off-site construction companies don't provide their services to long distances from their factories. The reason usually lies in the failure to manage the logistics of the project. On account the lack of right logistics, excessively high transport cost in relation to transport of prefabricated components from factory to construction site are calculated.

2.1 The transport of wood-based prefabricated components

In off-site construction, the transport of prefabricated components is an important loop between the components manufacturing in factory and assembly on construction site. The transport involves i) off-site transport – shifting from factory to site and ii) on-site transport – shifting within construction site area. The off-site transport is represented by horizontal transport to longer distances. Components are by goods vehicles shifted from a factory to storage area on construction site or to some assembly equipment (in case of cantilevered construction). Even if, the railway transport is applied in the construction sector, the transport of components for wood-based prefabricated construction projects is mostly realized by means of vehicles. The transport of components within area of construction site can be horizontal or vertical to short distances; several types of vehicles and cranes are applied. Prefabricated components are stacked on a vehicle with respect to a construction schedule. The installation sequence should be taken into account. The plan should ensure a right layout of the components on the vehicle for the purpose of well-organized successive taking of material during assembly without placing it in the storage place. Both types of transport can be used to transport different types of prefabricated components. The prefabricated products involve beams, flat walls and modular components. It is important to plan a reasonable logistical flow of all the resources – material, equipment, and human – for a whole off-site construction project.

The case study involves three different construction systems of wood-based buildings: i.) the panel construction system ii) the column-beam construction system, and iii) the system of "Structural Insulated Panels (SIPs)". The construction cost (involving cost of labour and material), the equipment rental cost and the transport cost with regard to the specific available logistics chains were estimated for the three mentioned variants of construction system of a wood-based family house.

The model building of the wood-based family house in Pezinok, which is located about 17 km from Bratislava, was applied in the case study.

2.2 The types of analysed construction systems

The panel construction system of the family house is characterized by large-scale panels, manufactured in a factory and assembled on a building site. The panels are delivered to construction site in the third stage of prefabrication – with windows installed (Figure 3).

Figure 3 The panel construction system

The column-beam construction system is characterized by framed light-weight construction from structural timber elements (Figure 4). The principle of the construction system was taken from America and Canada, and nowadays, it is the most widespread construction system of wood-based family houses in Canada.

Figure 4 The column-beam construction system

The construction system based on Structural Insulated Panels (SIPs) is characterized by modern sandwich construction (Figure 5), the core of which consists of hardened polystyrene and is clad with oriented strand boards (OSB). Unlike classic wood-based buildings, the cross-section of the construction doesn't contain a wooden frame.

Figure 5 The construction system of Structural Insulated Panels (SIPs)

2.3 The transport distances in the case study

To estimate the transport cost of the wood-based construction in the three mentioned variants of the construction system, the model case of the family house in Pezinok was seen about. The town of Pezinok is located about 17 km from Bratislava (BA), the capital of Slovakia. To determine the transport cost, the transport of the components from the city of Bratislava to the town of Pezinok was considered. The following list of suppliers of construction material for the studied construction systems introduces the distances from factories or from warehouses to construction site in Pezinok:

- supplier of the structural timber: Sawmill Holz transport BA – the transport distance 22 km,
- construction material: Building materials Woodcote BA – the transport distance 17 km,
- trussed tie-beams: Dachteam BA – the transport distance 17 km,
- gypsum fibre boards: Baustoffmetal – the transport distance 19 km,
- windows: Incon BA – the transport distance 22 km,
- Structural insulated panels: Europanel BA – the transport distance 22 km.

2.4 *The estimation of construction costs of the model wood-based building*

The construction costs were estimated with the help of software Cenkros4. It is the most used construction cost estimating software in Slovakia. It enables efficient processing of price offers with current prices of building materials and construction works. The software uses the database of building materials, which is processed by Cenekon as the largest supplier of price list databases in Slovakia. The construction costs were calculated on the basis of design documents of the three construction systems of wood-based buildings.

3 Result and discussion

We can say that siting of the presented family house in Pezinok is strategically advantageous in terms of logistics of construction resources. In the vicinity of the capital, it is possible to provide a logistics network of resources at much good level. If delivery of some source fails during the construction process, it is possible to replace it with another source, without increasing cost and wasting time. In other places of the country, such an alternative replacement of resources could be considered as a logistical problem which can result in a significant increase in cost and in extension of construction time. Especially, when it is concerned the construction operations from the critical path in the CPM plan.

The transport of the wooden panels in the variant of the panel construction system is carried out by means of trucks. The layout of different pieces of perimeter and partition panels on the truck is in suit with the assembly order of the family house. The perimeter and partition panels and trussed tie-beams are transported in a vertical position, i.e., in the position in which they are to be installed in the house. If horizontal components, such as floors and finished roof parts, should also be used, the same logic would apply. Thus, the components should be lying in a horizontal position and in the order of assembly. In the case of this construction system, the storage of components in the construction site is not necessary, as all the components are unloaded by crane directly from the truck and are assembled into the building.

The transport of the components in the case of the column-beam construction system is carried out by the flatbed vehicles with a mechanical arm. The timber elements should lie on three base prisms, in a horizontal position. The timber elements and other elements of the column-beam construction system must be protected from the weather by covering with a tarpaulin. The Fermacell gypsum fibre boards and Isover insulation boards should be placed under the roof inside the building, in order to protect them against possible moisture.

