ATTITUDES TOWARDS USING WOOD IN THE DANISH BUILDING SECTOR

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The Danish political strategy aims to reduce 70 % CO2 emissions by 2030. One way to achieve this goal is by choosing alternative building materials, particularly by using more wood in buildings. Research shows that wood is still not used broadly in the Danish building sector, compared to neighbouring countries, due to design traditions, legislation barriers, and lack of experiences and solutions. Thus, this study investigates the Danish construction sector's current status and attitudes towards using wood in buildings, identifying the perceived barriers and benefits. A nationwide survey was collected from 155 respondents, including engineers, architects, municipalities, and professional building owners. The results indicate that actors have a positive mindset towards using wood and recognize its benefits, revealing that 15 % of actors use wood frequently in their projects, and 52 % are interested in this transition. However, numerous technical aspects must be solved, e.g., risk of fire and moisture. Building owners are the most prominent influencers to promote using wood and are responsible for progressing broader sustainability goals. Furthermore, a knowledge gap among designers was detected.

Keywords: wood; buildings; sustainability; attitudes

INTRODUCTION

Denmark aims to reduce 70 % CO2 emissions from buildings by 2030. One way to achieve this goal is by choosing sustainable resources and energy-efficient building materials by promote using more wood in buildings. Accordingly, the Danish building regulations are currently regulated by including a new sustainability building class to promote sustainability in buildings, ready in summer 2022 (The Danish Housing and Planning Agency, 2020). A recent national strategy for sustainable construction calls for using more wood in construction (Danish Ministry of housing, 2021). Wood is an environmentally friendly material and a renewable resource that provides neither waste nor pollution (Danmarks træportal, 2021). In new construction, wood is a substitution of materials produced under greater CO2 emissions (Rasmussen *et al.,* 2020), contributing to an improved indoor climate quality (Institute, 2021). It is a necessary structural material in modern construction, offering the potential for cost-efficient and high-quality, sustainable construction

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(Harris and van de Kuilen, 2016). In Europe, a growing interest in wooden construction as a sustainable building solution calls for strengthening the positive image of wood. There are plenty of forests in the Nordic region, and wood has always been the dominant material for low-rise construction (Martin Einfeldt, 2020). In Denmark, 8 % of the buildings are constructed from wood. Assuming that it is possible to convert 10% of the buildings each year to construction with a high proportion of wood, buildings will contribute to the sustainability transition by saving 1.2 million tons of CO2 from 2020 to 2030. It corresponds to an increase in the net climate impact of 22 thousand tons of CO2 per year, corresponding to building 631 more wooden buildings with a high proportion of wood instead of conventional construction (Rasmussen *et al.,* 2020). There is a boom in multi-story wood construction (MWC) in Europe, but not yet in Denmark as we are behind other countries. The Danish construction sector has had a tradition of bypassing wood, giving uncertainty and misunderstandings about methods, fire protection, legislation, and economic aspects of wood construction. Also, in countries with as little forest area and wood tradition as Denmark, such as UK and Netherlands, huge wooden houses have been built (Martin Einfeldt, 2020). Thus, this study investigates actors' attitudes towards using wood in Danish construction, exploring the current national status and pointing out factors that impact actors' decisions, aiming to increase the proportion of wood in construction by highlighting wood benefits and tackling challenges.

LITERATURE REVIEW

Wood is an attractive material with a low carbon footprint; each cubic meter of wood binds one ton of CO2. It uses less energy and water and is 100% renewable from sustainably managed forests. In construction, wood is highly flexible, light, and robust. It is well-suited for prefabrication and can significantly reduce construction time. When well-engineered, wood constructions are perfectly fire-safe (Danish Technological Institute, 2021). Life Cycle Assessment (LCA) research in Norway and Sweden compares the environmental impacts of substitution between wood and alternative materials, confirms that wood is a better alternative material regarding CO2 emissions (Petersen and Solberg, 2005). Climate impact data from LCAs were presented for 60 Danish buildings with various construction and building materials, shows that buildings with wooden loadbearing structures have the lowest climate impact (Zimmermann et al.,2020). The ecological and environmental benefits of wood constructions are indisputable, providing healthy housing (Švajlenka and Kozlovská, 2020). A Danish case study of 40 hybrid timber construction apartments provides a vision of what sustainable social housing can look like, has 70% lower CO2 emissions and 28% lower life cycle costs than buildings with traditional materials (Craig, 2021).

