Criteria catalogue and analysis model to manage complexity in prefabricated timber construction

S Geier, Dr-Ing[1], P Schwehr, Prof Dr

Lucerne University of Applied Sciences and Arts, Competence Center Typology & Planning in Architecture (CCTP), CH-6048 Horw

[1] Corresponding author: sonja.geier@hslu.ch

Abstract. Prefabricated timber construction often comes with demanding planning processes and uncertainties due to higher complexity. Hence, a great potential to optimize design, construction, and economic efficiency is not put to use. In the future, the challenge will be to have project management that is able to handle complexity. The criteria catalogue and the analysis model, developed in my doctoral thesis at TU Munich, are a first step towards the systematic and typological structuring of prefabricated timber construction in terms of complexity. The criteria catalogue makes it possible to describe and record functional and technical specifications as well as the aspects of the design and construction process and implementation, in terms of less or greater complexity. The project-specific system presentation in the analysis model is the basis for a common understanding and a transparent and target-oriented exchange of information among different disciplines, including the client. The application of the model in practice is described by means of a case study. The outlook of this paper describes how the developed analysis model provides a new approach in order to support planning security in Building Information Modeling (BIM).

1. Starting point

1.1 Complexity and planning security in prefabricated timber construction

«Timber Construction is complex», this statement stubbornly persists in practice without any plausible or profound hypothesis in literature. The «Manual for Multi-Storey Timber Construction» (*Atlas mehrgeschossiger Holzbau 2017*) describes timber construction as *«more multi-layered, thus more complex.»*

It says: «*The market offers an almost over-differentiated selection of different materials with many different construction possibilities*» [1]. Published in 2017, this comprehensive manual does not specify, why timber construction shall be «more complex». The question about complexity, however, is relevant, as in practice, it is this alleged complexity that is blamed for many difficulties and deficiencies that might arise in the planning process for prefabricated timber construction. For example:

- <u>Uncertainties</u> in the estimate of costs of alleged «complex» timber constructions in early planning phases. If a project team lacks the experience in early project phases of timber construction, the estimate of costs can be a major challenge: In Switzerland SIA 102:2014 Service Modell demands a cost accuracy of 15% in the Preliminary Project (SIA Phase 3.1) [2]. In Germany it is 10% in the Draft Planning Phase [3]. With the lack of experience and knowledge as to which constructions are simple and uncomplicated to realize and which situations require more effort and/or higher costs, safety margins are the rule. The worst case scenario is significant costs overruns. Both scenarios fail to rebut the widespread prejudice that timber construction is more costly [4] or correct the ratio.

- Concerning the interdisciplinary communication, those involved in the planning process complain about misunderstandings, double or bad planning, which effects the cost and schedule reliability as well as the process and the quality of design and execution [5].
- Concerning the expert-layman communication between the timber company and the developers, people report about the difficulties in transparent communication of context and impact of specific requirements or constructions in timber construction. Non-experts often do not have the understanding for cost-drivers, as these are not «visible» [6].

So although ecological arguments are in favour of wood, many actors raise arguments against it in the planning phase, summarized under the title «timber construction is complex», albeit without giving any reasonable explanation. The aim of my thesis at the Technical University in Munich was to close this gap and to contribute to the planning security in timber construction. The main focus was to determine the reasons for the complexity of timber construction and to derive solution approaches for handling complexity in planning and construction processes.

1.2 Definition complexity in the building construction and prefabricated timber construction

There are various definitions of the term complexity (in general). What is common to all of them is that complex systems are characterized by changing relations and they are unpredictable and cannot be planned ahead. They develop, they change and cannot be broken down into linear chains of cause and effect. If you follow these explanations, (planned) mechanisms and structures (including airplanes) per se are not complex at all, only complicated. Thus a timber construction is not complex but only complicated.

