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THE BUILDING PROCESS – A BOUNDLESS MULTIDISCIPLINARY RESEARCH PROJECT RELATED TO WOODEN MULTI-FAMILY HOUSES IN SWEDEN

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Abstract:

The wood-building industry of multi-family houses is increasing its market share in Sweden, yet the research and education are not incorporating a total building process perspective. Typically, research is conducted in individual areas without having an overall coordinated perspective, which increases the risk of sub-optimisation. In a unique project in Sweden, several components in the building process have been studied within one project; "City development project Torparängen". The purpose was to gain a broader understanding of what influence the development of wooden multi-family houses, combining the effect from technological and non-technological advancements, which intended to support the development of a new wood building strategy.

By reviewing several areas within the building process provided information related to how market strategies, procurement methodologies, leadership and project management, equally influence the development as the more traditional fields in the industry, i.e. material handling, lean production, logistics and production improvement. Further, having the possibility to capture end-user preferences in this process provides opportunities to develop a more agile building process, adjusting market and production activities accordingly. The study was conducted during two years and involved approximately 250 respondents in different roles, and active in the building process within companies and governmental organisations across Sweden.

Key words: *wooden multi-family houses; research and education; multidisciplinary; development strategy; building process.*

BACKGROUND OF WOOD-BUILDING DEVELOPMENT WITHIN VÄXJÖ MUNICIPALITY

Several buildings out of wood had been constructed in Växjö, even before the first wood construction strategy was adopted in Sweden. The same year, 1994, as the ban on building houses over two floors with wooden frames was abolished, Värendshus built a three-story house using wooden frames that became the first building built following the new building regulation (VKAB 2016). Shortly after that, in 1996, Sweden's first modern 5-story wood-frame building was built at Välludden, Växjö, as a demonstration building for the purpose of developing wood construction technology following changes to the regulations. Thereafter, a research project was initiated 'Multi-storey buildings with wooden frames and light flooring' (VKAB 2016). The municipality had already been working to strengthen the local business community and the university, prior to its timber building strategy. Therefore, since the municipality adopted their wood construction strategy 2005, they have continuously worked to identify partners and contribute to the processes that promote wood construction.

Växjö municipality has since its goal of becoming a fossil fuel-free municipality actively been working on profiling itself as a municipality focusing on environmental and climate and has the slogan 'Europe's Greenest City' (Växjö Kommun 2011). An important aspect in the municipality's environmental and climate ambition has become its focus on using wood as a construction material, where 50% of all municipal new construction projects will be wood-based by 2020 "(Växjö Kommun 2014). Växjö municipalities renewed wood construction strategy "Växjö - the modern wooden town" contains more links with the municipality's goal of reducing carbon dioxide emissions per the municipality's environmental program (Växjö Kommun 2013).

With the new urban development project, Torparängen in Växjö provides new opportunities for a wood-building arena to once again take on the role as Sweden's leading municipality related to wood construction. Torparängen can provide the basis for increased cooperation related to research, business and education. Hence, the university and the municipality can jointly work together and create a greater interest in the industry for wood constructions, which can provide an increase of more sustainable housing being produced in an economically cost-efficient way. The aim in Växjö municipality's wood building strategy is to increase the proportion of wood-based construction in new developments, which is among others defined as 50% of new developments by 2023 should be based on a wood-based construction solution. Implementing this strategy requires a combined approach that create both economic- and technical possibilities for sustained development.

Research project Torparängen

In recent years, a number of high residential buildings have been built using a wooden frame. Several of these buildings are advanced constructions and are products of best practices and innovative solutions. Commonly, the technical challenges are, e.g. sound transmission, vibration, stabilisation, moisture and statics etc. But equally important are the controlling mechanisms if the buildings can be built or not, i.e. construction cost, the long-term financial and operational implications of building using a wood frame. This can include areas such as process management, logistics, industrial construction, production management and procurement.

Project Torparängen includes a major research study, which is seen as the starting point for a new wood construction focus in Växjö and how the Växjö-model can be transferred and generate a boost for a national wide wood-building drive. The benefit with the project is that the research has followed a specific development located in Växjö, which provided access to the decision-making process from start to finish not common in other research projects. The project proposal contains several parts, preliminary studies, procurement, production, technical conditions, operationalization and follow-up, Fig. 1. All of these elements have been defined in 10 research projects.