Wood must be a natural choice of building material for multi-story construction (Danish Technological Institute, 2021). Finland, Sweden, and Norway work proactively with wood in more extensive structures and focus on developing solutions but still lack knowledge in MWC (Rasmussen *et al.,* 2020). There are sufficient wood resources to increase the use of wood substantially, but several factors hinder this. An analysis of wood substitution is a complex issue since the substitution influencing factors are found along the entire wood supply chain and involve several industries, socio-economic and cultural aspects, traditions, price dynamics, structural and technical change (Gustavsson *et al.,* 2006). Enhancing wood in construction requires strengthening its orchestration of partner networks and capabilities (Toppinen *et al.,*

2018). The wood's aesthetic appearance in buildings is appreciated most by frugal and responsible consumers, whereas comfort, environmental friendliness, and longevity are important to consumers (Kylkilahti *et al.,* 2020). A study shows that most building owners believe that wood buildings, compared to concrete and steel buildings, are more aesthetically pleasing, create a positive living environment, and use materials that regrow (Larasatie *et al.,* 2018). A survey among 373 architects in Southeast European countries reveals a positive perception of using engineered wood products (EWP) in all countries. Most respondents believe that EWPs will increase in the future. Results indicate knowledge gaps between respondents and, conversely, where awareness and willingness to use EWPs exist (Kitek Kuzman *et al.,* 2018). Architects in Sweden can be good advocates for the increased use of EWP. The low environmental impact is the most common reason to select EWPs. The influence on material selection, knowledge, experiences, and architect's attitude in using EWPs affect the prospect of increased use (Markström *et al.,* 2018). Prospects for timber frame multi-story buildings in England, France, Germany, Ireland, the Netherlands, and Sweden shows that the main driving forces are environmental concerns. The potential for MWC hinges on architects, developers, and contractors' attitudes (Jónsson, 2009). The share of MWC is still limited in Denmark, lacking experience in this field (Martin Einfeldt, 2020). The most considerable potential of increased use of wood in Danish buildings is climate, environment, and economy. Building with wood is efficient regarding construction and assembly speed (Rasmussen *et al.,* 2020).

The European building sector has an achievable potential for net carbon storage of about 46 million tons CO2-eq./year in 2030. To unlock this potential, a bundle of instruments is necessary for increasing the market share for EWPs against the backdrop of existing policy instruments such as the gradual introduction of stricter rules for carbon emissions trading or more incentives for the voluntary use of innovative wood construction materials (Hildebrandt, Hagemann and Thrän, 2017). Timber engineering is vitally crucial to the sustainable development of society. However, it lacks research funding, both historically and today (Harris and van de Kuilen, 2016). In recent years, wood has rapidly developed into high-tech construction material, and the market for EWPs is rapidly grooving every year in European countries (Klarić and Obučina, 2020). The spread of wood-based constructions in the Central European region is hindered by insufficient knowledge of potential and actual users (Švajlenka and Kozlovská, 2020). In Finland, the MWC diffusion is heavily dependent on the regulatory framework and the construction industry structure. The risk-averse nature of the construction value chain resisting the uptake of new practices appears to be a more significant hindrance for the future market potential of MWC. It requires increasing competition within the MWC sector and co-operation between wood product suppliers and the construction sector to attract investments, reduce costs, and make MWC practices more credible throughout the construction value chain (Hurmekoski, Jonsson and Nord, 2015). In Norway, challenges involve a lack of developers' and constructors' knowledge and experience in MWC. Lack of local producers of wood-based construction materials and infrastructure challenges in material delivery (Danish Technological Institute, 2021). Building with wood has a slightly lower cost for acquisition, operating, and maintenance. However, the market situation and investment horizon are crucial factors (Rasmussen *et al.,* 2020). Having practical experiences with wood buildings helps professionals realize the benefits of wooden construction and deconstruction phases (Li and Xie, 2013).

