buildings

MDPI

Article

Factors Influencing Choice of Wooden Frames for Construction of Multi-Story Buildings in Sweden

Alireza Bahrami *, Jonas Jakobsson and Tobias Söderroos

Department of Building Engineering, Energy Systems, and Sustainability Science, Faculty of Engineering and Sustainable Development, University of Gävle, 801 76 Gävle, Sweden
* Correspondence: alireza.bahrami@hig.se

Abstract: Construction of buildings with wooden frames higher than two stories has been permitted in Sweden since 1994. As construction of multi-story buildings with wooden frames is relatively new, people in the construction industry are more likely to construct these buildings with concrete frames. The current research evaluates the factors influencing the choice of wooden frames for construction of multi-story buildings in Sweden. The purpose of this study is to explain which advantages and disadvantages construction companies in Sweden consider with wooden construction and to highlight the factors for why multi-story buildings are built with wood to a lesser extent than with other materials. The main goal is to investigate what factors or assumptions construction companies base their decisions on, and whether experience and competence in wooden frames for construction of multi-story buildings are considered in short supply in Sweden today. The chosen method for this research is a descriptive survey study with a qualitative and quantitative approach. The survey is based on respondents from five leading building companies in Sweden with regard to the companies' revenue. The respondents had either previous experience in constructing multi-story buildings with wooden frames, experienced respondents (ERs), or no experience, unexperienced respondents (UERs). 63% of the respondents were ERs, while 37% of them were UERs. It is resulted that the respondents think there is a lack of competence and experience in wooden frames for construction of multi-story buildings in Sweden. Factors that have the greatest impact on decisions to construct with wooden frames are positive environmental and climatic aspects as well as production advantages. Factors that are considered as major obstacles to construct with wooden frames are cost, acoustics, and moisture problems.

Keywords: wooden frame; construction; multi-story building; environment; climate; moisture; cost; stability; fire

Citation: Bahrami, A.; Jakobsson, J.; Söderroos, T. Factors Influencing Choice of Wooden Frames for Construction of Multi-Story Buildings in Sweden. *Buildings* **2023**, *13*, 217. https://doi.org/10.3390/buildings13010217

Academic Editor: Nerio Tullini

Received: 29 November 2022
Revised: 9 January 2023
Accepted: 10 January 2023
Published: 12 January 2023

1. Introduction

During the 18th and 19th centuries, the population of cities increased. Most buildings were constructed with wood materials and bounded by narrow streets, which meant that fire could easily spread between buildings. In 1874, a fire regulation was introduced that prohibited construction of wooden buildings higher than two stories. This regulation was valid until Sweden joined the European Union (EU) in 1994. The long ban on constructing multi-story wooden buildings led to a habit of working with concrete and steel. Since construction of multi-story buildings with wooden frames is relatively new, many in the construction industry feel safer and have more knowledge of working with concrete and steel than wood. This partly explains why today multi-story buildings are constructed higher than two stories with wooden frames to a relatively small extent in comparison with multi-story buildings using concrete as the frame material in Sweden. In 2018, only 13.1% of the new multi-story residential buildings were constructed with wooden frames [1]. The corresponding figure for buildings with concrete frames was about 85%. However, multi-story buildings with wooden frames seem to have a bright future, and the proportion

of multi-story buildings with wooden frames increased to 20% in 2019, whilst multi-story buildings with concrete frames fell to 79% in the same year.

Fire risks in wood-framed multi-story buildings were analyzed by Hultquist and Karlsson [2]. The results from a project aiming for industrialized development of a multi-story timber-framed house system were presented by Stehn and Bergström [3], which focused on the customer satisfaction and production-design problems/possibilities. Gustavsson et al. [4] investigated life cycle primary energy use and carbon dioxide emission of an eight-story wood-framed apartment building. Tykkä et al. [5] assessed the development of timber-framed firms in the construction sector and whether the EU construction policy innovation contributed to innovation at the firm level. Swedish architects' perceptions, attitudes, and interest toward steel, concrete, and wooden frames in multi-story buildings were examined by Hemström et al. [6]. The influence of regulations, perceptions, and promotions on the emergence of an innovative system for wood-framed multi-story buildings in Germany, Sweden, and the United Kingdom was evaluated by Mahapatra et al. [7]. Dodoo et al. [8] conducted a life cycle primary energy analysis of low-energy timber building systems in multi-story residential buildings. Ferri and Lam [9] designed four- and seven-story timber buildings with the same floor plan focusing on stability calculations and critical uplifting forces for both buildings. The wood-framed multi-story construction market potential in Europe was explored by Hurmekoski et al. [10]. Swedish architects' views of using engineered wood products in buildings were studied by Markström et al. [11]. He et al. [12] reported experimental results and numerical simulations of shaking table tests on a two-thirds scale four-story timber–steel hybrid structure. A broad picture of views of Swedish actors regarding the use of wood products in multi-story residential buildings was provided, and measures for an increased use were suggested by Markström et al. [13]. Wijnants et al. [14] assessed the potential environmental impact reduction of light-weight wooden frame constructions for rooftop extensions. Ahmed and Arocho [15] investigated the existing awareness level of timber building material in the U.S. construction industry, construction-related challenges, and recommendations to increase its current acceptance level. The structural health of timber structures was monitored in different research works [16–19]. It was recognized that monitoring may help prevent damages, and the most important parameters to be monitored are the moisture content of wood, indoor and outdoor climate, deformations, displacements, cracks, delamination, and pre-stressing forces. The results of a lateral performance study on a glued-laminated timber frame infilled with cross-laminated timber shear walls by means of an experimental method were presented by Xue et al. [20]. Thermal and acoustic properties of materials for timber building construction were studied by Caniato et al. [21]. The performance of cross-laminated timber and reinforced concrete walls in a multi-story building was assessed by Bahrami et al. [22]. A comparative study on cross-laminated timber and reinforced concrete floors was conducted by Bahrami et al. [23] with regard to their load-bearing properties. Kuai et al. [24] examined non-linear deformation behaviors in light-framed timber walls. Caniato et al. [25] evaluated designers' expectations of conventional and green timber buildings. Quantifying robustness in tall timber buildings was presented by Voulpiotis et al. [26]. A novel punctually supported timber building system for multi-story construction was structurally developed by Krtschil et al. [27]. Ahn et al. [28] studied the circular economy in mass timber construction. Ma at al. [29] provided insights on how the in-plane rigidity of ceiling diaphragms could affect the overall seismic performance of gypsum-plasterboard-braced light timber-framed buildings. Abdoli et al. [30] investigated the effects of the fastener type, end distance, layer arrangement, and panel strength direction on the lateral resistance of nailed and screwed single shear lap joints in cross-laminated timber panels.

