Implementing Innovative Ideas in Structural Engineering and Project Management
Edited by Saha, S., Zhang, Y., Yazdani, S., and Singh, A.

ISBN: 978-0-9960437-1-7

COST CALCULATION IN PREFABRICATED TIMBER CONSTRUCTION: PROCESS ANALYSIS ON SITE AND APPLICABILITY FOR FUTURE PROJECTS

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Advancements of recently developed timber products such as cross laminated timber (CLT) and its increasing application in construction demand economical standardization and unification. Therefore cost calculation of solid wood building systems need to be established. Following the systematic analysis of operation procedures, a research project was carried to gain accurate data on effort and performance values for future cost calculations. The absence of specific literature on cost calculations of timber buildings leads to evaluations based on in-house knowledge without cross company references. So a data acquisition on labor costs and machinery expenses on site is required to obtain primary data and input parameters in the cost calculations. Because of the high grade of prefabrication of timber structures, labor costs are the leading influence parameters. The methodology according to the technique of REFA and the specific circumstances of the timber installation process were implemented into the analysis to generate an appropriate system for the examination of these new building systems. To create a feasible and applicable database of values performance factors and activity values have been examined on site, interpreted and edited for future cost calculation of cross laminated timber assembly works. This survey on site contributes another module in the lack of knowledge to optimize the construction management within the construction process of large scale timber buildings.

Keywords: Construction management, Standardization, Operation procedures, Effort and performance values, Labor and machinery expenses, On site survey, Input parameters, Timber building system, Cross laminated timber, CLT.

1 INTRODUCTION

Modern large scale timber construction systems are different to the traditional work of carpenters known over centuries. This is mainly caused by technical developments of products in the last decade as well as the size, complexity and application was extended significantly. Therefore the processes of an agile trade require further analysis to ensure confidence and settlement within the building market over the next years. Although cross laminated timber (CLT) experienced great success as an alternative building material it was hardly examined up to now, regarding most economic aspects and building management in general. The presented survey allows a cost calculation especially for prefabricated timber elements with substantial effort and performance values as input parameters with a large reliability for timber construction companies to optimize critical financial aspects in order to originate an appropriate building system.

2 PRINCIPLES OF INSTALLATION IN TIMBER CONSTRUCTION

The operation processes during the construction of a timber structure include complex procedures and coherent sequences, which need to be identified to provide financial success. These processes contain an intensive planning phase with a high detail level in an early planning stage (Ringhofer and Schickhofer 2013).

Hence the preparatory work is of major interest in every timber project as the grade of prefabrication can only be ensured by a decent and extensive work preparation. This includes the planning of the fabrication, the time and construction progress charts, the set out of the building site equipment, the planning of all required resources as well as the cost calculation implementing all circumstances (Duschel and Plettenbacher 2012).

The requirements and conditions of logistic processes in the factory and on site, the lifting machinery and additional accessories, as well as the planning of a sufficient number of personnel for the installation can decide between success and failure during the short period of the main construction phase (Hofstadler 2007).

The background and input parameters for costing systems within timber construction are not as well established as for traditional building materials such as steel and concrete (Dress and Paul 2000). To deal with this situation in timber projects, a widespread research project with general data collection on site and determination of input parameters for cost calculations was carried out (Schlagbauer 2011).

3 DATA COLLECTION ON SITE

The examined timber building was realized in 2014 in the southern region of Austria, approx. 30 km southwest of Graz. The monitoring during the main construction phase lasted from 13th to 21st May 2014 and was carried out by one observer (Eder 2015).

3.1 Principles of the Investigated Project

The investigated object provides three levels above ground with two apartments on each level forming a typical medium size multistory condominium. The building consists of a concrete basement for secondary rooms, while the ground floor, two upper floors, staircase, lift shaft and access balconies were constructed completely of CLT.

Figure 1. Site of investigated object during construction (Eder 2015).

The connections between concrete and timber resp. timber to timber elements could be achieved with standardized steel angle brackets, which are widely used in today's timber structures in conjunction with special accredited timber screws and concrete anchors. Within this structure 2,245 m³ of CLT and 150 m of solid wood strips was incorporated. Additionally 350 steel angle brackets in conjunction with 5.500 special timber screws and 4,600 perforated nails guarantee the stability. The entire timber construction was realized within eight days and was carried out by a local carpenter, who appeared as the construction company and investor at the same time.