Literature (in general) provides various discussions and definitions of the complexity in building construction: Williams T mentions structural and organizational uncertainties [7], Bertelsen S refers to internal interdependencies, dynamic ambient conditions for the process, fragmented structures of building enterprises and the temporary system of social interactions [8]. That means the term complexity in building practice is used inaccurately. A challenge in construction, technology or design does not necessarily generate complexity (only in exceptional cases).

Within the framework of a situation analysis, my thesis identified and discussed further causes, specifically for timber construction with high levels of prefabrication:

- The lack of standardization of superstructures and over-differentiated variety of products cause uncertainties and the lack of overview within the planning team. [5]
- Functional requirements such as sound protection, fire protection, thermal insulation and moisture protection must be guaranteed in the interdisciplinary, cross-sectional analysis of primary, secondary and tertiary structures. Conflicts of interests and goals must be solved.
- Product specifications/capacities, supply chains, transport and logistics may already influence the design and should be considered early enough – albeit they cannot be controlled by the planning team only, and thus lead to uncertainties. [9]
- Pre-fabrication requires clear and complete execution planning for the production planning. Thus, decisions must be made earlier than with conventional construction methods. Interdisciplinary interaction in order to clarify all (relevant) planning details, takes place in a shorter period of time and with a higher network density. [10]
- The period between a decision (upon planning) and the visible assembly on-site is longer, thus increasing the risk that volatile influences or unforeseen events might thwart the plans. [10]

Thus, the complexity of prefabricated timber construction is not due to construction or architecture but to uncertainties, interdisciplinary interdependencies, conflicts of interests and goals and a higher density of social interaction. A web of manifold «complicated» challenges regarding how to manage interdisciplinary collaboration is thus the reason for any complexity in timber construction with a high level of pre-fabrication.

1.3. Managing complexity in the planning process

Building means deciding – despite all uncertainties, conflicts of interests and goals and the risk of the unforeseen. According to Schwehr P, a project team can only function with a solid base of knowledge and decisions [11]. In line with the interpretation of complexity discussed above, planning security means that it is impossible to foresee everything. Planning security means rather the security to deal with uncertainties, unforeseen events and to solve conflicts of interests and goals during the negotiation processes, through a high level of interdisciplinary interaction. So the management of complexity requires project-specific support through:

- establishment of a common understanding of the project, of terms and language and the priorities during project development (Big Picture).
- transparency and traceability of influential factors, dependencies and possible interactions (internal and external).
- knowledge and understanding of negotiable and not negotiable aspects.
- clarity in the exchange of information in inter-disciplinary communication (expert- and expert-layman-communication).

The conclusion in my thesis was to develop a typological structure of project characteristics and influencing factors in pre-fabricated timber constructions, demonstrating the project specific interaction of all complicated (und thus complexity generating) aspects and criteria in order to support interdisciplinary collaboration in the project team.

2. Criteria catalogue and analysis model

2.1 Methodical procurement and set-up of criteria catalogue

This typological structuring and the «complicated» i.e. complexity-generating criteria are derived from finished projects as part of the WoodWisdomNet research cooperation leanWOOD [12]. A total of 14 projects were investigated. In 45 narrative interviews and 9 interdisciplinary discussion groups criteria, qualified as «difficult» in planning and execution, were discussed from multiple perspectives.

These criteria were classified (less difficult to very difficult), supplemented with all normative and legal references and summarized in a criteria catalogue. Having finished the first version of the criteria catalogue, its validity was tested against the leanWOOD-case studies and other timber construction projects from previous research projects and double checked with practice partners for relevance and practical suitability.

2.2 Structuring of the Criteria Catalogue

Right now, the Criteria Catalogue comprises 35 criteria. The criteria were divided into three categories:

- Criteria that define the «Requirements» relating to task, functionality, surroundings, legal and normative framework conditions and the needs/wishes of the developers.
- Criteria that define the technical and design-related system approaches and details that are developed and/or decided by the project team in «Design + Construction».
- Criteria that influence the «Implementation» in production, logistics and assembly.

Each criteria category is documented in the Criteria Catalogue in a separate chapter. Figure 1 shows screenshots of individual pages of the criteria catalogue.

