



## A SURVEY OF THE DESIGN OF TIMBER-CONCRETE HYBRID BUILDINGS IN SWEDEN

Carl Larsson<sup>1</sup>, Michael Dorn<sup>2</sup>

**ABSTRACT:** There is a growing interest in timber buildings in Sweden and increased availability of Glulam (GLT) and particularly Cross Laminated Timber (CLT) products. Timber buildings, though, often have difficulties in fulfilling the performance requirements of a building project. The use of concrete elements in addition to timber elements in the load-bearing structure is a widespread solution, introducing timber-concrete hybrid buildings. The study presents responses from interviews regarding ten different timber-concrete hybrid building projects in Sweden with a load-bearing structure above the foundation level in both timber and concrete. Four main types of timber-concrete hybrids were found: a CLT structure on top of a concrete structure, a post-beam system in GLT with CLT slabs and concrete walls, a post-beam system in GLT with concrete hollow core slabs, and a timber structure with some slabs in concrete. The results show that timber-concrete hybrid buildings are flexible and suitable for various construction types. The reasons for using concrete in timber construction were primarily to increase self-weight, obtain longer span lengths, and overcome shear wall capacity issues. There is still a lack of competence in the design of structural timber projects, and at most, five different structural designers were involved in the load-bearing design of a single building. This highlights issues regarding project management of the design process within timber-concrete hybrid buildings.

**KEYWORDS:** Timber-concrete hybrid, CLT building systems, Timber building systems, Structural management

### 1 INTRODUCTION

The use of timber in modern, large-scale building projects in Sweden is low compared to concrete. In recent years, though, there has been a growing interest from the construction industry, from architects and from developers to use timber as the primary material in the load-bearing structure of buildings [1]. It is well known that an increased share of timber products like sawn timber, glulam timber (GLT), and cross-laminated timber (CLT) in buildings is beneficial from an environmental perspective. For example, the load-bearing structure is identified to significantly impact the carbon footprint during the construction phase [2].

Timber-concrete hybrid buildings use both materials in the load-bearing system and are a possibility widely used to increase the use of timber overall. Plenty of timber-concrete hybrid structures are operating, including showcase examples like the 18-story Brock Commons in Vancouver, the 24-story HoHo Tower in Vienna, and the 10-story Banyan Warf in London. However, the research in this area is limited compared to other hybrid structures, where several topics have been studied regarding structural systems, connectors, and modeling.

This study aims to give real-life examples of how timber and concrete are combined in hybrid structures today in the Swedish construction industry without going into technical solutions or the performance of these buildings.

In addition, the study focuses on the structural design phase, where many decisions are made, e.g., the requirements of the building, how the building will be built, and which structural materials will be used. The study is based on interviews with structural designers, contractors, and developers involved in these projects.

The following research questions are addressed:

1. How are timber and concrete combined in a typical Swedish project? What is the reason for this?
2. How do structural designers work in the late design phase of a timber-concrete hybrid project?

### 2 METHODS

The study applies a qualitative research methodology based on interviews with primarily structural designers involved in the late design phase in the construction process of building projects in Sweden. In several of the studied projects, complementary interviews were held with other people involved in the respective project, such as developers and contractors. The qualitative method was chosen because it allows the researcher to secure vivid and accurate accounts based on the interviewee's personal experience in building projects [3].

Ten different projects were identified as they were recently completed or under production in early 2020.

<sup>1</sup> Carl Larsson, Linnaeus University, Sweden carl.larsson@lnu.se

<sup>2</sup> Michael Dorn, Linnaeus University, Sweden michael.dorn@lnu.se

Interviews regarding these projects were performed, at least two for each project. In total, 17 people were interviewed, eleven structural designers, one developer, and five contractors. Several respondents have worked on more than one project; in these cases, interviews were held separately for each project. Of the structural designers, there were six timber element designers and five concrete element designers. The concrete element designers acted in some projects also as the main designer. Most of the interviews were held in Swedish, except with two of the timber element designers who were located outside Sweden.