1. Market study, why is not wood used to any extent in construction today?
2. Procurement and tendering
3. Construction development
4. Production
5. Delivery and assembly, including lacer scanning
6. Wind-induced vibrations
7. Acoustics and vibrations
8. Measurements of moisture and heat
9. Measurements of vertical relativity displacements
10. End-user analysis, expected and perceived customer value

The research has managed to produce 25 different studies within the scope of the different phases, Fig. 1.

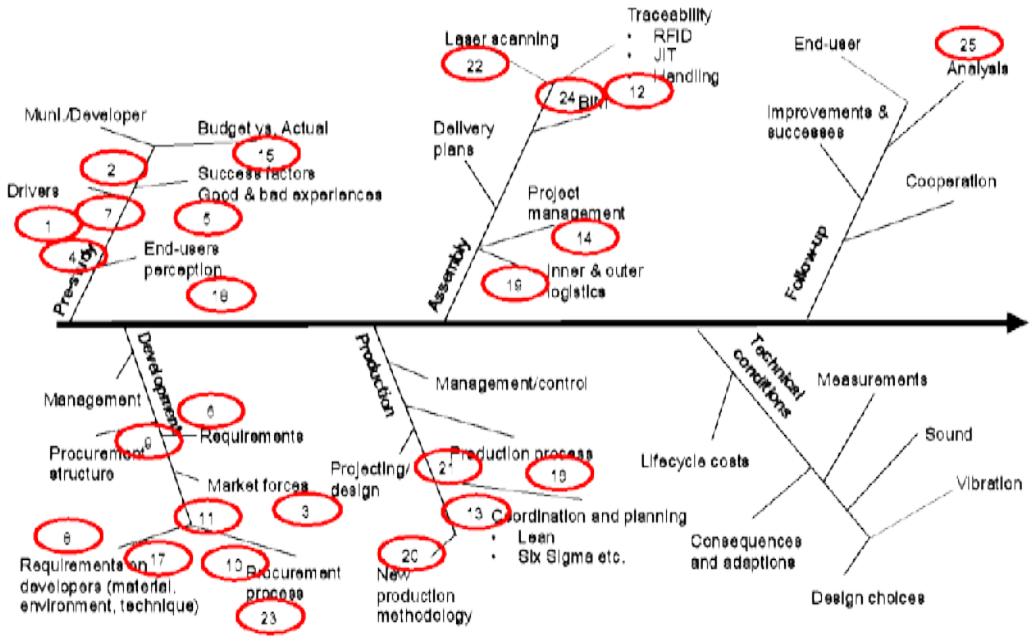

Fig. 1.
Mapping the research projects in the general structure.

These projects have been held together and through coordinated project management to provide a birds-eye perspective throughout the project and not lose focus related to the interconnectivity between the sub-projects. The research sub-projects where decided at the start of the project as being of importance for the development of the wood-building construction industry and incorporate an end-to-end perspective.

RESULT FROM RESEARCH PROJECT TORPARÄNGEN

The recent increase of sustainable development strategies enhances the importance of urban planning focusing on ecological sustainability (Carmona 2009). Also, The UN has included 17 global sustainable objectives emphasising the importance of sustainable building-solutions, using local materials

that can be recycled locally (UN 2015, Process Objective 11c; UN-Habitat 2016, §71, §76). The EU's ambition is to reduce greenhouse gas emissions by 20 % by 2020 (Regeringskansliet, [Government Offices of Sweden], 2017) whereas the Swedish target is a reduction of 40 % compared to the 1990 emission levels (Boverket, [National Board of Housing, Building and Planning], 2016a). Buildings using wood frames have nearly half of the climate impact to a comparable building using a concrete solution, which would have a positive effect on fulfilling the environmental target linked to the projected building demand during the coming decade (Norén & Jarnehammar 2001; Gustavsson & Sathre 2006). The execution of new building development plans is the responsibility of the Swedish municipalities, based on their internal strategies combined with the Government's goals towards sustainability (Boverket 2016b). Hence, the building development plan is intended to incorporate the environmental effect by combining new building strategies and technologies (FORMAS 2012). Also, new initiatives with a focus on climate change in our economies recommend the development of wood-based industries to improve sustainability (EU, 2011. COM 2020) and implementing technology and strategies to increase wood as an environmental and sustainable building material (EU 2012. COM 433).