The construction companies are still reluctant to consider wood as a mainstream building material for construction of multi-story buildings using wooden frames. There are limited studies in the literature focusing on different factors influencing the choice of wooden frames for construction of multi-story buildings in Sweden, which is the knowledge

gap in identification of the factors. However, to help solve this problem, this issue is the focus of the current research, which signifies its importance to demonstrate the significant contributing and hindering factors in the progress of using wooden frames in multi-story buildings by the construction industry. This research is carried out utilizing a descriptive survey study with a qualitative and quantitative approach. The research questions are as follows:

- How do construction companies give reasons about the choice to choose or not to choose a wooden frame for construction of multi-story buildings?
- What are the influencing factors on this choice?
- Do the construction companies consider that experience and competence in wooden frames are in short supply in Sweden?

Responses of representatives from five leading building companies in Sweden based on the companies' revenue are presented and discussed. The respondents with either previous experience in constructing multi-story buildings with wooden frames, experienced respondents (ERs), or those with no experience, unexperienced respondents (UERs), are taken into consideration.

2. Method

The adopted method for the current research is explained herein.

2.1. Design

This research was conducted based on a descriptive survey study with a qualitative and quantitative approach. The survey questions were formulated carefully and clearly with a focus on open-ended questions as well as some quantitative yes/no questions. At the beginning of the survey, the respondents were asked to answer demographic questions about their background information with a concluding question if they have experience in constructing multi-story buildings with wooden frames. Depending on whether the answer was yes or no to the question of having experience, the respondents were sent to different sections of the questionnaire where the questions were adapted to the experience for the ERs or lack of experience for the UERs. A majority of the survey questions were about how the respondents choose frame material, what factors are taken into account in the decision, what advantages and disadvantages they see with wooden frames, and how they look at the competence and experience in wooden frames in Sweden.

In the section for the ERs, questions were also asked about what challenges they encountered in the projects, whether their attitude toward wooden frames for construction of multi-story buildings has changed after the project was completed, and what obstacles they have seen in the increased construction with wooden frames in Sweden.

In the section for the UERs, questions were asked, for example, if they have considered constructing multi-story buildings with wooden frames, what would be required for them in order to do so, and also if they think that there is good information about wooden frames from industry organizations such as Swedish Wood.

2.2. Participants

A strategic selection of respondents was made. The companies were chosen based on those that had the largest turnover on the market in 2019. The study focused on the five largest companies according to the list of [31]. Respondents were selected from these companies with the insight into the design process. Respondents were sought from all over Sweden within the companies, and the request for the participation was sent by e-mail to 74 people at these companies, of which 19 people responded to the survey.

We chose to focus on the construction companies with the largest turnover in Sweden. This is based on the idea that they influence the Swedish market and the choice of frame material to the greatest extent. Since more sawmills and wood industries are to be found in the northern part of the country, opinions on wooden frames in multi-story buildings may vary. Opinions may vary due to possible differences in material availability and costs.

We chose participants for the study who work in different parts of the country to have a large geographical spread, which could possibly show differences in the attitude toward wooden frames in multi-story buildings.

2.3. Implementation

The sent e-mail to the participants had a request that either they themselves participate in the study or recommend someone else at their company. Upon the acceptance of the participation, the questionnaire was sent to the respondents via e-mail, which contained an information letter about the study and a link that led to the questionnaire. The letter included the information about anonymity, willingness to participate in the study, estimated time to respond to the questionnaire, and deadline for their submission. The survey was available to the respondents digitally for two weeks, and they could send in new answers if they wanted. The forms were created through a Google form, and all collected data were saved electronically. The survey questions are presented in Appendix A. The results of the survey were compiled in a Google form and analyzed statistically in Microsoft Excel. All the mean values in the results are reported as mean ± standard deviation. The results are reported in the text and figures and as descriptive statistics in the following section.

3. Results and Discussion

The 19 respondents to the survey were geographically spread over large parts of Sweden from the north to the south. The selected companies were represented with two to five respondents. The respondents' experience in the building industry varied between 4 to 35 years, with a mean value of 20 years (±9 years). The standard deviation (±9 years) is a measure of how much the different values from the respondents' experience in the industry deviate from the mean. Most of the respondents had an educational background with a master's degree in engineering (42%) or a bachelor's degree in engineering (32%). Other educations that were represented were, for instance, high school education and a master's degree in biology. A majority of the respondents held managerial positions at the companies, such as technical manager, project manager, group manager, regional manager, and department manager. Other positions that were represented among the respondents included project leader, design leader, specialist purchaser, and business analyst.

Working tasks conducted by the respondents were mainly project development of housing, but there were a variety of services among the respondents, for example, contracting activities in buildings and civil engineering, consulting for self-developed residential projects, management of the work in technology and sustainability, and project management. Twelve respondents (63.2%) were ERs, while seven respondents (36.8%) were UERs.