The questionnaire contained nine questions and is presented in Table 1. The test interviews were analyzed to verify that the questionnaire gives responses that fulfill the overall research questions of this study.

**Table 1:** Questionnaire of the interviews.

Question
1 What are the name and the background of the project?
2 What was the reason for mixing the use of concrete and timber?
3 How has the structural design been divided into different involved contractors or designers?
4 Which designer has been responsible for the collaboration of the structural designers?
5 Which designer was responsible for the total stability of the structure?
6 When did the project agree that the structure had enough stability and which analysis was to be performed?
7 Which project partner was responsible for the robustness criteria of the structure, and which method was used for these criteria?
8 Which structural data were shared between the different structural designers involved, and what software was used?
9 Lessons learned from your point of view in these types of projects?

### 2.1 Data analysis

Grounded Analysis [4] was performed as a data analysis method for the open-ended questions. It allows the data collection and analysis to proceed simultaneously, allowing the researcher to obtain a complete picture of the respondents' views on their building projects. The Grounded Analysis is commonly used in Management Research [5] and was performed using the suggested methodology by Easterby-Smith & Thorpe [6]. The answers' consistency was controlled by performing interviews with at least two stakeholders for each project. This is also the reason why only ten building projects were

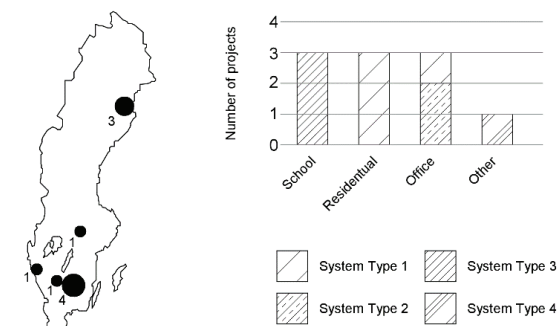
included in the final analysis, out of 16 suitable projects identified initially.

## 3 RESULTS

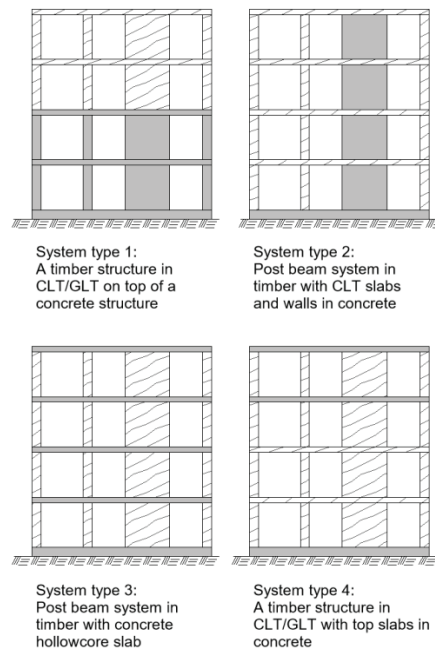
### 3.1 Projects

Two Swedish mid-size cities have focused on construction with timber, where political processes were created to foster new developments; Växjö in the Southern and Skellefteå in the Northern part of Sweden, respectively. A relatively large number of the studied project are therefore located in these two towns, see Figure 1. The purpose of the buildings was categorized as schools, residential buildings, offices, and others.

From a structural point of view, four different system types of the timber-concrete hybrid were found in the ten projects identified, shown in Figure 2. The categories and building types do not necessarily coincide.



**Figure 1:** Project locations and purposes of the buildings in the studied projects



**Figure 2:** System types of the load-bearing structure

### 3.2 Reasons for choosing a timber-concrete hybrid

The reasons for using timber structural elements in a project are shown in Figure 3. The respondents mentioned the following reasons:

- Architectural competition: The use of timber resulted from an architect competition where timber construction was part of the winning entry.
- Property developer's demands: The property developer required a timber structure.
- Municipality demands: The municipality demanded a timber structure, e.g., enforced in a land allocation process.