There are a few simple rules for transporting the components for the building based on the SIPs. The rules are important to follow. The panels must always be transported and stored horizontally. Unloading on the construction site can be done by hands, as the heaviest panel weight is about 80 kg. When shifting by hands, it is important not to pull the top OSB of the SIPs. When storing, it is necessary to place the panels on three thin plates (it the beginning, in the centre and at the end), so that the panel is in a horizontal position. The panels can be stacked on the top of each other and the maximum load on the bottom panel is 1500 kg. The panels and other components of the building based on SIPs must be protected from the weather.

One of deficiencies in transport, storage and assembly of the family house lies in the fact that in all three variants of the construction system, the prefabricated components are not provided with Radio Frequency Identification (RFID) tags. From logistics point of view, the tags would simplify the identification of the components in the overall construction. Several research studies suggest that construction is one from the least digitized industries [16,17]. Recently published academic research and industry reports in the fields of Industry 4.0 and smart manufacturing of various components are also examined to provide detailed information on the current implementation of Industry 4.0 principles in various sectors of the economy [18]. In the presented case study of the family house, the costs related to transport of the prefabricated components to the construction site are calculated individually in the different construction systems of wood-based building. Based on the calculations, the resulting values of the costs are presented in the following graphs (Figure 6).

In available price-list databases of construction materials, the transport cost is involved in the unit price of each construction material if transport distance from a warehouse to a construction site is no more than 50 kilometres. Thus, the transport cost is included in the item “Material” provided that the transport distance is up to 50 kilometres (Figure 6). In case of prefabricated components that are not covered in the databases, the transport cost must be calculated individually in accordance with the distance from a factory to a construction site. The individual transport costs are presented by the item “Material Transport”. Following the carrying companies, the calculation of individual transport costs involves a flat rate and the tariff rate depending on the number of kilometres from a warehouse to a construction site. In all three variants of the construction system, the construction cost of the family house is comparable. The construction cost of the wood-based family house is as follows: i) 33 568.92 EUR in the panel construction system, ii) 31 505.54 EUR in the column-beam construction system and iii) 34 379.87 EUR in the construction system based on SIPs. The highest transport cost – 1.30% of the total construction cost - was found in the variant of the column-beam construction system. In the study, the SIPs based construction system is characterized by the medium-large transport cost – 1.04% of the total construction cost. In the variant of the panel construction system, the transport cost is only 0.13% of the total construction cost. Such a low value of the transport cost was achieved mainly due to small distance from the production plant of prefabricated wooden panels to the construction site in Pezinok.

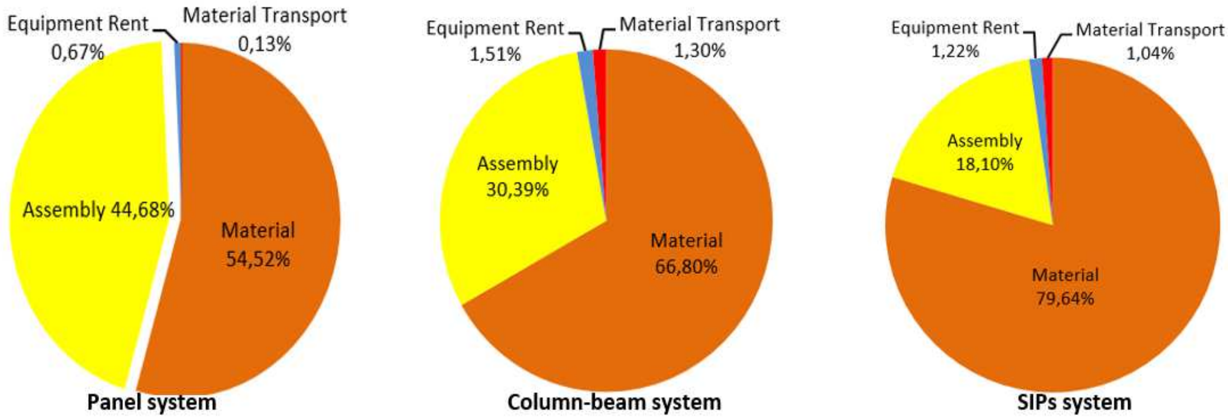

Figure 6 The cost of the material transport within total construction cost in three variants of the construction system (from the left): the panel construction system, the column-beam construction system, the SIPs system

4 Conclusions

When choosing the material base of a building, the investor makes decisions in accordance with the purchase cost. In marketing presentations of wood-based constructions, a reduction in the construction cost is initially expected, compared to a masonry construction system. However, in practice, the higher cost of wood-based buildings compared to masonry structures, is often proven. The prefabricated components make a higher cost of the wood-based construction system compared to a masonry construction system. The higher price of prefabricated houses is compensated by higher construction quality, higher accuracy in details and especially by better speed of construction. To ensure efficiency, economy and competitiveness, the contractors in off-site construction must make a precise plan of the logistic flows of construction resources, such as material, workforce and equipment. The contractors of prefabricated wooden buildings must count on the overhead costs associated with the production of prefabricated components, the operation of production plant with equipment, more demanding transport and assembly equipment and the overall logistics plan so that all resources are in the right place at the right time. The transport cost and the transport and storage methods of three presented variants of wood-based constructions – i.) the panel construction system, ii.) the column-beam construction system, and iii.) the construction system based on SIPs - are analysed in the paper. Managing logistics issues before and during construction will ensure that critical processes are completed at the right time and thus, the delivery dates are honoured. The analysis and the proposal of a methodology for the use of existing Advanced Planning & Scheduling (APS) methods to optimise and to improve the production and logistics planning in the segment of prefabricated buildings in Slovakia will be the subjects of the further research.

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