3.1. Results from ERs

Most of the respondents indicated that they choose frame material individually for each project. They thus did not work with standardized solutions but adapted the frame to the project's conditions. Several respondents stated that the choice of frame is often made before the contractors are involved in the project. If, on the other hand, you are involved in the project early or you yourself are a client, you have more options. One respondent answered that the workflow of the frame choice varies, while another declared that they always construct with wooden frames. When asked why the respondents choose wood as the frame material in their projects instead of other frame materials, they responded as presented in Figure 1. 58% of the respondents answered that it is because of the sustainability and environmental aspects. One respondent claimed that a great environmental focus is fundamental, and wood is an environmentally superior material. However, 33% of them believed that wood is chosen as the frame material due to the requirements of clients which cannot be affected. Political decisions (8%) and production advantages (8%) were also reasons given by the respondents.

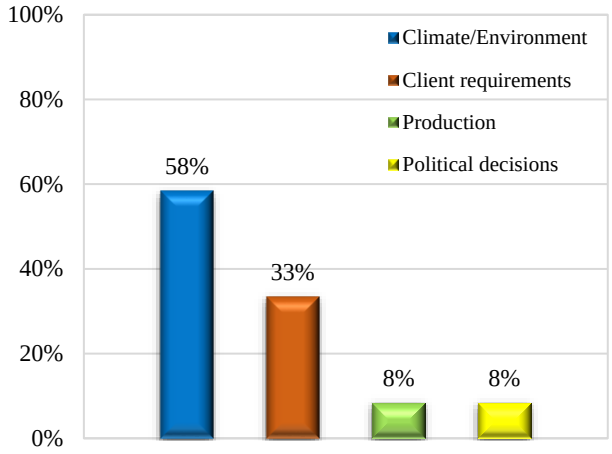

Figure 1. Reasons of ERs for constructing with wooden frames.

All the respondents considered themselves to some extent to be able to influence clients' decisions. Two respondents believed that they could influence clients if they were involved in projects at an early stage but pointed out that the clients always make the final decision. One respondent believed that it can be difficult to influence the client if the client does not bring the idea of a wooden structure into the project. The respondent also said that multi-story buildings with wooden frames are about 10% more expensive in total construction costs than traditional concrete frames, which makes them more difficult to sell.

The advantages that the respondents considered to be crucial in choosing wood as the frame material are reported in Figure 2. 58% of the respondents claimed that wood has production advantages, and one of them said that they construct with wood for a learning perspective. One respondent, however, referred to the fact that political decisions have influenced their choice of frame. 58% of the respondents considered that the climate or environmental benefits and the low climate impact were crucial advantages of choosing wood as the frame material. Other advantages that the respondents mentioned were time and production advantages, such as that wood is an easy-to-work material with low weight, and the frame erection is fast. Two respondents (17%) thought that prestige or profiling was an advantage when one constructs with wooden frames. By profiling, one respondent meant that the builder is profiled as a climate-smart industry player, which is seen as an advantage. Other advantages were good indoor environment (8%) and good working environment (8%).

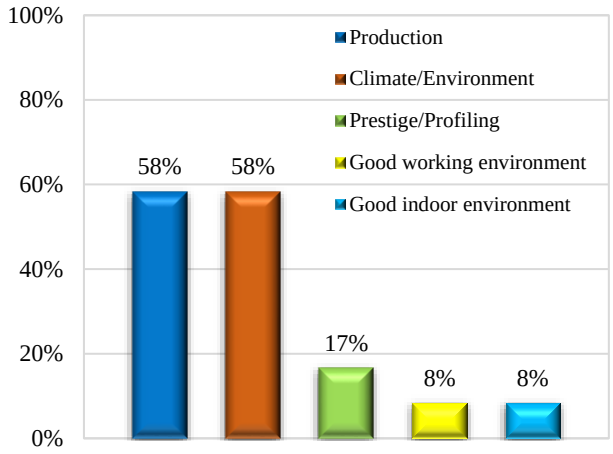

Figure 2. Advantages influencing decision of ERs to choose wooden frames.

The respondents not only considered the advantages of constructing with wooden frames but believed that there are also certain disadvantages which should be taken into account. Figure 3 shows the proportion of respondents' answers regarding the disadvantages. The respondents highlighted moisture (50%), cost (42%), acoustics (33%), stability (33%), wood volume (17%), and fire safety (8%) as disadvantages of wooden building projects.

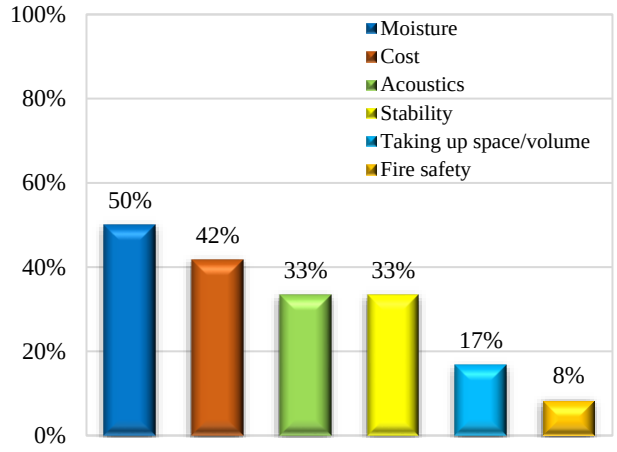

Figure 3. Disadvantages of constructing with wooden frames considered by ERs.

The obtained results from the asked question regarding the biggest obstacles against the increasing use of wooden frames for construction of multi-story buildings are illustrated in Figure 4. 75% of the respondents answered that the cost is the biggest obstacle. Four respondents (33%) considered moisture-related problems to be a major obstacle, however, one of them (8%) also mentioned acoustics as an obstacle. Other obstacles that the respondents believed were present were competence (17%), uncertainty about solutions (17%), culture or tradition (8%), concerns about working life (8%), wood volume (8%), and shorter spans (8%).