Humidity affects the durability of wood, and the long-term exposure to moisture accelerates the decrease in mechanical properties and long-term strength of wood with a certain degree of deterioration in the process of exposure (Wang, Cao and Liu, 2020). The potential of a biological attack, ultraviolet light degradation, and dimensional stability in EWPs to produce a durable material requires developing technologies that resist biological and physical damage. Some technologies already exist but remain too costly (Morrell, 2017). Fire safety can be as high in timber-frame buildings as in other types of buildings when suitable construction methods are used (Karlsson, Gudnadottir and Tomasson, 2020). A Canadian study highlights wood density's influence on the percentage of wood failure and shear strength (Morin-Bernard *et al.,* 2020). In Denmark, solutions for wood load-bearing structures must be developed to support buildings up to five stories and requests examples of how wooden buildings with more than five stories can be built, focusing on acoustics and fire challenges (Danish Ministry of housing, 2021). Challenges remain in fire and height limits for wooden buildings. Individual technical assessments are needed in planning due to a lack of pre-accepted solutions, which should be addressed. On-site acoustic testing during the construction phase is required instead of acoustics simulations to meet regulations in the design phase. These factors have hindered wood construction development, as they create greater risk and costs for developers. A limited policy has been introduced to develop wood construction competencies. Teaching competencies within Danish institutions could be more vital to meet this demand and equip the next generation with wood skills and knowledge. The industry must take greater responsibilities to achieve competencies in wood construction (Craig, 2021). According to Rasmussen *et al.,* (2020), Denmark's most significant barriers are the lack of knowledge and experience in using wood as a building material and constructing wooden buildings. Challenges in fire safety, the acoustics of floor slab partitions, and moisture impregnation. In construction sites, it is challenging to protect wood materials from moisture. In the operation phase, moisture management, durability, and maintenance costs are challenging factors. Also, building regulations fire requirements hinder advisors from recommending the use of wood (2020).

METHODOLOGY

A mixed research approach was applied, including a quantitative and qualitative online survey questionnaire according to Dillman (2007), distributed to 640 organizations within the construction industry with more than ten employees specifically targeting engineers, architects, municipalities, and professional building owners, collected from 155 responses. The survey aimed to investigate the construction sector's current status and attitudes towards using wood in buildings, identifying the perceived barriers and benefits. The survey was conducted by using Microsoft forms, consisting of closed-ended questions with multiple-choice options, yes/no questions, and rating questions according to the Likert scale (Likert, 1932), along with open-ended qualitative questions to extend in-depth some of the respondents' answers, elaborating the perceived benefits, experiences, and challenges of wood construction. Colleagues tested the survey to evaluate the clarity of questions. Organizations were obtained from the Danish Central Business Register (CVR virk, 2021). The survey was available during December 2020, and a reminder mail was sent two weeks after the initial mails, where the research objectives and values were highlighted to motivate actors to respond. The results indicate the general state of organizations' attitudes towards using wood in buildings with a response rate of 24%. Based on similar studies, a response rate of 15-35% is considered adequate

for analytical purposes for surveys, considering an expected response rate in this range and a sampling error of 10% (Dillman, 2007). The questionnaire firstly includes introduction questions describing the respondent's role, organization location, and general status of implementing sustainability in building projects. Then, substantive questionnaire items follow, including the perceived benefits, experiences, attitudes, and challenges when using wood in construction.

