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Building services in timber construction – Investigation on difficulties and reliefs during the installation procedures in multi-storey timber residential buildings

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Abstract. Multi-storey timber construction has undergone a strong positive development in Austria in recent years. However, while there are constant advancements in materials, construction technologies, production stages and assembly methods in timber construction itself, the design as well as the installation procedures of building services in multi-storey timber buildings lags far behind these technological progresses. The principles of planning and installation of building equipment are generally similar to those within solid mineral constructions that could be identified in the holistic research project TGA-Timber. A comprehensive investigation of the installation procedure on 3 multi-storey timber-construction projects has been carried on site and during prefabrication within the past 2 years in Austria at Graz University of Technology. The emphasis was set on the identification of disorders and delays caused by installation procedure of HVAC-building equipment in timber construction. The results of this research release the large potential of optimisation of piping runs as well as time- und cost savings within the installations process of building equipment as part of an overall economical optimisation. This publication is an excerpt of the results generated for these construction site analysis and deals in particular with difficulties and disturbances that have occurred.

1. Introduction

The percentage of multi-storey timber constructions, in particular housing projects, has undergone a strong positive development in Austria in recent years. Between 1998 and 2018 the percentage of timber residential buildings increased from 14 % up to 24 % measured on living area [1]. However, while there are constant advancements in materials, construction and manufacturing technologies and prefabrications and assembly methods in timber construction itself, the design as well as the installation procedures of building services in multi-storey timber buildings lags far behind those technological progresses. However, due to the advancement of higher energy efficiency of buildings and denser building skins building services become more and more important.

In order to demonstrate how the installation work in timber construction sites is currently performed and which challenges and problems arise, workflow-analysis were carried out on three timber construction sites for the research project TGA-Timber [2]. This research project under the leadership of Holzforschung Austria, aimed, among other research objectives, at an economic analysis of the current state of installation work. Part of this analysis was the survey of the current state of the installation



process and a comparison of different levels of prefabrication. The analysis identified, that the principles of planning and installation work of building services are generally similar to those within solid mineral constructions.

2. Analysis of building systems in multi-storey timber constructions

2.1. Initial situation

Hausladen [3] defined already in 2008 six design guidelines for the prefabrication of buildings equipment in multi-storey timber projects as part of a research project. On the one hand, these guidelines meet the demands on a high degree of prefabrication and a high degree of flexibility, on the other hand, they also offer increased protection against moisture leakage. In addition to the principle of the central vertical and horizontal piping runs is a separation of the building services equipment from the structure, the permanent accessibility and thus also control and maintenance a major requirement of buildings services in timber constructions.

2.2. Research objectives

But, in which way do the buildings services engineers involve Hausladen's guidelines and how do HVAC installers handle these new challenges which arise at timber construction sites? Some answers could be given through the workflow-analysis for the research project TGA-Timber in the years 2017 and 2018 coupled with the investigation of the MEP plans and tenders. Additional effort values have been examined in detail within the analysis which show the differences of efficiency of installation procedures of the varying prefabrication levels.

2.3. Analysis of the plans and tenders

Before starting the workflow-analysis the HVAC-Plans and tenders had to be investigated to get an overview of the underlying documents for the installers. The investigations revealed, that the plans for building services for the two on-site-constructions-projects didn't differ to those of conventional solid brick or concrete constructions. Hausladen's six design guidelines were not considered at all, on the contrary, there were no timber-specific peculiarities of the piping runs recognizable. In some cases, the layout of the pipes was shown on the plans only in one floor, the piping runs of the other floors was incumbent on the executing HVAC-technicians. This fact resulted in deviations between the plan layout and the execution with varying floor plans or window arrangements. In contrast, the building services plans for the turnkey project showed exactly the pipelining in walls and at floors, which resulted in no scope for the installers.

A similar picture as in the planning provided the analysis of the specifications for the HVAC tenders for the construction site assembly. Regardless of the timber construction, these descriptions were thus adopted unchanged from the standardized specification for building services LB-HT (current version 012) or from previous projects. An adaptation of the position wordings to the requirements of timber construction, or at least a revision of the wording, was completely absent in all three analysed tenders. The additional research objective therefore arose as to how inaccuracies in the planning and tendering process affect the assembly work.