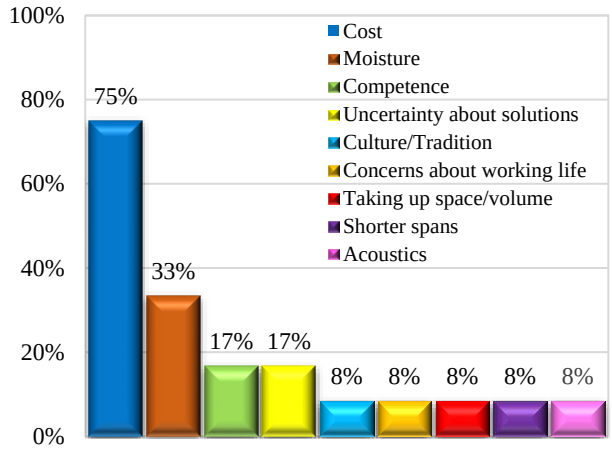

Figure 4. Biggest obstacles against increasing use of wooden frames considered by ERs.

Finally, the respondents were asked to evaluate some factors based on how much they influenced their decision to choose wooden frames in projects. The respondents were given a value of 1–5 on the various factors, where 5 corresponded to the greatest impact. Figure 5 displays the mean values of how the respondents valued these factors. The results demonstrated that the environmental impact has affected the respondents' decisions most, with an average value of 4 and standard deviation of ±1.3, followed by shorter construction time 3.3 (±1.4), time expenditure 3.3 (±1.3), political pressure 3.3 (±1.5), and economy 2.8 (±1.4).

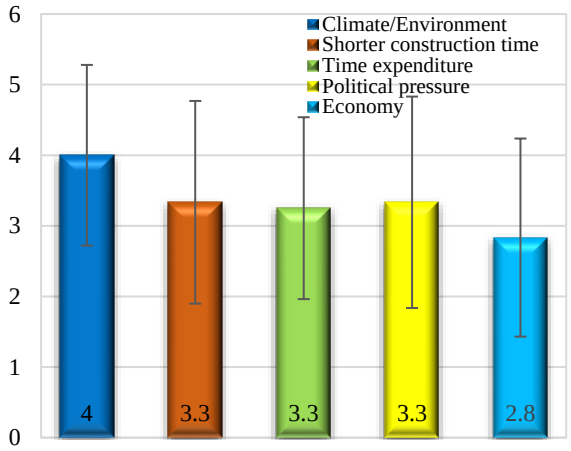

Figure 5. Ranking of influencing factors on decision of ERs to choose wooden frames.

3.2. Results from UERs

All these respondents answered that they have established frame solutions or systems which they use in their projects. Most of their building systems consisted of concrete frames. Advantages that the respondents took into consideration for wooden frames are depicted in Figure 6. Most of the respondents (71%) pointed out climatic or environmental benefits of wood as a frame material. However, one respondent stated that there are some views on whether wood is a more climate-smart material compared with other materials. 71% of the respondents mentioned production advantages, while 43% of them saw the light weight of the wooden frame as an advantage. One respondent thought that the light weight could reduce the cost of foundations.

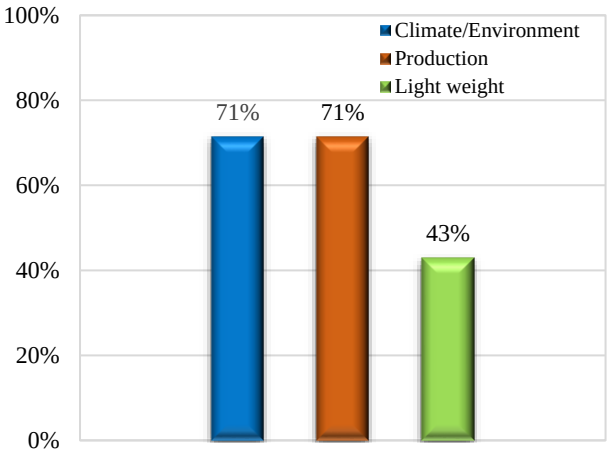

Figure 6. Advantages of constructing with wooden frames considered by UERs.

Figure 7 indicates the disadvantages of constructing with wooden frames considered by the UERs. Sound insulation and moisture sensitivity were noticed as major disadvantages by 86% and 71% of the respondents, respectively. One respondent explained that extra measures were required to ensure the sound requirements. Another respondent claimed that it was difficult to protect the material from moisture during the construction period. The same respondent mentioned that there was limited experience (14%) of wood as a frame material, which was considered as a problem. In addition, 29% of the respondents said that wood construction can have negative climate and environmental impacts, as they considered that today's forestry is not sustainable and leads to reduced biological diversity and large emissions. One of these respondents mentioned that if it is to be constructed with wood, the material must come from sustainable forestry. Furthermore, 43% of the respondents indicated that the fire risk must be evaluated, and the fire requirements become more

complicated to solve in a building with a wooden frame. Stability problems were addressed by 29% of the respondents. One of these respondents described that the frame stability deteriorates compared with concrete. This was clarified by another respondent who said that buildings may be too light with a wooden frame and that extra weight may need to be added. Additionally, 14% of the respondents stated that the buildings' maintenance during their life cycle constitutes an increased cost.

