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COST CALCULATION IN PREFABRICATED TIMBER CONSTRUCTION: METHODOLOGY OF ASSESSMENT AND GENERAL REQUIREMENTS

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Cost calculations within the construction industry can be performed at various levels of detail. Starting at a very general level using component-dependent cost parameters (eg: cost per cubic meter of gross volume [€/m3]) the calculation can be done in the most detailed method by evaluation the individual cost components (material, equipment and labor) separately for every single task. For the traditional construction operations like masonry or concreting works a lot of information is provided to determine the performance values within a close range. For the field of cross laminated timber (CLT) constructions these substantially basics are not well established yet. The actual calculations are often based on in-house knowledge of timber companies without cross company references. To enhance the calculation basics a modified REFA analysis method (REFA 1984, Schlagbauer, Heck and Hofmann 2011) was conducted to collect on site observation data. The results of the task distribution analysis showed very similar results compared to other construction works on the level activities and interruptions with a mean value of approximately 75 % activities. But at a closer look greater deviations were found as main CLT-tasks have a value of 59% compared to masonry work (38%) or concreting work (51%). This bigger share of main activities within CLT works can especially explained by the high level of prefabrication work but has to be considered within the calculation.

Keywords: Construction management, Operation procedures, Performance values, Labour expenses, REFA, Timber building system, Cross laminated timber, CLT.

1 INTRODUCTION

The evolution of new production methods within the construction industry is always accompanied by economic considerations and therefore the need of scientific examination to explore the basics for a development process is high. At present, work flow and future time expenditures - the two main input factors for cost calculations - were commonly estimated based on the knowledge of a foreman or site manager. For a target-oriented and profitable tender, the basic knowledge is insufficient to provide adequate basics for an economical long-term strategy. As cross laminated timber (CLT) structures gain more relevance in the construction business of multi-story residential buildings in western European countries a research project was established by a timber construction company to create an authoritative forecast of the anticipated

work flow and future time expenditures as both represent the main input factor for cost calculations.

2 COST CALCULATION REQUIREMENTS

The cost calculation of a construction project can be performed at various levels of detail. On the one hand, the initial costs of the grossest form of cost estimation based on component-dependent cost parameters (e.g., cost per cubic meter of gross volume [€/m3], cost per square meters of gross floor area or square meters of floor space [€/m2]) can be determined; on the other hand, the single working process, spit into detail can be evaluated step by step. Using a calculation method based on component-dependent cost variables, it is necessary that a large number of similar projects is analyzed to prevent corruption of the data by singular outliers. For a detailed estimation of the future costs, it is essential to evaluate the individual tasks in detail and combine their costs in the course of the detailed calculation process. For the field of CLT construction projects sufficient calculation basics are missing as most the companies can evaluate only a few similar projects already completed. Consequently the component-based costing method can only be executed taking the results of a larger bandwidth of costs into account. For these companies the calculation assessment based on the different tasks is a targeted solution for a rapid development of a stabile database since similar work processes are carried out at different projects and building types. Basically three main cost components can be identified within CLT projects: cost of the equipment, costs of material and labor costs. For the rating of machine and material expenses the own equipment has to be evaluated or external offers can be obtained to gain hourly rates. Both procedures enable to reduce the estimation risks within a closer range. Only the element of labor cost is subject of greater estimation risks as neither companies nor external cross-company references are available. Therefore, this sector is a relevant research area, which is actually processed in the course of initial cooperation projects.

3 METHODS OF DATA COLLECTION FOR LABOR PERFORMANCE

To execute the work process analysis on site two major systems can be used. The first and most common system is the method according to REFA (REFA 1984). The second major system is the MTM (Methods Time Measurement)-method (Bokranz, Landau and Deutsche 2006). Both methods allow recording of the allocation of different tasks and the according duration to fulfill a task. Both are also able to record tasks performed by a single person or by a group of workers. For the examination in the current research a modified REFA method (REFA 1984; Schlagbauer, Heck and Hofmann 2011) was used. Executing the evaluation method, two aspects of the working process can be evaluated in detail: the workflow and the performance value.