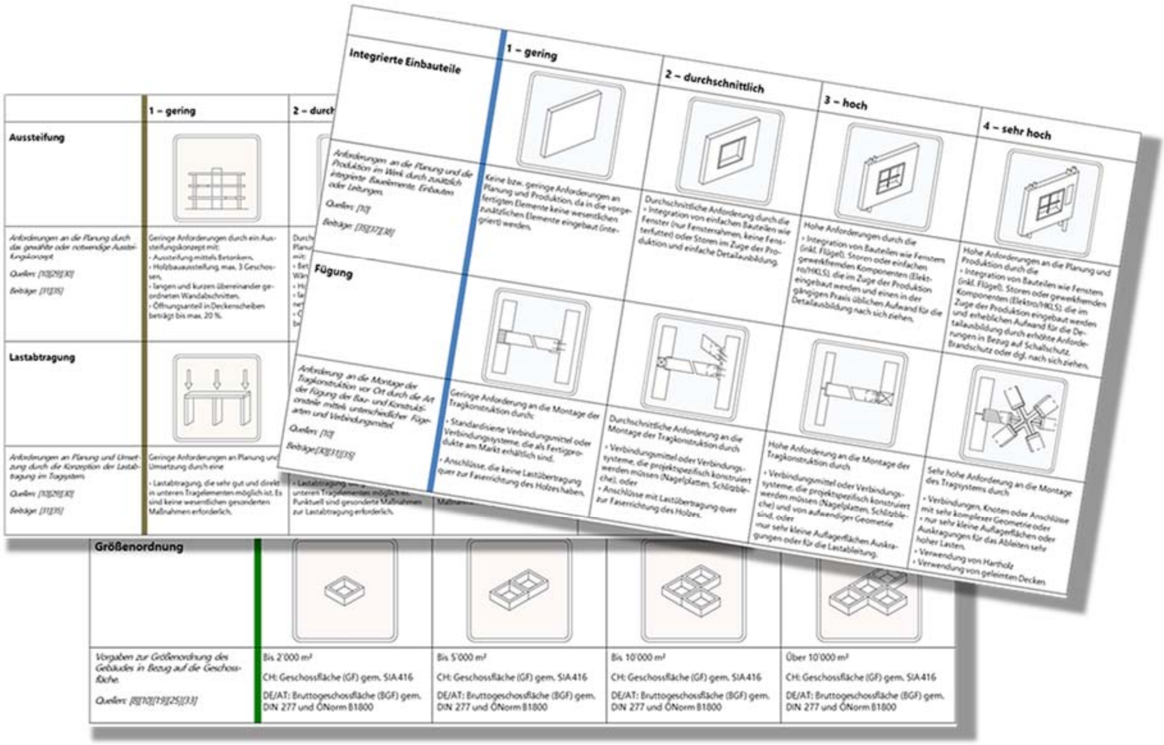

Figure 1: Screenshots of individual pages of the criteria catalogue [13].

As an example for one of these criteria the «Height Limitation» in the chapter «Requirements» shall be explained (see Figure 2):

Buildings in urban areas may be limited in height, because it might have to correspond with the roof line of the neighboring buildings. In order to achieve acceptable room heights, thin ceiling constructions must be applied, which exclude certain ceiling systems a priori, and also have an impact on horizontal cable and pipe ducts in suspended ceilings. This could possibly be compensated with horizontal space resources, where groups of ventilation lines could supply a smaller area and thus have smaller dimensions. If neither applies (level 3 or 4) the choice of ceiling systems is even more limited and/or inevitable crossings of lines and tubes require partial lowering.