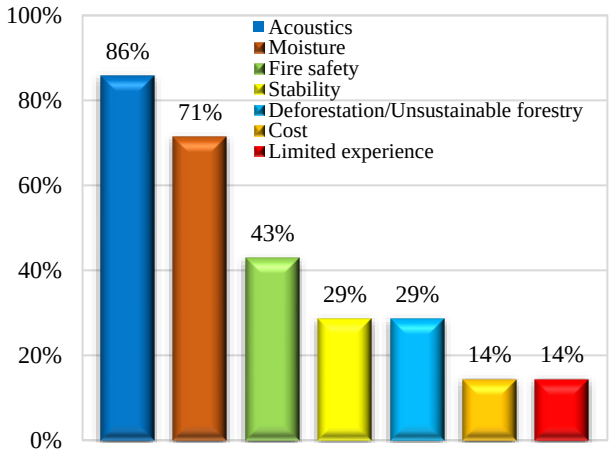

Figure 7. Disadvantages of constructing with wooden frames considered by UERs.

The UERs were finally asked to evaluate six different factors based on how much influence they had on their decision not to construct with wooden frames. The respondents had to give a value from 1–6 on the various factors, where 6 corresponded to the greatest impact. Figure 8 presents the mean values of how the respondents ranked these factors. The results showed that moisture problems and experience or lack of competence were the factors that affected the respondents the most, both with the mean value of 4, but with the standard deviations of ±2.3 and ±1.7, respectively. Other factors were economy, sound insulation, stability or durability, and fire safety, with the mean values of 3.7, 3.7, 2.9, and 2.1, respectively, however, their standard deviations were ±2.0, ±1.3, ±1.6, and ±1.1, respectively.

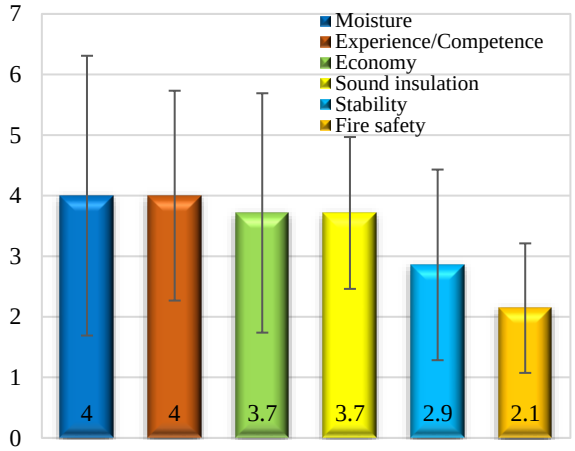

Figure 8. Ranking of influencing factors on decision of UERs not to choose wooden frames.

3.3. Comparisons of Results from ERs and UERs

In this section, results from the ERs and UERs are compared and discussed. The comparison of the advantages of using wooden frames stated by the ERs and UERs is reported in Figure 9. As can be seen from the figure, production (63%) and climate or environment (63%) constituted the greatest advantages of using wooden frames. The

remaining advantages were the light weight of wood (16%), prestige or profiling (11%), good working environment (5%), and good indoor environment (5%).

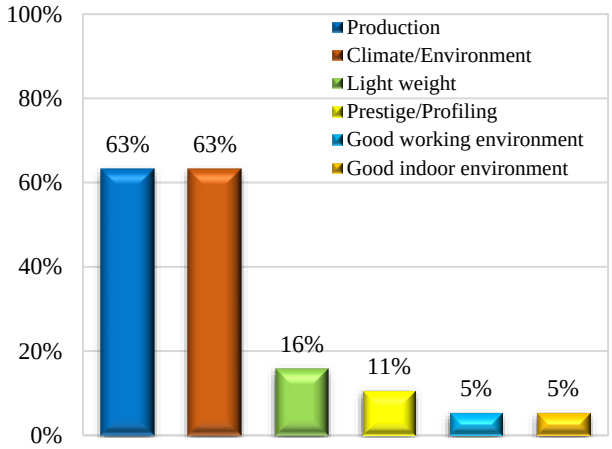

Figure 9. Comparison of advantages of constructing with wooden frames considered by ERs and UERs.

Figure 10 compares the disadvantages of constructing with wooden frames considered by the ERs and UERs. The figure illustrates that moisture problems (58%) were the biggest disadvantage. Other disadvantages were acoustics (53%), cost (32%), stability (32%), fire safety (21%), deforestation (11%), volume (11%), and limited experience (5%).

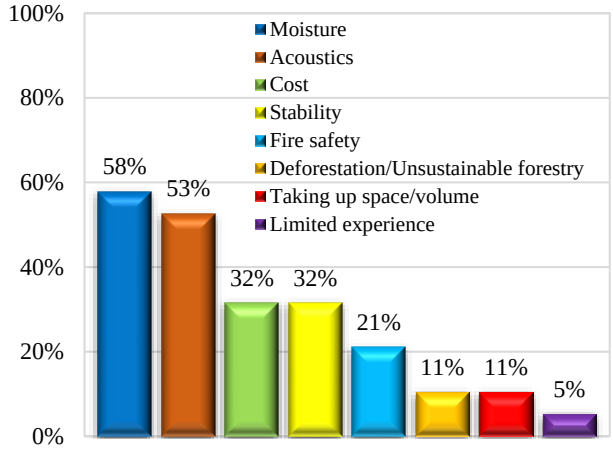

Figure 10. Comparison of disadvantages of constructing with wooden frames considered by ERs and UERs.

Half of the ERs (50%) believed that higher competence and more experience are required for wood compared with, for instance, concrete. However, 29% of the UERs stated that higher competence and more experience were necessary, whilst 57% of the UERs had an opposite idea about this issue. One of the UERs did not consider himself to know whether they were required or not. The comparison of the combined results from the ERs and UERs is displayed in Figure 11. It can be witnessed from the figure that 53% of all the respondents felt higher competence and more experience were not required, while 42% of the respondents thought the opposite.