3.1 Productivity Analysis

The investigation of the performance value sets the basis for further cost calculations. For the determination of accurate performance values the length of a specified task (in hours), the involved workers and the amount of work (e.g. square meter of cross laminated timber, one single wall element, all decking / roof elements, the whole

building) has to be recorded. Then the performance value can be calculated by dividing the duration fulfilling the activity by the number of workers and the amount of work. In the calculation of future projects the known efforts in combination with the investigated circumstances can be adapted to forecast the work time efforts within the tendering process.

3.2 Work Flow Analysis

Additional to the performance analysis the work flow has to be investigated into depth. Therefore the recordings of the individual tasks are displayed in an allocation diagram to identify the biggest shares of tasks. Also the workflow of a construction process can be shown by using an operation sequence diagram. The allocation diagram enables the comparison of different work styles or work tasks on an aggregated level; the operation sequence diagram allows to show the appearance of different recorded tasks within the work flow. It gives an insight of how alternating or continuous the work sequences occurred. Both analysis combined support the detailed description of the working process and improve the data quality. In this context it is necessary to describe and collect specific data as it's a matter of fact that the more precise the description of tasks and processes is done the better the outcome and usability of the data is at the end. Therefore the detailed work flow analysis sets the basis for a low-risk calculation.

4 TASKS IN TIMBER CONSTRUCTION

The installation process of cross laminated timber (CLT) panels allows a large amount of prefabrication work ahead of the installation work on the construction site. This affects the working process and allows reducing the on site installation time.

4.1 Influences on Cross Laminated Timber Constructions

Investigating the construction process of CLT buildings four major influence areas are identified: logistics ahead of the construction site, logistics on the construction site, appropriate lifting devices and labor force.

4.2 Main Tasks Within the CLT-installation Process

Based on the discussion with construction workers, foreman and project managers the following major tasks could be determined: the installation of wall, decking or roof elements, the joints between this panels, the installation of mechanical connectors such as bolts, screw anchors and clamps, the assembly of beams and columns, the assembly of staircases and elevator shaft and final the installation of the outer paneling. All these major tasks can be assigned as "main activities".

4.3 Distribution of Tasks in CLT Building Process

According to the modified REFA analysis (Schlagbauer, Heck and Hofmann, 2011) the distribution of the recorded tasks of a recently investigated CLT-project (Eder 2015) is shown in Figure 1.

Figure 1 clearly presents, that more than 70 % of the recorded tasks belong to activities while 13 % can be assigned to operational interruptions, such as Interruptions due to workflow and due to dysfunction. The remaining share of 14 % can be assigned to personal interruptions, such as interruptions due to recreation, including the statutory defined break, or due to personal needs.

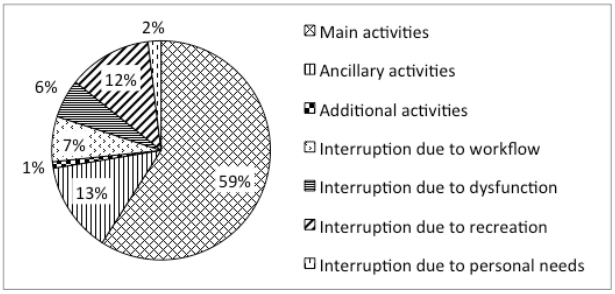

Figure 1. Classification of all working days into activities and interruptions (Schlagbauer, Heck and Hofmann 2011, Eder 2015).

5 COMPARISION OF PROCESS-ANALYSIS RESULTS

In order to assess the specific findings of a timber construction task accurately a brief comparison with two other construction activities is given. Based on this comparison, the influences presented above can be considered as significant differences between the different types of construction work. For the comparison timber construction work processes with bricklaying or concreting works the results of previously published examinations are presented.

5.1 Task Distribution for Bricklaying Works

In 2011 Schlagbauer, Heck and Hofmann presented the distribution of bricklaying tasks with the following results: *"the investigated main and ancillary activities sum up to over 70% of the working day. When it comes to interruptions the conclusion can be drawn that interruptions due to recovery cause the major part of breakes with 16% of the working time. At a closer glance at this category it can be seen that these 16% are made up 13% by restricted breakes by the employer and 4% by individually chosen breaks of the workers additional to the 6 % interruptions due to personal needs".*

5.2 Task Distribution for Concreting Works

In 2012, Schlagbauer, Heck and Hofmann indicated the distribution of concreting work tasks and pointed out that the *"distribution of formwork and concreting work tasks showed almost the same activity (81%) and interruption (19 %) distribution, but the shares of main and additional activities were different to the masonry workers as"* activities can be subdivided into 51 % "main activities", 31% "ancillary activities" and interruptions can be subdivided into 2 % "due to work flow", 1 % "due to dysfunction", 12% "due to recreation" and 2 % "due to personal needs".