ANALYSIS AND DISCUSSION

Responses covered the whole country with a satisfactory response rate from all targeted actors, as 23 % of responses were professional building owners, 26% architects, 28% engineers, and 23% municipalities. Respondents were asked about their status for implementing sustainability in building projects and readiness to apply building regulations new sustainability class, where 52% observe sustainable development but are not ready yet, 34% already include sustainability significantly in their projects, and 14% have no or minimal knowledge in sustainability. Results show that the actors who have a big focus on sustainability are architects, meaning that they play a significant role in promoting sustainability in buildings. However, results show that they do not always use wood in their projects despite focusing on sustainability.

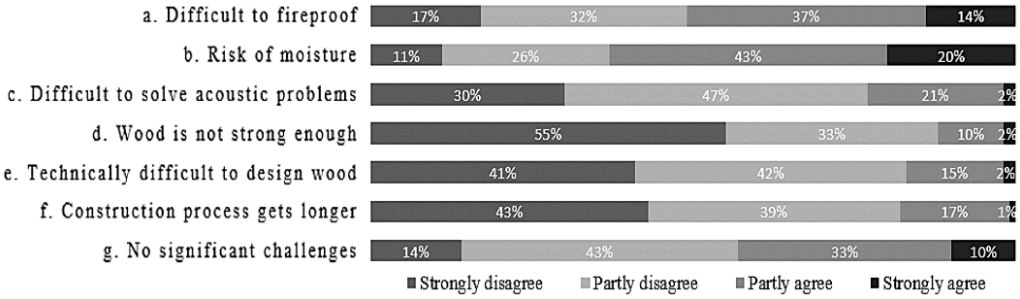
Fig 1 (a-g) illustrates challenges in wood load-bearing structures (WLBSs) Challenges in fireproofing are shown in Fig 1-a, revealing that 37% of respondents partly agree on the presence of fireproofing challenges in WLBSs, and 32% partly disagree, 14% of actors strongly agree, while 17% strongly disagree. Reflecting that despite the fire challenges, there is a possibility to solve them, but only a limited group of actors are experienced in this area. It is found that consultant engineers partly disagree on fire barriers and are more positive towards using WLBS, indicating that engineers are more experienced in finding proper fire safety solutions.

This reflects the knowledge gap among designers in fire protection strategies. According to the Danish Technological Institute (2021), wood construction is perfectly fire-safe when well-engineered. Thus, fire challenges in WLBSs can be solved by using proper solutions. Ensuring fire safety is a design prerequisite in wood construction with the necessity of integrated engineering (installations and structure) and architectural expertise. Fig 1-b refers to moisture challenges; 43% of respondents partly agree, and 20% strongly agree, indicating moisture problems in WLBS and lack of technologies and solutions to prevent moisture. Fig 1-c shows difficulties in solving acoustic challenges where 47% of responses partly disagree, and 30% strongly disagree, meaning that the building sector is positively developing in finding soundproofing solutions for WLBS and have already found suitable solutions.

Fig 1-d refers to the robustness of WLBSs, showing that 55% strongly agree that wood is a robust material and 33% partly agree, meaning that wood is perceived as a solid and robust material used in buildings' load-bearing structures. Fig 1-e shows that most actors (83%) confirm that it is technically easy to design WLBSs. Most responses (82%) in Fig 1-f show that using wood will not prolong the building process. Finally, in Fig 1-g, 44% of actors confirm challenges in WLBSs. Thus, moisture and fire are the most challenging aspects. Factors that can hinder this are the building regulations' strict fire requirements. Similarly, Rasmussen *et al.,* confirm that the most significant perceived challenges are lack of knowledge, fire safety, and building regulations fire requirements that hinder using wood, moisture impregnation, and acoustics for partition slabs (2020). However, acoustic challenges were not

highly rated by respondents in this survey. It also appears that there is a knowledge gap among designers in finding technical solutions.