The following reasons for using concrete elements over timber elements in the projects were mentioned by the respondents:

- Economy: Timber solutions were too expensive; replacing some structural elements with concrete elements was more economical.
- Experience: Concrete was used on critical structural elements due to a lack of experience and/or knowledge of designing with timber.
- Span width: The use of timber was not feasible due to limited span widths with timber structures. These limitations include dynamics and limited height issues.
- Shear wall capacity: Concrete walls were used due to the increased shear capacity of the wall but also, i.e., for connectors.
- Self-weight: Concrete elements were used to increase self-weight to handle the uplift forces of the structure.

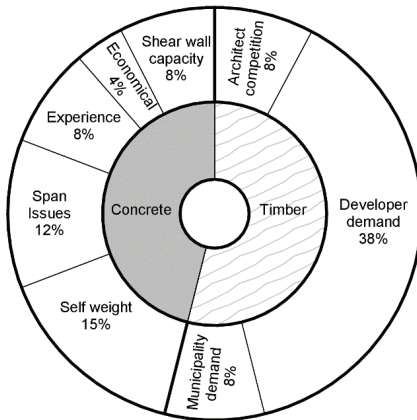


Figure 3: Reasons for a specific load-bearing structure. One mention by a respondent equals 4% of the figure

### 3.3 Project management in structural design

For this study, a *designer* is defined as the company represented as a structural designer within the building project, not the number of individuals working as structural designers.

The total number of structural designers in the projects differs between 2 to 5, with a mean of 3.3 structural designers involved. As seen in Figure 4, no correlation is seen between the number of designers and the contract worth. All respondents highlight that each designer is responsible for their field of expertise and the respective structural elements. Typically, the following structural designers were involved:

- Main designer
- Timber element designer
- Concrete element designer
- Additional designers (e.g., truss, roof, or steel constructions)

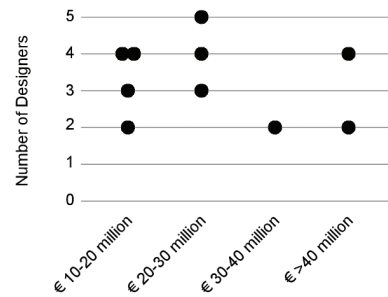
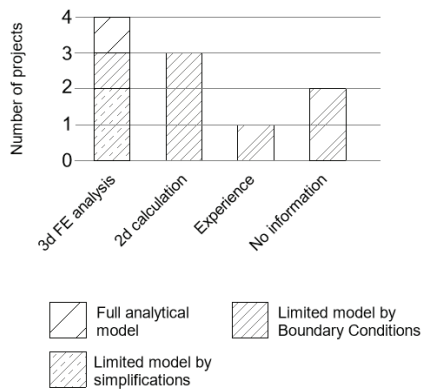


Figure 4: Contract worth and the number of designers within the projects

A project's main designer was responsible for collaboration between the partners and the overall coarse calculation checks of other designers' work. In nine of the projects, a specific designer was assigned as the main designer. In one of the projects, there was a contradictive response from the respondents who had this role.

In the nine projects with a designated main designer, the main designer was also responsible for the foundation design. In addition, there is a wide range of tasks related to the role, spanning from the design of precast concrete and steel trusses to details of the building envelope. For a load takedown and stability analysis of the complete building, the main designer had a unified model for calculation in one project. As for the other nine projects, the timber element designer was responsible for these calculations.

Figure 5 shows the type and complexity of calculations performed, mainly 3d Finite Element (FE) analysis and 2-dimensional calculations. The number of included structural elements in the calculational models also varies. The results show that the designers made two different main assumptions for calculations when not including all elements: the first is that the designer simplifies these elements to fictitious beam or shell elements with properties considered suitable, e.g., rigid elements; the second is to view such elements as (fixed) boundary conditions in the calculational model.