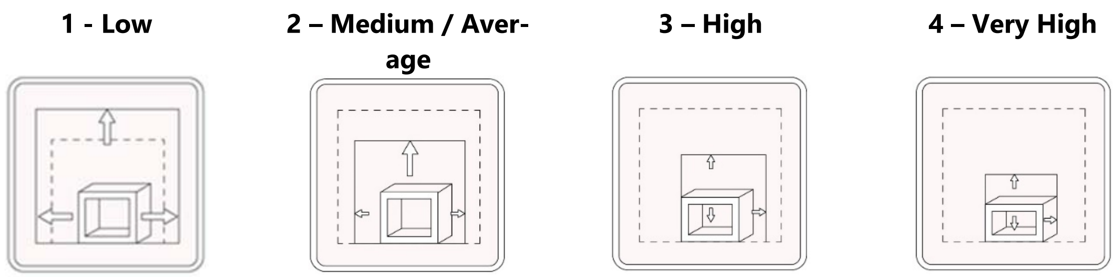

Figure 2. Criteria «Height Limitation» shows four levels of difficulties from level 1, (Low) to 4 (Very High) [14]. Level 1 (Low) shows no limitations in heights and horizontal expansion. Level 4 (Very High) shows a massive limitation in horizontal and vertical expansion.

The criteria «Height Limitation» describes the example as to how architects, timber structural engineers, building technicians and experts in fire and sound protection and structural physics have to tackle the challenges of room and ceiling height as well as cable and pipe ducts. In the case of different interpretations of priorities in the project, such as the priority of system separation, the condition that ducts may only be placed in suspended ceilings, or the question as to whether open ducts are possible, the key players may try to develop solutions on different assumptions.

2.3 Visualisation in the analysis model
The criteria catalogue systematically combines experience and know-how derived from individual, isolated experiences, summarized in a checklist. In order to visualize the assessment of a project and in order to support interdisciplinary communication through Visual Management, a visualization system was developed that generates a project-specific overall profile. In my thesis the Sunburst-Diagram was further developed (see Figure 4). The set-up of an analysis model and the derivable parameters for the planning team are explained below on the basis of real specific case studies.

3. Case study «Top Floor Addition Saumackerstrasse»

3.1 Project description [15]
The case study «Top Floor Addition Saumackerstrasse» describes the refurbishment of a multi-family house (year of construction 1948) in an urban area (Zurich). The total set of 21 apartments on three floors was to be left untouched as far as possible. The facade was insulated, new balconies were added to the facade and a controlled domestic ventilation was installed. The top floor addition replaced the uninsulated roof construction and made room for six new apartments. The element construction method was applied using box beam elements. The developer's goal was to create low-cost housing, thus the project had to be carried out in a tight financial framework.

Number of apartments:	21 + 6	Total construction time:	7 Months
Main usable area	1.970 m^2	Timber elements assembly:	3 Months
Completion	October 2015	Construction costs:	1.227 CHF / m^2 HNF
Architekt	*kämpfen für architektur ag*	Total costs:	1.580 CHF / m^2 HNF

Table 1. *Overview of the basis parameters of the project «Saumackerstrasse» (source see above)*

Figure 2. Installation of the pre-fabriacated roof elements. Photo: *kämpfen für architektur ag*

Figure 3. Interior view loft. Photo: *kämpfen für architektur ag*, Photographer: R. Rötheli

3.2 Assessment by means of the analysis model
Figure 4 shows the case study «Top Floor Addition Saumackerstrasse» in an analysis model. The three categories, Requirements, Design + Construction and Implementation are highlighted in different colors (green/brown/blue) and the difficulty levels (1-4) are graphically displayed with bars of different lengths.

The grey bar in the background shows the so-called «Reference Profile». The Reference Profile makes it possible to display experiences from previous projects and to constantly specify them in the course of future projects.

Figure 4 clearly shows that the «Requirements» in «Saumackerstrasse» were low to average, compared with the Reference Profile. For example fire protection was no big challenge. The required standards for sound protection, energy efficiency and earthquake protection were not unusual. However, Figure 4 shows one challenge. The «Existing Structures» were assessed as level 4. The reason was that the existing apartments had to remain untouched, thus offering little space for ducts in the staircase. The ducts to the new apartments had to be split without any system separation. As a result, the installation along the basement ceilings to the building services had to be solved on-site. In an interview the construction manager admitted that there were no additional costs, but that deadlines has been exceeded. The advantage of a rapid construction progress could not be transferred to the entire construction period. This might have been avoided through better planning during the early planning phase.