3.2 Aim and Methodology

To collect accurate data for the cost calculation to use a similar timber projects in future, using effort and performance values, an adapted methodology of REFA was applied within this investigation of this object (Schlagbauer 2011, Riedinger and Steinmetzger 2000). This included a series of hardcopy issues for the manual data recording on site. Before the actual start of the construction work these recording sheets were listed into detail, differentiating into the expected operating processes, the daily construction progress and the building system and methodology used, separated for each worker on site on each single day (Schlagbauer 2011, REFA 1992). This ensures that appropriate effort and performance values can be generated by analyzing all influencing factors and including all site parameters accompanying the works.

3.3 Data Recording

Following the methodology of REFA especially the multi-moment-recording-system with a five minute observation interval formed the data survey for this building. So the gatherings on each day with eight working hours results in 96 control samples per worker. Therefore 570 records/day resp. 4.560 values during the installation were generated for the working crew consisting of six workers and foreman (Eder 2015).

4 EVALUATION OF COLLECTED DATA

An extensive evaluation of the generated information after the data collection on site and an elaborately analysis using a proven scientific methodology ensures accurate values for future calculations. The aim was to gain a realistic insight on actual effort and performance values following the executed work in a timber building (Eder 2015).

4.1 Analyzed Construction Sequences

The analysis of the building progress followed two major courses: the first evaluation included the type of times required for work. The second way assesses the work following the activities carried out and interruptions that occurred on site (Eder 2015).

Using the first evaluation system applying the analysis of different types of times a splitting into basic time, additional time and recreation time was applied. These three types can also be combined in a proportion of the entire time. Times which were not identifiable for the observer are not included in these percentages. The left diagram of

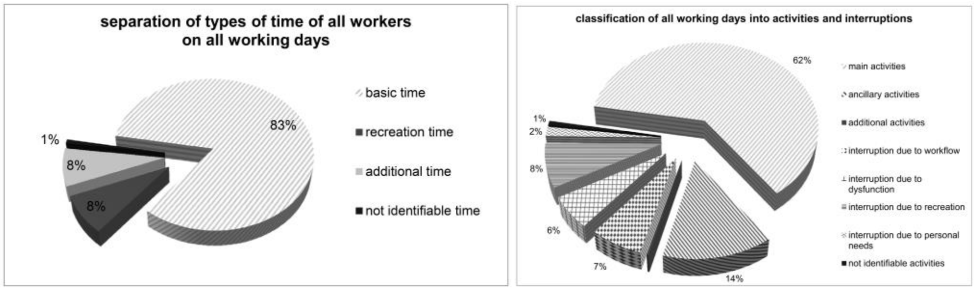

Figure 2. Separation of types of times of all workers on all working days (left graph). Classification of all working days into occupation and interruption (right graph) (Eder 2015).

figure 2 shows, that the entire building time of the CLT object was generated by 83 % basic time. This states a high productivity. Following the specific literature the additional time as well as a recreation time of 8 % each forms a rather low impact in the effort and performance values of similar projects.

Additionally a classification of the basic time of all workers involved on site following a subdivision into *good*, *medium* and *bad* working behavior shows that the generated percentage of the basic time is above the boundary value of 80 %. Therefore all working days can be classified as *good* within this project.

By using the second way of evaluation of the collected data a separation into occupation, interruptions and not identifiable tasks needs to be implemented. Furthermore the category occupation is split again into main activities, ancillary activities and additional activities. All interruptions are classified into influences due to workflow, due to dysfunction, due to recreation and due to personal needs. The not identifiable activities for the observer are included in this evaluation as well.

The right diagram of figure 2 states, that within the eight working days 62 % of the occurred working time includes main activities, whereas 14 % can be classified as ancillary activities and 23 % formed interruption time including the performance of all six workers. A classification as used before into *good*, *medium* and *bad* working behavior states again that all eight working days reached the level *good*. This ranking assumes well organized circumstances on site and highly motivated labor.

4.2 Results of Analysis

Based on the evaluation following the assessment the effort and performance values could be calculated subsequently for the installation of the timber building (Eder 2015).

4.2.1 *Effort and performance values for wall elements*

The generation of effort and performance values for the installation of CLT wall elements was undertaken for every single element in a first step to be summed up in an average value contributing all wall elements. Firstly, a single value was generated of every activity required on one element. This included the fixing of lifting accessories, lifting and positioning, removal of the lifting accessories, final placement, connection between timber to timber and timber to concrete, the inclusion of sealing strips, the attachment of the supporting structure for balconies as the insulation on the wall elements between two apartments, all combined in the graph below.