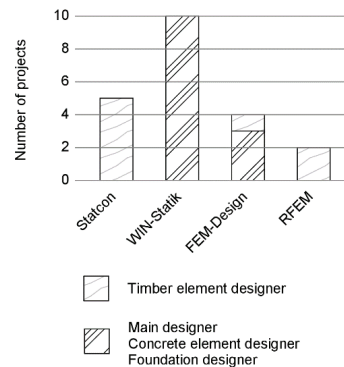
**Figure 5:** Type of global calculations performed on timber-concrete hybrid structures

In addition, the findings from the interviews conclude that the criteria of the requirements for horizontal stability differ. Of the ten investigated projects, answers were given for only six. The type of stability criteria within these projects was:

- Maximum load-bearing capacity for a defined truss member.
- Horizontal displacement criteria for the overall building height or story height.
- Comfort criteria such as accelerations due to wind load.
- "Engineering knowledge" (no calculation, stability was considered obvious).

According to all respondents, information on characteristic or design loads, reaction forces, and section forces are exchanged between the designers in the design process. In addition, complementary information in terms of sketches, drawings, or documents was exchanged, explaining these loads. In none of the studied projects, the designers shared their entire structural model for calculation with the other designers. However, three respondents mention that the documentation of calculations is available when their designing task is complete.

All respondents use more than one type of software. The software used in these projects is listed in Figure 6. In general, the timber element designers used the software RFEM by Dlubal [7] for 2D and 3D FE-analysis and design and Statcon by Elecosoft [8] for 2-dimensional element design. The foundation and concrete designers use the WIN-Statik package [9] for 2-dimensional design and FEM-Design [10] for 3-dimensional FE-analysis and design, both by StruSoft.



**Figure 6:** Type of calculation software used by the designers

## 4 DISCUSSION

### 4.1 Projects

The study shows four major types of timber-concrete hybrid structures among the studied projects. Previous research primarily discusses timber-concrete hybrids using a post-beam system in GLT with CLT slabs with concrete walls [11] [12] (System type 2 in this study) or systems used for high-rise buildings [13] (System type 4 in this study). This study shows two alternative timber-concrete hybrids, a CLT structure on top of a concrete structure and a post-beam system in GLT with concrete hollow core slabs.

The result shows that it is manageable to replace traditional structural elements with timber structural elements in various ways and still fulfill all requirements of a modern building in Sweden. The findings also show that the use of the building has a significant impact on the structural elements that are in concrete or timber, as seen in Figure 1.

The selection of the projects does not reflect the overall construction industry in Sweden, as the project locations and the number of projects do not match the overall building permits in Sweden [14]. Contact to the project partners was primarily done within the SBUF network, the Development Fund of the Swedish Construction Industry.

However, a voluntary database for timber projects in Sweden, Woodprint Sweden, shows that a majority of these timber projects are located in the cities of Växjö and Skellefteå [15]. This confirms that the selection of projects in this study is representative of seven of the studied projects located in these cities. The municipalities of both these cities have strategies for increasing the number of timber buildings [16] [17], which explains the high number of projects within these cities. It also confirms that the number of timber projects is closely related to political decisions and public actions [18].

#### 4.2 Reasons for a load-bearing structure in both timber and concrete

The main reason for the use of timber in the main structure was the property developer's demand. It is added that in seven projects, municipalities or other public organizations acted as property developers. As confirmed under the project discussion, the rising number of timber projects is due to political decisions and public action. The respondents in this study make the same conclusions, stating that property developers and municipalities are highly represented as key figures for decision-making in favor of a timber structure. Municipalities are both landowners and/or developers in several projects, implying that Sweden's public and political role in timber building is crucial.

Reasons for choosing concrete instead of timber for some elements (apart from the foundation) are mainly due to economic or structural issues. The respondents do not point to other known problems with timber construction, such as acoustic and fire demands. This was also seen in another study where the Swedish architects' perception of using timber as the construction material was investigated [19]. The authors concluded that acoustic and fire demands came in fourth place after issues regarding uncertainties and lack of control over the decision to use timber as the structural material. Altogether, this implies that previously known problems with timber materials in load-bearing constructions are manageable within a modern Swedish building project.