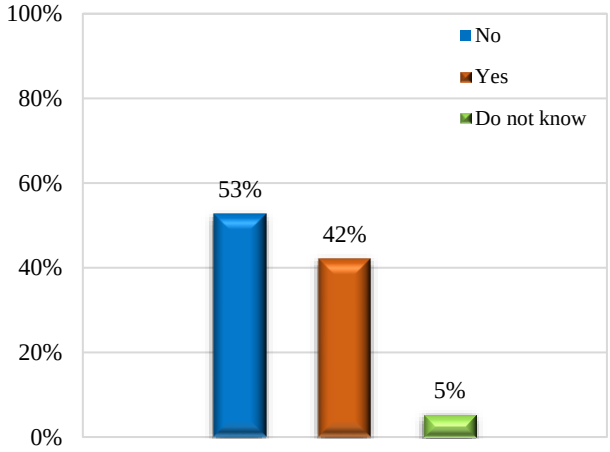

Figure 11. Comparison of combined results regarding necessity of higher competence and more experience in wooden frames considered by ERs and UERs.

When the ERs were asked if they think that there is a shortage of competence in wooden frames in multi-story buildings, 67% of them had a positive answer, 25% had a negative answer, and 8% had no idea about it. However, 57% and 43% of the UERs answered positively and negatively to the same question, respectively. Figure 12 depicts the compared combined results from the ERs and UERs, which clearly demonstrates their positive and negative answers to this question which were 63% and 32%, respectively.

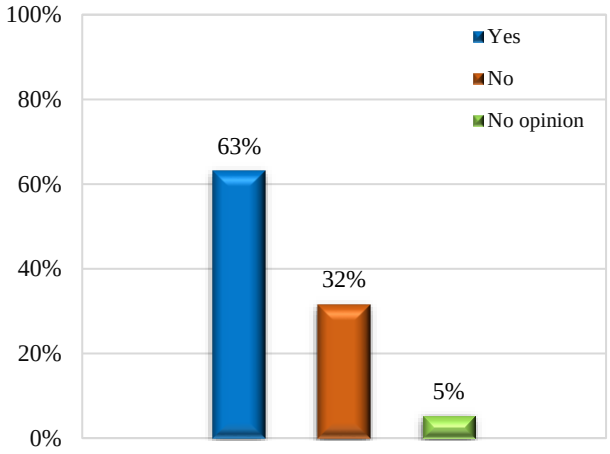

Figure 12. Comparison of combined results regarding shortage of competence in wooden frames considered by ERs and UERs.

Finally, the ERs and UERs were asked if they felt that newly graduated engineers possessed knowledge in wood construction or if they felt that it was lacking in their education: 36% of the ERs answered as missing, 9% not missing, and 64% had no opinion. However, 86% of the UERs answered that they had no opinion about it. The combined results regarding lack of knowledge of newly graduated engineers in wood construction are compared in Figure 13.

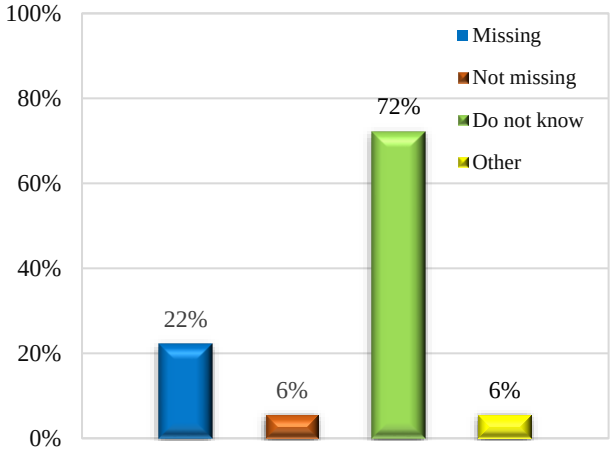

Figure 13. Comparison of combined results regarding lack of wood construction knowledge of newly graduated engineers considered by ERs and UERs.

In some cases, opinions differed between the ERs and UERs. This might be because projects with wooden frames in multi-story buildings are complex and that the experience thus has a major impact on the possibility to see advantages and disadvantages as well as to understand and manage challenges.

4. Conclusions

The factors which can influence the choice of wooden frames for construction of multi-story buildings in Sweden were investigated in this research using a descriptive survey study with a qualitative and quantitative approach. Generally, the results showed that climate or environment, production advantages, cost, moisture, and acoustics were factors that had major impacts on the choice of the frame material according to the respondents. Other factors that influenced the choice of the frame material were whether the client had specific requirements, or the contractor had established solutions for this choice. Most of the respondents considered that there is a lack of competence in the construction of multi-story buildings using wooden frames in Sweden. A crucial factor for this can be because of the absence of in-depth teaching in wood construction in engineering education programs. The positive factors that most of the respondents considered to be vital for the choice of wooden frames were their low climate footprint and the production advantages. The ERs considered the cost as a significant factor that hinders the increased construction with wooden frames. The UERs, on the other hand, considered that the main disadvantages were the acoustics and moisture problems. Multi-story buildings with wooden frames are not being constructed today to the same extent as multi-story buildings with concrete. This may be due to the fact that multi-story buildings with wooden frames are a relatively new concept, and more research and knowledge are required for constructors and practitioners. The outcomes of this research will be helpful for the industry practitioners, companies, and building owners to adopt wood as a mainstream building material. The study will also enhance the acceptance of constructing multi-story buildings using wooden frames in the Swedish construction industry.

Author Contributions: Conceptualization, A.B., J.J. and T.S.; methodology, A.B., J.J. and T.S.; validation, A.B., J.J. and T.S.; formal analysis, A.B., J.J. and T.S.; investigation, A.B., J.J. and T.S.; resources, A.B.; writing—original draft preparation, A.B.; writing—review and editing, A.B.; project administration, A.B. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Survey questions

Background questions

Valid e-mail address:

- What company do you work for?
- What education do you have?
- How long have you worked in the construction industry?
- What position do you have at the company?
- What tasks or services does your company perform?
- In which region do you work?
- How many employees are there at your workplace?
- Do you have previous experience in constructing multi-story buildings with a wooden frame?
    - Yes (Forwarded to the section—Have constructed multi-story buildings with a wooden frame).
    - No (Forwarded to the section—Have not constructed multi-story buildings with a wooden frame).