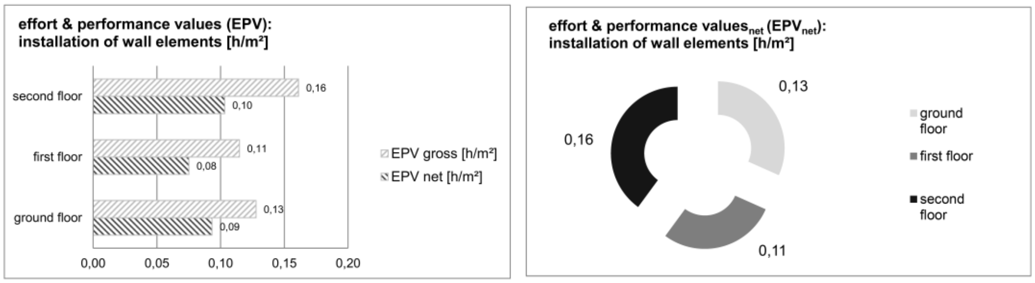

Figure 3. Average effort and performance values for installation of wall elements (Eder 2015).

The figures above give an average value for the installation of a CLT wall panel at ground floor of 0.13 h per m², a value of 0.11 h per m² at first level and 0.16 h per m² on the second floor of the building.

The differing value between ground floor and first floor can be explained by a missing training effect. The higher value for the installation in the second floor is leaded by the fact that the crane driver of the mobile crane had not a continuous view on all areas of installation and was therefrom dependent on the briefing by the foreman.

4.2.2 *Effort and performance values for decking / roof elements*

Following the same procedure the evaluation for the installation of decking resp. roofing elements can be summarized as displayed in the next graph.

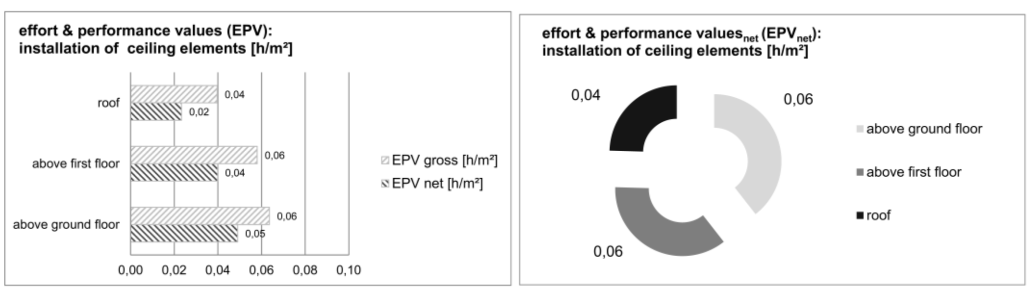

Figure 4. Effort and performance values for installation of ceiling elements (Eder 2015).

The figures show that the installation of a CLT decking element above ground floor has a value of 0.06 h per m², above first and second floor 0.04 h per m² CLT panel. The higher value for the installation above ground floor can be explained by the fact that the number of elements counted 14 instead of 10 in the 1st and 2nd floor. This causes a larger number of splicing's and a higher value of timber screws to be installed. Furthermore the generation of effort and performance values for the level compensation between the concrete surface and the first timber wall elements at ground floor was carried out using the time recordings of the timber construction company as they were done before the observer visited site. However by using this data, an average effort and performance value of 0.21 h per m leveling could be determined.

5 CONCLUSION AND OUTLOOK

Especially technical advancements and increase of prefabrication allow the construction of multistory timber buildings by accelerating this building sector. The reputation of an ecological building material strengthens the growth on the market over the last years.

Producers and companies often use their own in-house data during the cost calculation process caused by the lack of general literature referring to this topic. So, the evaluated data and generated effort and performance values can be implemented in future cost calculations of similar projects with unfavorable constraints. They must be assessed in each case again to get an appropriate costing system referring to the uniqueness of timber buildings. Companies should widely use accurate data in their costing processes in order to outplay their position in the worldwide market.

The high potential of timber construction methods can clearly be spotted in the short period of installation required on site in comparison to brick and concrete works. Additionally the amount of site installation equipment is less corresponding with smaller areas for temporary storage as the delivery happens just in time. Apart from non-influenceable weather conditions the installation time is affected by the lifting facilities and mobile cranes as well as the erection performance of the team on site.

These arguments are potentials for timber construction. However in many cases they are not commonly used as they are hardly quantifiable and rateable. Cost facts and time influencing circumstances are difficult to be separated between the collaborating companies on site as many activities cannot be clearly assigned to special trades.

Although timber construction has a high potential for pioneering tasks especially when implementing turnkey strategies, it is helpful to transform and extend the advantages of a material into an integral building systems. Effort is required not only in the technical and material sector but more than ever in the building economic domain to allow the ecologically friendly material to become a widely used building system.

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