3. Data collection on site

To answer the preceding questions three multi-storey housing projects for the workflow-analysis at the construction-site were found. Two of these buildings were on-site-construction projects with partly prefabricated walls and ceilings, the third project was a turnkey-prefabricated project with about 120 almost similar apartment-units. Due to the differences of these projects promising results were finally achieved.

3.1. Aim and methodology

For the workflow-analysis the methodology according to REFA [4] which is commonly used for solid brick and concrete building systems was used. Specific characteristics of the installation procedure of HVAC-building equipment were implemented consequently into the analysis.

The main aim of these data collections was the derivation and analysis of disturbances resulting from the new building systems of multi-storey timber construction. While the HVAC installation process in mineral solid construction can be regarded as standard for the involved planners and technicians, there are new details, assembly methods and interfaces with other crafts, which planners and installers have not met yet. In the workflow-analysis special attention had therefore been paid to timber specific design details.

3.2. Presentation of the investigated projects

The investigated projects were multi-storey residential buildings for urban areas. The two on-site projects consist of two to four timber-storeys on a concrete basement with 38 (Project 1) respectively 56 apartments (Project 3). The walls are prefabricated 2d timber frames and CLT-elements supplemented with prefabricated CLT-ceilings. The buildings services equipment was assembled completely at the construction-site. On the other hand, the third investigated project (Project 2) exists of almost 120 turnkey prefabricated room-units with an integrated bathroom which were finished in a production hall. They are constructed of CLT-ceilings and -walls and timber frame walls. The HVAC-installations were partly prefabricated in a separated workshop-area within the production hall and then assembled in the timber-module, partly the installations procedure was done completely in the timber-module without prefabrication.

3.3. Data recording

The data survey for those buildings was done by the workflow-analysis following the REFA-technique. The HVAC installers of the three constructions sites were observed over a period of 66.25 hours between August 2017 and February 2018. Especially the multi-moment-recording-system MMR with a five-minute observation interval showed good research results, in particular for the timber-construction related interruptions of the installation process. Accordingly, a total of 2107 data were recorded, which corresponds to an observation period of about 176 hours of installations time at all three construction sites. The number of concurrent working installers varied between two and six. In addition, discussions with HVAC planners and site managers for the timber construction and the buildings services supplemented the results of the workflow-analysis.

4. Evaluation of collected data

Due to the comprehensive data collection, the required results listed above could be evaluated and derived. In the first step, the entire workflow was broken down into the three categories of activities, interruptions and non-identifiable activities. The collections of the individual areas of activity was done by means of multi-moment-recording. Based on this, the occurred dysfunctions were filtered, their causes identified, and a time loss evaluation carried out.

In the analysed buildings two different production and assembly methods were inspected. One was the in-situ HVAC-installation process assembled on prefabricated CLT-ceilings, CLT-walls and plasterboard-walls and the other was a turnkey prefabricated room-unit including the building services. Aim was to gain realistic time-values for disruptions and to find out who is responsible for these interruptions.

4.1. Analysis of the study

The analysis of the workflow according to REFA provides for a subdivision of the data into the main categories activity and interruption. Additional non-identifiable activities, e.g. the absence of the technician or the observer, are also going to be recorded. Subsequently, the interrupts were broken down into interrupts caused by dysfunction (e.g., waiting time), recreation and personal needs (e.g., telephone

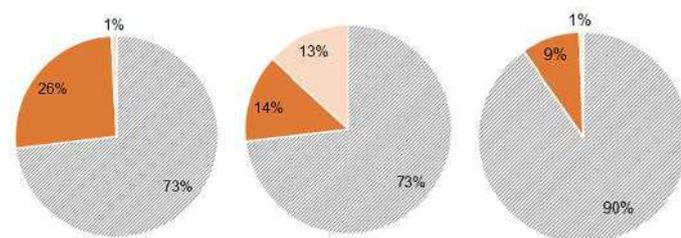
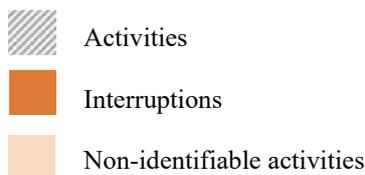
call). The data were recorded by means of multi-moment-recording, with the activities of all subjects recorded at intervals of five minutes.