Fig 1 (a-g): Respondents challenges when using wood as a load-bearing structure



Besides, other challenges were optionally defined by 43 respondents. New wood suppliers must be aware of the challenges that wood construction poses to be more effective. The stiffness of wood is less than steel and concrete, creating challenges in deformations and wood import challenges. Maintenance is a problematic and risky aspect compared to traditional buildings. Building owners must accept that wood construction requires more maintenance as the influence of moisture and temperature in both construction and operation phases is challenging. It is revealed that the long-lasting properties of wood as load-bearing elements are unknown. Designers and constructors lack experience in WLBS. There is also a need to clarify the concepts early in the design and tender phases. Also, the need for regulatory adjustment, especially according to fire regulations. Generally, authorities and advisors are not familiar with wood, which provides resistance. Other challenges expressed by respondents are economy, conservative building traditions, municipality approval, lifetime concerns, and finding the correct wood type and construction system.

Results reveal that 58% of responses confirm the presence of challenges when using exterior wood cladding, mostly fire challenges, followed by maintenance cost and sensitivity to climate conditions. Other challenges collected from respondents' comments reveal that architectural and technical solutions are essential for service life and maintenance. Also, drying must be ensured, and moisture must be minimized, besides limited possibilities for facade expressions that suit big cities' architecture. Thus, architecture and building traditions are significant factors. Fire conditions and exterior wood cladding treatments are considered problematic factors. Fire impregnation and lack of fire documentation are challenges, and few actors can deliver the required fire classes. Documentation for fire impregnation can extend the entire life of buildings according to building regulations. Untreated wood changes appearance and becomes less consistent over time. One has to expect that the building envelope is a sacrificial garment and can get expensive in the long run. Besides, unequal patination depends on overhangs and façades orientation. The operation, maintenance, and service life of wood cladding are primary issues. It also requires craftsmen experience, which is partly sunk into oblivion. In the design phase, the replacement of some building elements parts when using wood must be considered. Moreover, there are several exterior wood cladding types, so actors must choose the right approved type. Today, we lack usable labelling schemes that can be used in tenders, obstructing promoting wood construction.

Fire safety and sensitivity to moisture remain the most significant challenges, as confirmed by 50 % of respondents. Comments from respondents reveal that building regulations hinder the use of wood for interior cladding in high-rise buildings as wood

surfaces must comply with fire requirements. The appearance of wood surfaces may change if treated incorrectly. When using raw cross-laminated timber, it shrinks by drying, leaving cracks that will be seen if not coated or surface treated, then repairs will be visible. Also, the patina varies depending on how much light it receives.

Results reveal that 89% of respondents confirm the environmental benefits, 92% agreed that wood improves the indoor climate and is also aesthetic, while 66% of respondents acknowledged economic benefits, indicating that the economy is still a challenging issue. According to construction effectiveness benefits, 68% of respondents agreed that using wood benefits the construction process using less construction time and 85% agreed that it is easy to construct with wood. Generally, 83% confirmed significant benefits linked to wood construction, indicating actors' positive attitudes towards using wood in buildings and a tendency to use more wood.

Results show that 63% of respondents have worked with wood construction instead of traditional construction, and 21% have not, while it was not relevant for 16% of them. Also, 40% of respondents claim that the biggest reason for choosing wood is building owners' wishes, while 31% of respondents choose wood according to advisors' recommendation, and 29% choose wood due to their significant focus on sustainable development. This indicates that building owners have the greatest impact on material choices in the design phase. Advisors, including architects and engineers, have a significant role in influencing builders' decisions, promoting the use of wood. Respondents were asked how frequently they have used wood in their projects in the last five years; 61% answered "sometimes" and 15% "mostly," while 24% answered "rarely," indicating that the building sector is tending to change its construction traditions towards more wood in construction with developing experiences. According to Craig, the industry must take greater responsibility to achieve competencies in wood construction (2021). Results show that wood is used in various types of projects, including new construction and renovation. It appears that wood is used mainly in single-family houses and residential buildings up to three stories but less in commercial buildings. Respondents' ongoing wood project typologies varied, involving daycare institutions, multi-story residential buildings, senior housing, culture houses, and renovation of schools, indicating the broad and flexible use of wood despite the various type of buildings. Consequently, high-rise wood construction is not expanded yet in Denmark, indicating fewer experiences and difficulties to comply with building regulations fire requirements.