The challenges of using wood as a building material are not only linked to technical limitations; equally important are the market factors. These factors are to some extent limiting the development potential for both producers of single-family and multi-family wooden houses, and where product and production development could be necessary to increase profitability and to be established in the market segment successfully (Besanko et al. 2013). Also, companies producing wood building solutions within the industry for multi-family houses have not fully taken advantage of the possibilities related to best in class industrialised building techniques and leverage this entry barrier (Stehn & Brege 2007). This can be advantageous considering the market segment is mainly developing towards industrialisation through the off-site construction of pre-fabricated building elements or modules and assembled on-site (Pan & Goodier 2011). This has several benefits in regards to the production environment, logistics, quality and cost, which is not equally favourable for on-site construction (Stehn & Brege 2007).

Market factors influencing the development

The focus on enhancing standards and technological capabilities, linked to the environmental advantages of using wood, has increased the utilisation of wood in building construction (Nord 2013). This affects the production costs, reducing rents for consumers, and increase its competitiveness towards traditional building materials and improve the development of wooden multi-family houses (Lindblad 2016). The construction using wood, in relation to traditional building material such as concrete, face a similar market situation, yet require alternative strategies to mitigate internal and external market challenges. Producers of wood-building solutions have an advantage with their off-site production technology, which will enable wooden single- and multi-family houses producers to outperform competitors using concrete (Nord 2013).

Therefore, companies producing wooden multi-family houses need to adjust and leverage their organisation towards the new market barriers to create a competitive advantage using, e.g. improved technological advances towards those companies already established within the market (Karakaya & Parayitam 2013) Additionally, political decisions and actions through legislation, duties, and taxation can support the companies' development into a new industry or market (Björheden 2006; Tudor et al. 2006). However, this should not solely be supported by political decisions, equally important are company activities to leverage internal synergies, i.e. financial planning, project development teams, strategic development, combined with governmental actions (Chiu & Yong 2004; Roberts 2004). Also, companies aligning their market strategies with the external market context, e.g. procurement situation, legislation and market maturity, have a greater possibility to minimise the effect from market entry activities (Venkatraman & Prescott 1990). The market barriers facing the producers of wooden multi-family houses are not static over time, rather something that evolves dependent on the internal and external market conditions, i.e. financial status, political situation, interest rates or legislation (OECD Policy Brief 2007).

Pre-conditions for building development

In 2005, a national wood-building strategy was adopted with the aim that 30 % of all new buildings within 10-15 years should use a wood-frame and that the number of buildings out of wood increase by 30% within five years (Ds 2004:1). Despite this, less than 10 % of the multi-family houses are currently being built in wood, and the building developments in Sweden continue to show an upward trend for using concrete in building solutions for multi-family houses (Sveriges Träbyggnadskansli 2017; Svensk Betong 2016). However, several municipalities in Sweden chose to develop against this prevailing trend, Växjö municipality being one of them. Hence, Växjö municipality have since the implementation of the national wood-building strategy focused on using wood in new building projects. The municipality is expected to achieve Sweden's environmental and climate objectives, while at the same time the government are attempting to influence

municipalities through the planning and environmental legislation that regulates construction (Boverket 2016c).

There are several possibilities and limitations to pose specific municipal requirements in the guidelines regarding land development agreement with reference to wood. The legislation permits municipalities to pose specific requirements and guidelines for land allocation agreements (Act on Guidelines for Municipality Land Allocations) based on the municipality's internal targets and policy documents (SFS 2014:899). However, the Planning and Building Act pose restrictions regarding the municipality's possibilities to pose specific technical requirements for land development projects. This complexity is also analysed by Sveriges Kommuner och Landsting [Swedish Association of Local Authorities and Regions] (SKL), reviewing land allocation and confirming the municipalities position using civil law to pose specific requirements when selling their land for building projects (SKL 2014). In order to identify the administrative instruments controlling the possibilities or limitations for the municipalities' prerequisites for the development of wood construction a number of regulations have to be reviewed; The Swedish Environmental Code (SFS 1998:808), The Planning and Building Act (SFS 2010:900), the Boverket's Building Regulations (BFS 2011:6) and The Public Procurement Act (SFS 2016:1145).