Table 1 summarizes these three main categories of the three analysed building projects. In project 3 the percentage of interruptions was significantly smaller (9 %) compared to the other two construction projects with 14 % and 26 %. But more important, at 2 %, project 3 had the lowest incidence of dysfunctions during the period of investigations, whereas in project 1 about 14 % of the investigated activities fell into the category of interruptions due to dysfunctions.

Table 1. Overview of the recorded categories of activities according to REFA for all three investigated projects [5]

	<i>unit</i>	<i>Project 1</i> <i>On-site-construction</i> <i>38 apartments</i>	<i>Project 2</i> <i>120 turnkey room-</i> <i>units</i>	<i>Project 3</i> <i>On-site-construction</i> <i>56 apartments</i>
Number of collected data MMR	[n]	740	1017	350
Corresponding time	[h]	61.67	84.75	29.17
Activities	[%]	73	73	90
Interruptions	[%]	26	14	9
Non-identifiable activities	[%]	1	13	1
Interruptions doe to dysfunctions	[%]	14	6	2

Categories



In the next step, on the one hand, for project 1 and 2 the delays due dysfunctions were assigned to the spheres of causation, on the other hand, timber-building-specific disturbances were identified, as shown in Table 2.

4.2. Results disorders and delays

First it was identified whether the disturbances were attributable to timber construction or whether they would also occur in a solid construction such as brick or concrete. Timber-specific dysfunctions are those that arise on the one hand by special new execution details, on the other hand, malfunctions due to improper tools and additional interfaces with other trades. General disturbances are e.g. planning errors (missing information) but also waiting times caused by inadequate working layout or correction of execution errors.

4.3. Results field of responsibility

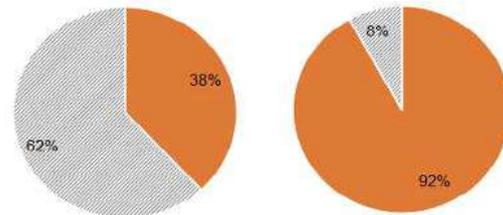
Table 2 shows the results of the field of responsibility of the disturbances in the individual spheres of planning (architectural and buildings services), construction monitoring and site management, working layout and prefabrication (considered for project 2).

Table 2. Share of timber-constructions related dysfunctions and field of responsibility of dysfunctions [5]

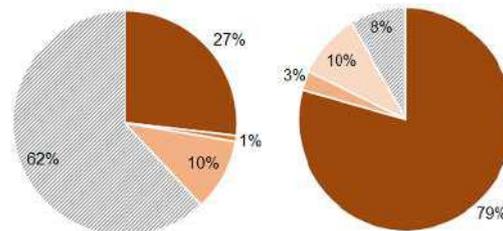
	<i>unit</i>	<i>Project 1</i> <i>On-site-construction</i> <i>38 apartments</i>	<i>Project 2</i> <i>120 turnkey room-units</i>
General interruption	[%]	62	8
Timber related dysfunctions	[%]	38	92
Caused by planning	[%]	27	79
Caused by working layout	[%]	1	0
Caused by construction monitoring and site management	[%]	10	3
Caused by assembly line production	[%]	0	10
Proportion of interruptions caused by disturbances	[%]	14	6

Classification of dysfunctions

-  General dysfunctions
-  Timber related dysfunctions

**Cause of dysfunctions in timber constructions**

-  Caused by planning
-  Caused by working layout
-  Caused by construction monitoring and site management
-  Caused by assembly line production
-  General interruptions



Causes of the high number of disturbances in the area of planning were e.g. extensive drilling in aluminium and steel profiles within plasterboard walls, as the pipelines in internal walls were not planned. That means, that the dimensions of the walls and aluminium profiles were too small and no installation space considered. Also, boreholes through CLT-walls, which are very complicated to perform without suitable tools, have not been considered separately in the plans.

Figure 1 shows the most problematic detail points for planners and installers in Project 1: The main challenge was the waterproofing of CLT-ceilings which is required in the Austrian Standard ÖNORM B 2320:2017 – Wooden residential houses – Technical requirements [6]. So far, little attention had been paid to this new detail. In some cases, planners did not take account of the waterproofing in plans and tenders, which led to negligence in execution. If the properties and schedule of the waterproofing process are not fixed, disturbances in the assembly process and associated additional costs are the consequence. In connection with the waterproofing of CLT-ceilings, new piping runs on the floors must also be taken into account or even better, the pipelines are completely installed in internal walls or as wall surface installations. These details require more space in internal walls, which must early be considered.