Respondents who use wood in their projects were asked where they most often use wood in their projects. For the WLBSs, results reveal that 25% use wood primarily for the load-bearing structure, 67% use it sometimes, and 8% have never used it. Regarding using wood as exterior cladding, results show that 39% of actors use wood often as exterior cladding, 52% use it sometimes, and 9% have never used it as exterior cladding. Regarding using wood as interior cladding, 24% of respondents use it frequently, 53% use it sometimes, and 23% have never used it as interior cladding. Generally, actors use wood mostly for the load-bearing system and exterior cladding, while less used as interior cladding followed by decoration purposes. Results reveal that architects use wood mostly for interior and exterior claddings and less for the bearing structure due to economy, clients' wishes, lack of experiences, and technical challenges. In contrast, engineers use WLBSs more than claddings. Here client wishes are the influencing factor. Thus, wood is a solid building material that can replace concrete in bearing structures. It also indicates that actors choose wood as exterior cladding due to its aesthetic appearance. According to the Danish

Technological Institute (2021), this must be combined with a wood surface treatment to protect against moisture and temperature variation. Building owner's wishes and decisions are the main barrier in choosing WLBSs, followed by lack of experience and knowledge in wood construction, then by economic considerations and technical challenges. Respondents were asked about who is responsible for promoting wood in construction. According to their responses, the biggest responsibility is directly linked to building owners and their architect advisors, followed by engineering consultants. It is revealed that architects have an essential role in proposing wood and providing efficient solutions, supported by engineers to solve the technical and construction challenges. Research by Markström *et al.,* (2018) addresses the influence on material selection, knowledge, experiences, and the architect's attitude in using EWPs. Thus, results confirm architects' essential advisory and facilitating role. Regarding learning and gaining knowledge in wood, 82% of respondents are interested in learning more about wooden construction, indicating their positive attitudes and tendency towards using it more.

CONCLUSIONS

The green transition, reducing the climate impact of buildings, calls for strengthening the positive image of wood construction. Wood must be a natural choice of building materials. An authoritative contribution to this growing movement arises from the Danish governmental strategy on climate change, which identifies a substantial increase of wood in buildings as a top priority. However, an encouragement of such a strategy raises some challenges giving the urgency of practical solutions for continued wood growth in construction. This paper emphasized actors' perceived benefits, experiences, and challenges of using WLBSs and claddings. Challenging issues remain on moisture risk and fire safety for high-rise buildings, calling for regulatory adjustment. Most respondents confirmed the environmental and social benefits gained from wood construction. The study reveals that building owners have the biggest impact on choosing wood in construction, and advisors, especially architects, have a major facilitating role in promoting wood. However, engineers are more experienced in solving technical solutions, revealing an experience gap between designers, and hindering wood progression. Here, it is revealed that the building industry has a great need for further education in wood construction. Thus, educational institutes need to address this need and educate future architects, engineers, and relevant professions to focus on wood construction solutions and methods to promote more wood buildings.

Additionally, the paper findings contribute to international research and practitioners by adding some experiences to learn from when using wood in construction, assisting in promoting this sustainable building material, which has a real potential for further adoption in construction globally. In addition, the paper contributes to construction management theory in terms of the industry's general poor adoption of innovation, new and uncommon practices, which is also realized as a challenging matter when calling for increased use of wood in buildings. Here a common thread can be drawn with adoption behaviour in other cases, such as digital technologies. Finally, the authors suggest further research to investigate the potential of industrialization and prefabrication of wooden construction to promote the use of wood in buildings and eliminate the various challenges. The survey's limitations include uncertainty in respondents' answers, especially organizations without significant experience in wood construction. Also, the survey did not include organizations with less than ten employers.

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