5.3 Differences in Task Distributions

Comparing the different task distributions displayed in Figure 2, it can be interpreted that on the first level the shares of activities and interruptions are on a very similar level for all three types of construction works.

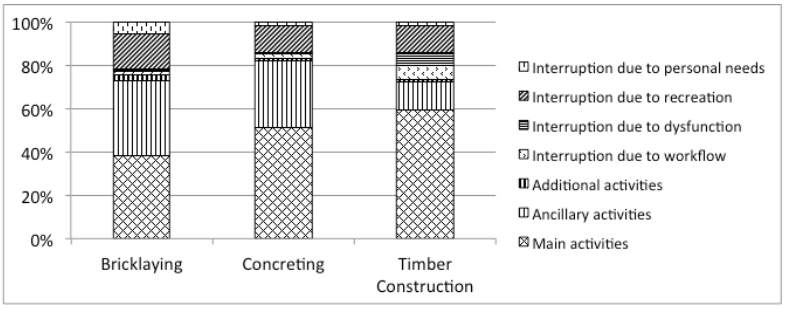

Figure 2. Distribution of tasks at 2nd level for bricklaying, concreting and timber construction work.

On the second investigation level the distribution of activities and also of interruptions shows larger deviations: (i) within timber work the additional ancillary activities are lower than at the two other work types; (ii) the interruptions due to the work flow as well as dysfunction of timber construction worker are on a higher level than at the two other working types. Both can be explained by the differences in the working process:

- Bricklaying work is a very labor-intensive type of work without the possibility of prefabrication except of mounting parts like a lintel. This leads to a high share of ancillary activities as most of the mounting work is done on site. As the working progress is connected directly to the physical performance of the labor, more personal breaks (interruptions due to recreation and due to personal needs) occur instantly (Schlagbauer and Heck 2013).
- Concreting and formwork work is a combination of prefabricated elements of formwork and reinforcement and fabrication on the construction site. As the assembly on site is reduced be the higher amount of prefabrication the ratio between main and ancillary tasks is different to bricklaying work. The higher level of activities compared to interruptions can be explained by the machinery driven type of work as the performance of concrete pumps and mixerconveyor sets the pace of the concreting work and the workers have to fit into these performance progresses.
- Timber construction work has the largest share of prefabricated elements and also the most machine-intensive work as all timber elements have to be moved by crane or other lifting equipment; therefore the ancillary activities quota is lower than for the other construction work types but compared to the other types of work the operational interruptions are higher.

6 DIFFERENCES IN CURRENT COST CALCULATIONS

Comparing the currently existing information for the estimation of cost values in the three different types of construction works it can be stated that in masonry and concreting works extensive and independent data bases are available. In the area of timber construction only a few individual and usually only in-house references can be found. Therefore the cost assessment of the individual cost components labor, material and equipment can be carried out for the area of timber construction only by a few companies.

Due to the increasing competitive pressure on the building market, it will be necessary for all timber construction companies to build up a database as this has been done before for masonry and concreting work already and ensure success during the bidding processes.

7 CONCLUSION

The detail level of the cost calculation for construction projects depends largely on the available data base. The calculation itself may start with a very coarse level on the basis of cost parameters of the overall object, going further to a more detailed level when component-dependent cost parameters (eg. cost per cubic meter of gross volume [€/m3], costs per square meters of gross floor area or floor space [€/m2]) are used. Finally the most detailed estimation can be performed when the working processes are described and evaluated in detail. Comparing the emerging division of timber construction with the traditional lines of masonry or concrete construction it can be seen that the data base for timber construction has to be established. This detailed analysis is however purposeful, to evaluate the tasks of the very uniform construction processes to rapidly gain a valid database for the individual tasks despite of different object types. These additional data would allow to enhance the actual performed cost estimations in many timber companies.

Comparing the different work processes it became clear at an aggregate consideration level of activities and interruptions, no major differences occur between the different work types. Only at a deeper view clear differences occurred between the work styles, which especially can be explained by the high degree of prefabrication in timber construction work compared to masonry work.

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