In only one project, the respondents answered that lack of experience in timber design was a reason for choosing concrete. However, one of the interviewed contractors responded that it was difficult to find timber designers in Sweden, and two of the timber designers in this study were located outside Sweden. On the one hand, this suggests that there are structural designers available who are confident in designing CLT components despite the lack of standard regulations such as Eurocodes and the National Annexes. Nevertheless, there still is a lack of experience and knowledge in timber design by Swedish designers, but also by architects and developers who need broader knowledge in the early stage of project development [19].

With most respondents working as structural engineers, developers, and contractors, key personnel in the decision progress, such as architects, are underrepresented in this study. Conclusions, therefore, might not cover the wide range of variables in the decision-making process in a modern construction project due to the limited number of respondents.

#### 4.3 Project management in structural design

As the interviews have shown, designers usually work in well-defined fields within their area of expertise. In particular, the results clearly show that the project's main designer is not the designer responsible for the load takedown and stability analysis of the entire building. The

timber element designer mainly performed these calculations.

Although a high number of structural engineers characterizes the investigated projects, no correlation was found between the number of involved designers and the different types of construction, nor the worth of the construction contract for the projects. However, the high number of structural designers is not unique to timber-concrete hybrid buildings. In Sweden, the topic of the number of designers included in construction projects has been discussed at least since the progressive collapse of a three-story building in Ystad in 2012. In a report by The Swedish Accident Investigation Authority [20], the high number of involved structural designers and issues regarding this resulted in revised construction rules. In 2015 [21] and 2018 [22], additional requirements were added, demanding adequate collaboration between different structural designers.

Still, it is noteworthy that in one of the ten projects studied, different answers were given regarding who was the main designer, showing that the different roles of structural designers still can be somewhat unclear and understood differently between various stakeholders within a project. Another topic is the variation of the types of analysis performed for the design calculations in these projects. The results conclude other findings regarding practicing designers where both Fröderberg [23] and Klasson [24] conclude that there is a large variety of design approaches and results.

As for the investigated timber-concrete hybrid projects, several different calculational approaches and design criteria for horizontal stability were used. Combining these results with the findings in this study regarding additional designers in timber-concrete hybrids highlights topics of risk management and project management of the involved designers in these projects.

Results from the interviews are unambiguous in that it is the specifying of load actions on and between separate structural elements that are shared among the designers. No shared models are used between the different designers. It is also clear that the structural designers did not want other designers' structural components within their own structural model for calculation if it was not considered absolutely necessary. Therefore, other designers' elements are either neglected or simplified with stiff elements or by boundary conditions.

Altogether, this leads to a well-working workflow with clear boundaries between the designers. It is also relatively easy to follow which designers are responsible for designing each element. However, one may argue that there is a risk with a fractioned structural model for calculations. The total systems' stiffness and compliance of, e.g., connections, is not considered in such models. Consequently, this will have an effect on the load takedown calculations and the design of the building, and, ultimately, the safety beta index for the structure as a whole.

As computer-aided structural calculations play a vital role for practicing structural engineers, the responses are of

great interest, especially due to the increased number of designers in timber-concrete hybrids. It is noted that the different types of calculation software used by the respondents cannot automatically share their files and models in between.

Other widely used software within the building industry, such as software drawings and modeling, geometric design, or BIM software, have a better basis for collaboration. For example, these fields have several common standards, such as Industry Foundation Classes (IFC) [25], that allow for an automated exchange between designers. This type of standard is missing for structural design software.

The practice of exchanging loads and sectional forces is obviously the most practical way of working. It might explain why the respondents in this study seldom model the complete building for analysis, only the parts that they are responsible for.

## 5 CONCLUSIONS

This interview study provides a brief and general overview of the state of timber-concrete hybrid buildings in Sweden. While clearly not exhaustive, some overall trends are seen, and the following conclusions are drawn:

- More structural designers are involved in timber-concrete hybrid projects than in regular building projects.
- Collaborative design and project management are identified as key aspects of a successful timber-concrete hybrid project.
- The responsibility for performing static calculations differs, and it is seldom that the main designer has a static model for the entire building.