Operational development

The industry producing multi-family wooden houses have had an upturn with higher demand due to an increased market requirement for accommodation and a new awareness of sustainability in the construction industry. Hence, like any other industry, the construction industry tries to be more effective to increase production and improve productivity, generating higher profitability (Lindblad 2016). One way of achieving this goal is to automate the production, similar to the traditional industrialised concepts in, e.g. automotive and electronic industries, which have already been implemented in certain areas of the industry to a varied extent. However, improvements in the information flow have not come as far as the developments of production methodology, and it is necessary to streamline the entire process and reduce the amount of manual and duplicated work using standardisation, thereby avoid sub-optimisation and improve productivity. This is not only applicable to the industrialization of the manufacturing process but also in a large degree to the design process (Lindblad et al. 2018a).

Furthermore, the requirements to increase efficiencies within the industry are not only focused on improvements in the information flow leading into the production process. Equally, the industrialization of the building processes to leverage the benefits of wood-building solutions by transitioning from traditional on-site production to off-site prefabrication is challenging and requires additional information and planning processes (Ohlager 2013). Also, well-balanced material flow is of great importance to obtain high productivity in the production process, which require a certain degree of technological development throughout the value chain (Jonsson 2008). These actions are deemed as important considering many house producers are in the starting phases of introducing advanced automation technologies in their off-site production processes and require detailed process control to take advantage of the strength of wood-building solutions and increase their market share. The conditions for the industrial market have also changed combined with this development and customer expectations regarding quality, high reliability, fast delivery and low price are getting higher, forcing companies to become more productive and update their processes in order to meet these new demands. In this context, well-functioning manufacturing processes with high-quality products and good production planning are required to fulfil these goals, which further emphasises a shift in focus towards internal operations and processes to better meet the customer's increased expectations (Nord 2013).

There are several areas to focus on in regards to the assembly phase of the building process, which are related to process improvement, efficiencies and increased environmental focus (Langlois 2004). Initially, the logistics process must become more efficient, starting with the inbound flow to the construction site. The use of transports, dependent on building solution influence the environmental impact, and an increased understanding provides greater possibilities to contribute to an environmentally sustainable solution. Hence, the use of heavy vehicles transports should be examined further to meet the climate objectives. There are currently several factors influencing the impact on the amount of emitted CO_2, most important have been the volume/weight factors related to the distribution of concrete of wood-building solutions. This is however only important in a like-for-like comparison where the driving distance from the production site to construction site is similar, which in these cases favour wood as a construction material. In reality, the market strength of concrete building solution provides a more comprehensive production infrastructure with shorter driving distances that can outperform the environmental advantage identified for wood-building solutions (Lindblad Lehman & Aggerstam 2019).

The effect of an efficient inbound logistics process on the construction phase is only fully efficient if the material handling process is structured and planned efficiently at the construction site. One factor in leveraging the effect of an efficient material handling process is to have a clear picture of the construction

site, which can be conducted using laser scanning. This procedure is used to produce a 3D-model that can be applied in different areas besides an efficient construction site, e.g. to document cultural buildings, reconstructions city models and calculate volumes. This information can be useful for the planning during the construction phase and later stages of the building process related to a suitable site infrastructure. This can be established by georeferencing certain areas for storage based on material type in relation to the construction cycle (Lindblad et al. 2018b).

There are problems identified with material deliveries and material management at many construction sites, making the material handling process at building sites a barrier that can contribute to improved efficiency. The activities related to making the material flow process more efficient on construction sites are associated to suitable storage sites, materials arrive at the wrong time, waste of storage space, unnecessary tracking of materials or wrong quantities arriving at the sites. This is a process that can be supported and improved by technology such as Radio Frequency Identification, RFID, which is a wireless technology used to identify objects and can be linked into BIM or on-site construction plans if required. Material handling using RFID can improve time effectiveness, minimise waste and monitor moisture levels in the material efficiently, creating improved sustainability within the building process.