A. Have constructed multi-story buildings with a wooden frame

1. Why did you choose wooden frame in the project(s) instead of other frame materials? Was the reason due to environmental concerns, economic advantage, political decisions, or something else entirely?
2. What advantages of wooden frames in multi-story buildings do you consider to be influencing when choosing a frame?
3. Please tell us a little about how you plan a new project. Are decisions about frames made individually for each new project or do you have an established solution regarding the choice of frame materials?
4. According to Statistics Sweden, approximately 20% of the multi-story apartment buildings today are produced with a wooden frame and approximately 80% with a concrete frame. What does the distribution look like for you and what does it depend on?
5. Do you consider that you have the opportunity to influence the client's decision regarding the choice of frame?
6. What types of challenges did you experience in the project(s)?
7. Do you feel that a higher level of competence and more experience are required for a wooden construction project compared with any other frame materials, for example, concrete?
8. Do you think that competence and experience in wood as a frame material in multi-story buildings is in short supply in Sweden? Please elaborate on your answer.
9. What do you think is the biggest obstacle to increased construction with wooden frames in multi-story buildings in Sweden?
10. What disadvantages do you see with wood as a frame material in multi-story buildings?
11. How has your attitude toward wood-framed building changed after completing such a project?
12. Do you plan to expand the production of multi-story buildings with wooden frames? Please explain why you will or not increase the production of multi-story buildings with wooden frames.
13. Do you feel that newly graduated engineers have knowledge in wood construction technology, or do you feel that wood construction technology is missing from their education?
14. Rank the factors below based on how much influence they had on your decision to build with a wooden frame? Rank 1–5, with 5 having the greatest impact.
    - Environmental impact
    - Time expenditure

- Shorter construction time
- Political pressures
- Economy

B. Have not constructed a multi-story house with a wooden frame

1. Please tell us a little about how you plan a new project. Are decisions about frames made individually for each new project or do you have an established solution regarding the choice of frame materials?
2. Do you consider that you have the opportunity to influence the client's decision regarding the choice of frame?
3. Have you considered constructing multi-story buildings with wooden frames? If no, what is the reason? If yes, why was another option chosen?
4. Do you feel that a higher level of competence and more experience are required for a wooden construction project compared with any other frame materials, for example, concrete?
5. Do you think that competence and experience in wood as a frame material in multi-story buildings is in short supply in Sweden? Please elaborate on your answer.
6. Do you think that there is good information available about wood as a frame material from industry organizations such as Swedish Wood?
7. What advantages do you see with wood as a frame material in multi-story buildings?
8. What disadvantages do you see with wood as a frame material in multi-story buildings?
9. What would be required for wood as a frame material in multi-story buildings to become relevant for you?
10. Do you feel that newly graduated engineers have knowledge in wood construction technology, or do you feel that wood construction technology is missing from their education?
11. Rank the factors below based on how much influence they had on your decision not to build with a wooden frame? Rank 1–6, where 6 is the factor that influenced the most.

    - Fire safety
    - Sound insulation
    - Experience/competence in wooden frames
    - Moisture problems
    - Stability/durability
    - Economy

Closing question (to all respondents)
Is there anything you would like to add that you think it is important for the study?

References

1. Statistics Sweden (SCB). Apartments in Newly Constructed Multi-Story Residential Buildings Based on Materials in the Frame, Year 1995–2019. 2020. Available online: https://www.statistikdatabasen.scb.se/pxweb/sv/ssd/START__BO__BO0201__BO0201M/MaterialiStommeFN/ (accessed on 13 April 2021). (In Swedish)
2. Hultquist, H.; Karlsson, B. *Evaluation of a Fire Risk Index Method for Multistorey Apartment Buildings*; Department of Fire Safety Engineering and Systems Safety, Lund University: Lund, Sweden, 2000; Volume 3088.
3. Stehn, L.; Bergström, M. Integrated design and production of multi-storey timber frame houses-production effects caused by customer-oriented design. *Int. J. Prod. Econ.* **2002**, *77*, 259–269. [CrossRef]
4. Gustavsson, L.; Joelsson, A.; Sathre, R. Life cycle primary energy use and carbon emission of an eight-storey wood-framed apartment building. *Energy Build.* **2010**, *42*, 230–242. [CrossRef]
5. Tykkä, S.; McCluskey, D.; Nord, T.; Ollonqvist, P.; Hugosson, M.; Roos, A.; Ukrainski, K.; Nyrud, A.; Bajric, F. Development of timber framed firms in the construction sector—Is EU policy one source of their innovation? *For. Policy Econ.* **2010**, *12*, 199–206. [CrossRef]
6. Hemström, K.; Mahapatraa, K.; Gustavssona, L. Perceptions, attitudes and interest of Swedish architects towards the use of wood frames in multi-storey buildings, Resources. *Conserv. Recycl.* **2011**, *55*, 1013–1021. [CrossRef]
7. Mahapatra, K.; Gustavsson, L.; Hemström, K. Multi-storey wood-frame buildings in Germany, Sweden and the UK. *Constr. Innov.* **2012**, *12*, 62–85. [CrossRef]