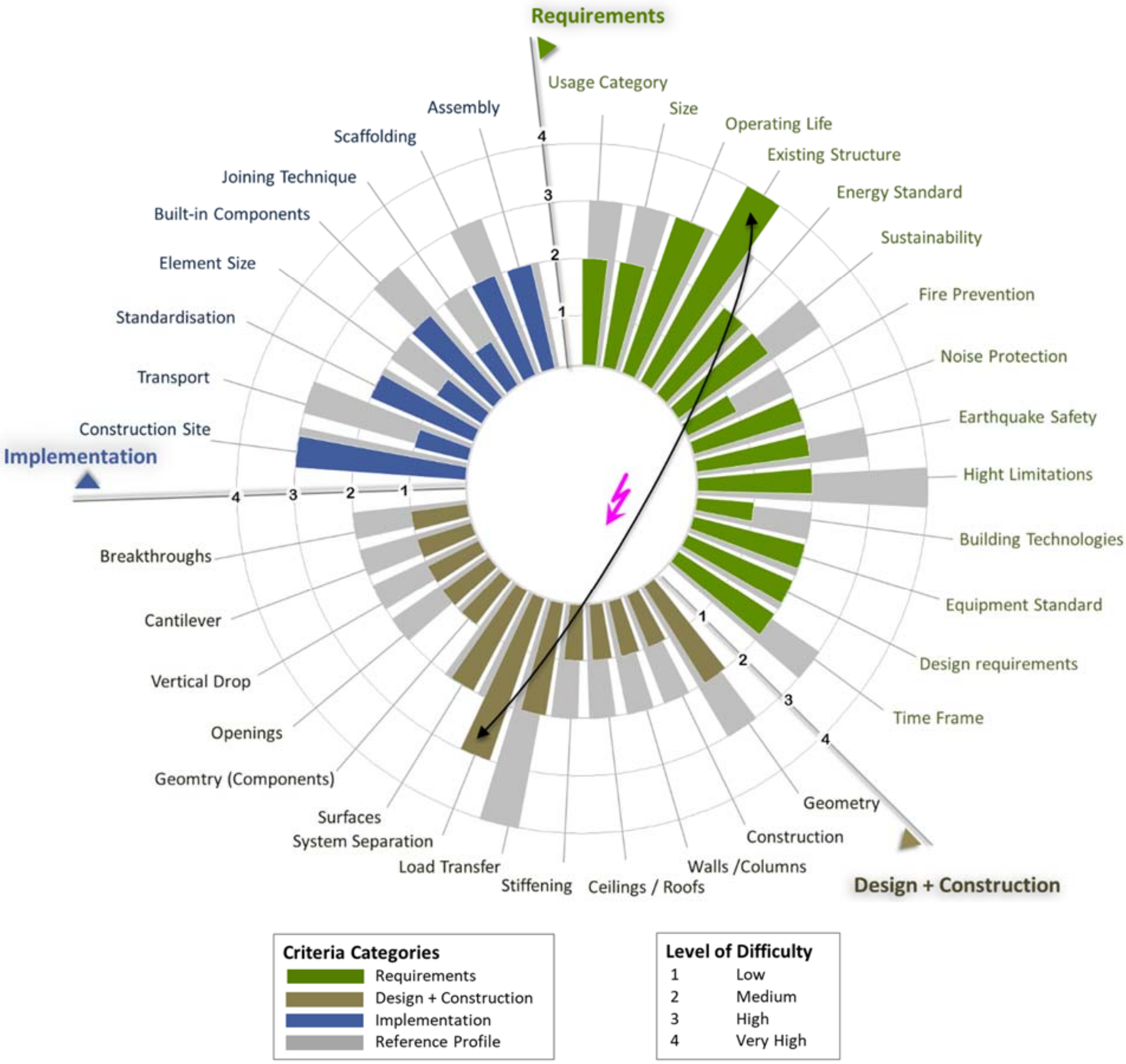

Figure 4. Diagram of the results of the project «Saumackerstrasse» in an analysis model