The findings conclude that in the structural design phase of the project, topics regarding collaboration are of great importance. This is prior to topics such as connectors, acoustic, and fire, topics that are usually common in timber buildings. These findings are of great importance for research as they highlight the importance of performing studies on full-scale structures and not only on single components, especially since several regulations are performance-based for the building and not material-specific for a single structural member.

The increased number of involved designers might affect the structural safety of a building. The large variety of design approaches gives different design loads for the single structural element. Fröderberg [23] concluded that the different design approaches done by practicing designers lowered the level of safety of the building significantly. As the safety factors in the current Eurocode framework are calibrated to a specific level of safety in buildings [26], the design approaches and assumptions made by the different designers involved in timber-concrete hybrid projects are of utter importance. Once again, this highlights the collaborative design topics discussed in this study.

In addition, the presented work highlights the importance of knowledge in timber engineering for designers in such projects, even if the main work within a project is within, e.g., prefabricated concrete elements. The knowledge of the needs and restrictions of other materials' elements must be considered.

In the long run, unified calculation and design models need to be introduced because these models should allow for better results since the building's overall behavior is reflected.

It is in the industry's best interest to quickly establish a well-functioning ecosystem for timber construction. The concrete industry, both in the prefabricated and the in-situ versions, can be a role model with its standards and how far it has come.

## ACKNOWLEDGEMENT

The authors would like to thank all interview partners for their participation. The research is funded by the Swedish construction industry's organization for research and development (SBUF, project number 13721 "Building systems in CLT and other materials") and Skanska Sverige AB. The research work is part of the project "Improving the competitive advantage of CLT-based building systems through engineering design and reduced carbon footprint" with support from the Knowledge Foundation (KKS, project number 20190026).

## REFERENCES

- [1] E. Markström, M. K. Kuzman, A. Bystedt, D. Sandberg, and M. Fredriksson, "Swedish architects view of engineered wood products in buildings," *J. Clean. Prod.*, vol. 181, pp. 33–41, 2018, doi: 10.1016/j.jclepro.2018.01.216.
- [2] A. Younis and A. Dodoo, "Cross-laminated timber for building construction: A life-cycle-assessment overview," *J. Build. Eng.*, vol. 52, no. April, p. 104482, 2022, doi: 10.1016/j.job.2022.104482.
- [3] R. G. Burgess, *Field Research: a Sourcebook and Field Manual*, vol. 91, no. 5. Routledge Taylor & Francis Group, 1982.
- [4] P. Yancey Martin and B. A. Turner, "Grounded Theory and Organizational Research," *J. Appl. Behav. Sci.*, vol. 22, no. 2, pp. 141–157, 1986.
- [5] E. Bell, A. Bryman, and B. Harley, *Business Research Methods*, Fifth Edit. Oxford: Oxford University Press, 2019.
- [6] M. Easterby-Smith and R. Thorpe, *Management Research*, Second. Sage Publications Ltd, 2002.
- [7] DLubal, "RFEM." DLubal, 2019, [Online]. Available: <https://www.dlubal.com/en/products/rfem-fea-software/what-is-rfem>.
- [8] Elecosoft, "Statcon." 2020, [Online]. Available: <https://www.elecosoft.se/programvaror/statcon>.
- [9] Strusoft, "WIN-Statik." 2019, [Online]. Available: <https://strusoft.com/products/win->