CONCLUDING STATEMENTS

Market evolvement

The gradually changing behaviour of the population, towards urbanisation, led to an increased shortage of available housing. This development has resulted in not enough companies are providing solutions for multi-family houses in wood. Potential companies that could fill this increasing demand are those in the single-family house industry. These companies have promising positions to invest in product development towards wooden multi-family houses and gain a competitive advantage by diversifying into the growing wooden multi-family house industry. The limited capability to fulfil the increased building demand also restricts the possibilities for development towards innovation, bio-economy and sustainability. The municipalities in Sweden are responsible for the planning of building development in their region based on their projected requirements. This normally involves the development of local strategies regarding, e.g. design, material choice and geographical development. By identifying drivers and barriers found in the industry and market, enables improved market entry activities related to public building initiatives using wood-based solutions. In this context, the industry experience barriers associated with the municipalities' actions and knowledge level related to wood as a building solution, combined with the strength of concrete as a building material is an issue since the municipalities tend to opt for familiar solutions. These factors contribute to uncertainty and sub-optimisation for the developers proposing a wood-based building solution and where increased sustainability in the building process cannot be achieved at the desired level.

Public actions

Växjö Municipality has during some time made a strategic decision to be profiled as a green city with a focus on sustainability, which has contributed to an increased focus on wood construction. Therefore, any new building developments under the municipality's control are required to test and present the new building developments based using a wood-building solution. Hence, the governance of the public process affects the development towards wood-based building solutions by communicating an ambition to focus on sustainability, which provides a faster pace regarding new developments using wood. Several areas have been identified as barriers, which provide guidance on how the Swedish municipalities can adjust their current process and enable a more efficient result: increased knowledge regarding the procurement process, changed approach towards land allocation activities based on new buyer/seller perspective, evaluating functional specification and increased knowledge regarding wood building solutions.

The municipalities have several options to initiate building developments based on the projected demand, e.g. using public procurement of new developments or the land allocation activity. Växjö Municipality has to a large degree opted for the land allocation activity since it provides more flexibility to pose specific demands regarding the building specification, which is not possible using public procurement that is limited by the public procurement act. The reason for these differences related to the selected models are based on land allocation activity is a sale of land with specific buyer requirements imposed on the developers by the municipality. However, this is not a view shared by the developers who have to provide a detailed proposal of their intended solution, which also is an activity more associated with a sales process. This can be derived from an unclear buyer/seller relationship that provides uncertainty in their internal expectations. Reviewing the interaction between municipalities and developers from a public procurement situation requires an understanding of the specific conditions and legislative constraints to efficiently reorganise the process (McCue & Prier 2008; Johnston & Seidenstat 2007). Furthermore, the perception of the participant's roles in the land allocation activity also influences how and what kind of information is

provided by the municipalities, which currently is lacking, and limit the effectiveness of the process (Nyman, Nilsson & Rapp 2005).

The municipalities are recommended to treat the land allocation activity similar to a normal procurement process to provide more control and transparency throughout the project life cycle. Only if the municipalities start adjusting their perception towards a procurement situation, instead of a sales situation defined in the land allocation process, will the possibility to evaluate the various process steps successfully be incorporated (Arrowsmith 2010). Hence, it becomes more important to design a new process that is adjusted to the land allocation activity, using clearly defined process steps of pre-acquisition, acquisition and post-acquisition. This will provide internal guidance for the municipality as well as increased transparency regarding the project requirements for the developers – evaluation criteria, extending municipalities' focus beyond the point of sale and project fulfilment rate as well as accountability for discrepancies with the initial proposal (Arrowsmith 2010; Dimitri 2013).

It would also be beneficial if the evaluation criteria could include quantifiable information such as project budget and cost per square meter, in addition to design and sustainability. The decision-makers within municipalities are more likely to continue opting for solutions based on concrete if they have a long tradition of evaluating building projects based on this solution.

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