4. Application and limits

4.1 Use as strategic project support

The main application field of the criteria catalogue and the analysis model is in strategic project support. Complexity-relevant information concerning the project can be scaled gradually and specified in the course of the project. The assessment of the criteria referring to «Requirements» can indicate potential challenges, also in comparison with the Reference Profile. These can be communicated to the developers in a transparent way. Subsequently, a comparison of different designs based on the criteria (mainly concerning the cost estimate) can also be supported.

As an instrument of visual communication the analysis model enhances the exchange of information and knowledge management within the interdisciplinary team and the communication with the developers in the course of the entire planning phase. Dependencies, interactions and the necessary settings of priorities become transparent, thus comprehensible. The clarity of the information transfer and a consistent meaning are supported, so misunderstandings in interdisciplinary collaboration and in expert-layman-communication are avoided. Also, it becomes easier for new team members to get acquainted with the project. Furthermore, the visualized project profile can support the transparency of project descriptions or requirement specifications.

The communication of superior and essential aspects in a project facilitates the handling of uncertainties in the decision-making process. The project leaders have a solid basis for targeted quality, deadline and cost oriented project management. The comprehension of the overriding assumptions enables appropriate project-specific action on the part of everybody involved («Empowerment»).

The assessment of the complexity to be expected and an overview of the project specifications also support the procurement and cooperation model. The relevant disciplines are already being applied in early and subsequent phases. The selection of the contract awarding procedure can take into account specific complexities.

4.2 Conclusion

The assessment by means of a criteria catalogue and the visualization of the analysis model contribute to the typologically structured understanding and communication of causal networks in prefabricated timber construction. The added value is the assessment of possible challenges and the creation of a common understanding for the project within the interdisciplinary team. It is no dogmatic classification.

Flexible criteria can also be supplemented or deleted, depending on the application, without limiting the functionality or significance. The recording of experiences from previous projects in a reference profile supports the people involved and provides a checklist for the project management. However, it does not provide a generally applicable algorithm that can replace expert conclusions.

5. Outlook

The digitalization of the building industry and the successive implementation of the Building Information Modeling BIM initiates a new methodical culture. Model-based automated interdisciplinary collaboration will characterize future planning processes. The understanding of the terms, the interpretation of the meaning, the orientation and the comprehension of the priorities are essential for information management and communication for interdisciplinary collaboration. In this context the analysis model offers a typological approach that has the potential to support the structural transformation into new management and collaboration models in general. In addition a further operationalization of the analysis model may contribute to the following areas:

- The development of a BIM-cost model is challenged by the transfer of parameter-based cost estimates to component-based cost calculations. Today parameter-based models (in early phases) for the assessment of different execution options in timber construction can hardly be verified with cost factors. If reference profiles of previous projects could be set up in an internal data bank, it could provide increased accuracy. Subsequently, the data banks or catalogues could

be pooled (e.g. BKI data bank for construction costs [16] or EAK catalogues of elements [17]) making a major contribution to cost security in timber construction.
- In in Switzerland the calculation of fees are on SIA 102:2014 [18], in Austria on LV.VM 2014 [19] and in Germany on HOAI 2013 [20]. What is common to all of them is that the basic services of the architects can be adapted to the increased expenses by means of adjustment factors or categories. However, these factors are rather vague in connection with prefabricated timber construction. The analysis model could enable an adequate assessment and, where appropriate, provide a billing system for architectural and engineer services in timber construction.

Thus, the criteria catalogue and the analysis model are the first important steps towards a typological structuring of prefabricated timber construction. The involvement of the digital planning environment could prove that timber construction is in fact attractive both ecologically and economically.

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