- statik.
- [10] Strusoft, “FEM-Design.” 2019, [Online]. Available: <https://strusoft.com/products/fem-design>.
- [11] T. Connolly, C. Loss, A. Iqbal, and T. Tannert, “Feasibility study of mass-timber cores for the UBC tall wood building,” *Buildings*, vol. 8, no. 8, 2018, doi: 10.3390/buildings8080098.
- [12] Skidmore Owings & Merrill LLP, “Timber Tower Research Project: Final Report,” Chicago, USA, 2013.
- [13] J. Chen, H. Xiong, and C. E. Ventura, “Non-linear simplified models for seismic response estimation of a novel tall timber-concrete hybrid structural system,” *Eng. Struct.*, vol. 229, no. October 2020, p. 111635, 2021, doi: 10.1016/j.engstruct.2020.111635.
- [14] J. Johansson, “Bygglov för nybyggnad, antal efter region, hustyp och kvartal [Building Permit of New Buildings, number and region, type and quarter],” *SCB*, 2020. <http://www.statistikdatabasen.scb.se/sq/84324> (accessed Mar. 10, 2020).
- [15] S. Träbyggnadskansli, “Woodprint Sweden,” 2020. <http://woodprintsweden.se/>.
- [16] Växjö Kommun, “Växjö Träbyggnadsstrategi [Timber Building Strategy in Växjö],” 2018. [Online]. Available: [https://vaxjo.se/download/18.cf4c4d716951d944dd1a4cb/1551961221853/Vaxjo\\_kommuns\\_trabyggnadsstrategi\\_-\\_layout\\_version.pdf](https://vaxjo.se/download/18.cf4c4d716951d944dd1a4cb/1551961221853/Vaxjo_kommuns_trabyggnadsstrategi_-_layout_version.pdf).
- [17] Skellefteå Kommun, “Träbyggnadsstrategi [Timber Building Strategy],” 2014. [Online]. Available: [https://www.skelleftea.se/Bygg\\_och\\_miljokontoret/Innehallssidor/Bifogat/Trabyggna\\_ddstrategin\\_skarm.pdf](https://www.skelleftea.se/Bygg_och_miljokontoret/Innehallssidor/Bifogat/Trabyggna_ddstrategin_skarm.pdf).
- [18] J. Lindgren and S. Emmitt, “Diffusion of a systemic innovation A longitudinal case study of a Swedish multi-storey timber housebuilding system,” *Constr. Innov.*, vol. 17, no. 1, pp. 25–44, 2017, doi: 10.1108/CI-11-2015-0061.
- [19] K. Hemström, K. Mahapatra, and L. Gustavsson, “Architects’ perception of the innovativeness of the Swedish construction industry,” *Constr. Innov.*, vol. 17, no. 2, pp. 244–260, 2017, doi: 10.1108/CI-06-2015-0038.
- [20] M. Karanikas and P. Dahlberg, “Slutrapport RO 2013:03 Husras på Aulingatan i Ystad, Skåne län, den 25 maj 2012 [Report RO 2013:13 Building collapse in Aulingatan i Ystad, Skåne län, 25 of May 2012],” 2013.
- [21] Swedish National Board of Housing Building and Planning, “Boverket mandatory provisions amending the board’s mandatory provisions and general recommendations (2011:10) on the application of European design standards (Eurocodes), EKS10,” 2015.
- [22] The Swedish National Board of Housing Building and Planning, “Boverket mandatory provisions amending the board’s mandatory provisions and general recommendations (2011:10) on the application of European design standards (Eurocodes), EKS11,” 2018.
- [23] M. Fröderberg and S. Thelandersson, “Uncertainty caused variability in preliminary structural design of buildings,” *Struct. Saf.*, vol. 52, no. PB, pp. 183–193, 2015, doi: 10.1016/j.strusafe.2014.02.001.
- [24] A. Klasson, I. Björnsson, R. Crocetti, and E. F. Hansson, “Slender Roof Structures - Failure Reviews and a Qualitative Survey of Experienced Structural Engineers,” *Structures*, vol. 15, no. June, pp. 174–183, 2018, doi: 10.1016/j.istruc.2018.06.009.
- [25] ICS, “ISO 16739-1:2018 Industry Foundation Classes (IFC) for data sharing in the construction and facility management industries,” 2018.
- [26] JCSS Joint Committee on Structural Safety, “Probabilistic model code,” 2001.