8. Dodoo, A.; Gustavsson, L.; Sathre, R. Lifecycle primary energy analysis of low-energy timber building systems for multi-storey residential buildings. *Energy Build.* **2014**, *81*, 84–97. [CrossRef]
9. Ferri, D.; Lam, S. *Multi-Storey Houses in Timber: Stability and Anchoring Systems*; Chalmers University of Technology: Gothenburg, Sweden, 2015.
10. Hurmekoski, E.; Jonsson, R.; Nord, T. Context, drivers, and future potential for wood-frame multi-story construction in Europe. *Technol. Forecast. Soc. Chang.* **2015**, *99*, 181–196. [CrossRef]
11. Markström, E.; Kuzman, M.; Bystedt, A.; Sandberg, D.; Fredriksson, M. Swedish architects view of engineered wood products in buildings. *J. Clean. Prod.* **2018**, *181*, 33–41. [CrossRef]
12. He, M.; Luo, Q.; Li, Z.; Dong, H.; Li, M. Seismic performance evaluation of timber-steel hybrid structure through large-scale shaking table tests. *Eng. Struct.* **2018**, *175*, 483–500. [CrossRef]
13. Markström, E.; Kuzman, M.; Bystedt, A.; Sandberg, D. Use of wood products in multi-storey residential buildings: Views of Swedish actors and suggested measures for an increased use. *Wood Mater. Sci. Eng.* **2019**, *14*, 404–419. [CrossRef]
14. Wijnants, L.; Allacker, K.; De Troyer, F. Life-cycle assessment of timber frame constructions—The case of rooftop extensions. *J. Clean. Prod.* **2019**, *216*, 333–345. [CrossRef]
15. Ahmed, S.; Arocho, I. Mass timber building material in the U.S. construction industry: Determining the existing awareness level, construction-related challenges, and recommendations to increase its current acceptance level. *Clean. Eng. Technol.* **2020**, *1*, 100007. [CrossRef]
16. Palma, P.; Steiger, R. Structural health monitoring of timber structures—Review of available methods and case studies. *Constr. Build. Mater.* **2020**, *248*, 118528. [CrossRef]
17. Baas, E.; Riggio, M.; Barbosa, A. A methodological approach for structural health monitoring of mass-timber buildings under construction. *Constr. Build. Mater.* **2021**, *268*, 121153. [CrossRef]
18. Baas, E.; Riggio, M.; Barbosa, A. Structural health monitoring data collected during construction of a mass-timber building with a data platform for analysis. *Data Brief* **2021**, *35*, 106845. [CrossRef] [PubMed]
19. Riggio, M.; Mrissa, M.; Krész, M.; Včelák, J.; Sandak, J.; Sandak, A. Leveraging structural health monitoring data through avatars to extend the service life of mass timber buildings. *Front. Built Environ.* **2022**, *8*, 887593. [CrossRef]
20. Xue, J.; Ren, G.; Qi, L.; Wu, C.; Yuan, Z. Experimental study on lateral performance of glued-laminated timber frame infilled with cross-laminated timber shear walls. *Eng. Struct.* **2021**, *239*, 112354. [CrossRef]
21. Caniato, M.; Marzi, A.; da Silva, S.M.; Gasparella, A. A review of the thermal and acoustic properties of materials for timber building construction. *J. Build. Eng.* **2021**, *43*, 103066. [CrossRef]
22. Bahrami, A.; Nexén, O.; Jonsson, J. Comparing performance of cross-laminated timber and reinforced concrete walls. *Int. J. Appl. Mech. Eng.* **2021**, *26*, 28–43. [CrossRef]
23. Bahrami, A.; Vall, A.; Khalaf, A. Comparison of cross-laminated timber and reinforced concrete floors with regard to load-bearing properties. *Civ. Eng. Archit.* **2021**, *9*, 1395–1408. [CrossRef]
24. Kuai, L.; Ormarsson, S.; Vessby, J.; Maharjan, R. A numerical and experimental investigation of non-linear deformation behaviours in light-frame timber walls. *Eng. Struct.* **2022**, *252*, 113599. [CrossRef]
25. Caniato, M.; Marzi, A.; Bettarello, F.; Gasparella, A. Designers' expectations of buildings physics performances related to green timber buildings. *Energy Build.* **2022**, *276*, 112525. [CrossRef]
26. Voulpiotis, K.; Schär, S.; Frangi, A. Quantifying robustness in tall timber buildings: A case study. *Eng. Struct.* **2022**, *265*, 114427. [CrossRef]
27. Krtschil, A.; Orozco, L.; Bechert, S.; Wagner, H.J.; Amtsberg, F.; Chen, T.-Y.; Shah, A.; Menges, A.; Knippers, J. Structural development of a novel punctually supported timber building system for multi-storey construction. *J. Build. Eng.* **2022**, *58*, 104972. [CrossRef]
28. Ahn, N.; Dodoo, A.; Riggio, M.; Muszynski, L.; Schimleck, L.; Puettmann, M. Circular economy in mass timber construction: State-of-the-art, gaps and pressing research needs. *J. Build. Eng.* **2022**, *53*, 104562. [CrossRef]
29. Ma, Z.; Li, M.; Liu, A.; Wang, J.; Zhou, L.; Dong, W. Seismic performance of single-storey light timber-framed buildings braced by gypsum plasterboards considering rigidity of ceiling diaphragms. *Structures* **2022**, *41*, 1207–1219. [CrossRef]
30. Abdoli, F.; Rashidi, M.; Rostampour-Haftkhani, A.; Layeghi, M.; Ebrahimi, G. Effects of fastener type, end distance, layer arrangement, and panel strength direction on lateral resistance of single shear lap joints in cross-laminated timber (CLT). *Case Stud. Constr. Mater.* **2023**, *18*, e01727. [CrossRef]
31. Building Companies. 30 Largest Building Companies by Turnover in Sweden. 2020. Available online: https://byggforetagen.se/app/uploads/2020/11/30-St%C3%B6rsta-2019-1.pdf (accessed on 13 April 2021). (In Swedish)