Another challenging new timber-specific detail was the covering of openings in CLT-ceilings to gain an appropriate fire protection in installation shafts. The enumerated detail points are just a few excerpts from the list of challenges and problems that had arisen due to incomplete plans, tenders and the lack of training of the installers.

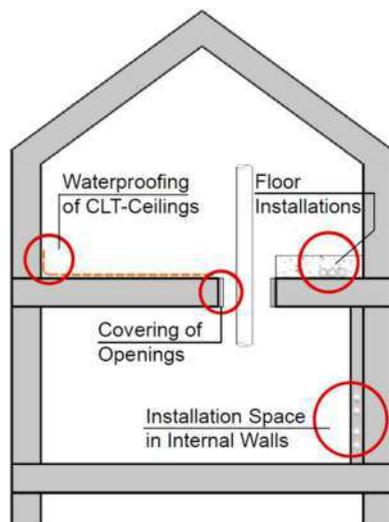


Figure 1. Problematic detail points for the installation process of building services in multi-storey timber buildings [7]

Project 2, which was entirely prefabricated in the production hall, has the largest percentage of timber-specific disturbances with 92 %. One reason is that turnkey 3d-modules need an exact planning and coordination of the assembly processes, so most of the disruptions are due to timber-specific services. Table 2 shows that 79 % of the dysfunctions of Project 2 are caused by planners. During the workflow-analysis a subsequent rescheduling led to the modification of 14 already equipped installation shafts. This fact shows, that changes of plans have an even more negative effect on the production flow caused by the high production speed of similar 3d-units through a production line.

Another special feature could be observed in project 2 in the course of the assembly line prefabrication: Due to the exact scheduling of the prefabrication and a person-specific work distribution waiting times occurred during the assembly process again and again. In this context, a great advantage of the prefabrication in the production hall with integrated workshop for all trades was recognizable: The proportion of disturbances caused by waiting times could be reduced by around 20 %. The reason was that installers could carry out module-independent prefabrication in the workshop, e.g. cutting, bending and joining of pipes. On the one hand, numerous of module-independent works outside the "installation location" were possible through the workshop area in the production hall, on the other hand, the installers were trained to bridge waiting times with necessary preparatory work at the workshop. There – in contrast to the assembly work in the modules, where a clear division of labour was found – the pending preparatory work was completed as needed.

These results of the construction process analysis illustrate the optimisation potential of the work processes with a high degree of prefabrication in a production hall. Considering appropriate workshop areas in on-site construction projects and training of contractors, that improvement in workflow could also be considered in conventional site assembly.

5. Output and conclusion

The presented abstract of results of the research project TGA-Timber with included workflow-analysis at three construction-sites illustrates the large number of challenges in planning and assembling of building services in multi-storey timber construction. Many years of experience in mineral solid construction are of little use to the planners, site managers and contractors in these new construction techniques, as early exact plan specifications, additional interface coordination with other trades and modified details must be considered. Failure to take these parameters into account will result in both time loss and economic consequences. For example, the initially small proportion of disturbances in Project 1 in the workflow-analysis recording period of 578 minutes added up, accumulated on the entire construction period to a loss of time of almost 60 hours. In addition, improper detailing leads to deterioration in quality and thus to the risk of water leakage in timber construction. Finally, there is the

requirement of clients after a regular check, done manually or by means of technical devices (sensors) in finished timber structures in order to detect moisture damages early on here.

Business models that allow qualified HVAC companies to intervene in the planning, execution and facility management of objects would partly close the detected knowledge gap, which was verified through the investigations of plans, tenders and workflow-analysis. However, this would require a comprehensive training of planners and installers in order to carry out planning, tendering and construction management for timber-construction-adequate piping runs and to be able to offer additional consulting services for companies with little timber-construction experience. Another important aim for multi-storey timber constructions should be the promotion of prefabrication including the buildings services, in order to transfer the time savings of prefabrication in timber construction to the HVAC installation process. In addition, continuous quality controls are easier to carry out in the production hall and assembly processes through prefabrication workshops are easier to optimize.

The results of this research release the large potential of optimisation of piping runs as well as time- and cost savings within the installations process of building services as part of an overall economical optimisation. They also can make a significant contribution to the sensitisation of planners and contractors, in order to guarantee an economic and technically correct execution of building services installations in timber construction projects.

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