TECHNICAL REPORT

Wood in Buildings

Technical and business development of wooden buildings, especially multi-storey timber buildings

Ulf Arne Girhammar

LULEÅ UNIVERSITY OF TECHNOLOGY

LULEÅ
UNIVERSITY
OF TECHNOLOGY

Wood in Buildings

Technical and business development of wooden buildings, especially multi-storey timber buildings

Ulf Arne Girhammar

Luleå University of Technology
Department of Engineering Sciences and Mathematics
Division of Wood Science and Engineering

ISSN 1402-1536
ISBN 978-91-7790-962-0 (print)
ISBN 978-91-7790-963-7 (pdf)

Luleå 2021

www.ltu.se

Contents

1. Introduction

1.1 Impact of wood in buildings

About 33 % of global CO_2 emissions from human activities come from the construction sector. A building consumes limited natural resources both during the construction phase and afterwards during the operating period. The framework of a regular multi-storey building accounts for about 60 % of the total CO_2 emissions during the construction phase. For today's highly energy efficient new buildings, the production phase in many cases corresponds to as much CO_2 as during the operating phase (100 years) for dwellings. CO_2 emissions could be reduced by 43 % if the building was designed in wood instead of concrete. For tall buildings, the difference is even greater.

Wood is the primary renewable material. Wood building is a functional, environmentally friendly and socio-economic construction. The wood industry is working hard with environmental issues, raw materials management and clean production. Wood-linked industries export a large proportion of their production in the form of components and systems to customers in a number of countries in Europe. They work with products that lead to lower energy and housing costs.

The society places increasingly tough economic, functional, environmental and aesthetic demands on construction. As a result, today we can see a number of clear development trends that are important for the future development in the wood industry:

- An ever increasing interest in the use of wood and refined wood products.
- An increasing degree of refinement and optimization of different materials and components by combining them into so-called composite or interacting structures and systems, often so called hybrids.
- An increasingly rigorous requirement for energy savings in and moisture-proofing of our buildings as well as in dry construction.
- An increasing degree of prefabrication of various building components to meet the qualitative and economic requirements that are imposed on both product parts and the building as a whole. To develop rational floor and wall components with effective connections to the entire building system.

Globally, urbanization is taking place, which, for Sweden, means that metropolitan areas and larger cities will have an increased demand for housing in the range of 900,000 dwelling by 2050. In these cities, both new construction will be needed as well as construction of additional floors on existing buildings.

An increased need for future housing motivates developing both design, planning and construction methods for tall wooden houses that help improve building quality by partly minimizing errors due to lacking or improper planning tools and partly by improving the design, function and assembly of the prefabricated units.

The industrial timber construction with its modular building systems and prefabricated units is particularly well suited for urban construction because buildings, regardless whether it is new new or complementary construction, can quickly be erected and with relatively small disturbances on the surrounding area and to competitive costs (to this beneficial energy and environmental benefits can be added).

An increasing proportion of the construction projects are prefabricated in whole or in part. This leads to a more rational, faster and cheaper assembly and thus higher quality at a lower total cost. An industrialized construction includes the need of efficient design tools, high degree of refined building components, rational industrial manufacturing and quick assembly methods at the building site.

It is well demonstrated that:

- forest growth in the Nordic region is greater than the harvest and that increased use of wood is an important potential and one of the crucial areas for economic growth
- the Nordic countries use wood much more than Europe in general, which means a great potential for export
- wood stores CO_2 and releases oxygen
- a timber building has a significantly more favorable impact on climate and the environment
- major energy savings are possible if the entire chain of energy consumption from plant to building as final product is taken into account
- wood buildings consume clearly less energy than the equivalent in steel and concrete.

1.2 The future of timber multi-storey buildings in the Nordic countries

Studies have shown that the rise of wooden multi-storey construction in the Nordic countries has turned out to be the most evident construction-related new business opportunity in the emerging bio-economy.[1] The most driving forces for this is due to the requirements on environmental sustainability and changes in the building regulations. However, architects, engineers and entrepreneurs associate wooden multistory construction with several challenges and uncertainties, primarily with respect to fire safety, stability, durability, and acoustic properties that first need to be overcome. In order to enhance the usage of wood on the markets, several information requirements must be met, including design conditions, regulations and standards, environmental footprints, and sustainable design.

Also, the consumer knowledge is yet relatively low when it comes to building materials impact on human health. Based on interviewee responses, personal health benefits surpassed though generic environmental benefits as the main rationale for choosing wood over other possible materials in housing. A conclusion is also that some saw the sustainability of wood as a competitive advantage of wooden multi-storey construction, but only after the technical building requirements are first met, and once wood-based solutions in construction are placed at the same level as alternative materials in terms of competitiveness. The following quote illustrates this stance: "It [the sustainability] is something that will help us surpass [other materials] if we can get to the same level in terms of competitiveness and technical know-how [as for the other materials]."

1.3 Entrepreneurship – business models and development

Entrepreneurship is usually considered as the ability to identify possibilities and create resources to take advantage of these possibilities or, more succinctly expressed, the creation of new, extended or changed business operation.[2] Applied on the building industry, the development in this respect is then about creating business models and business strategies for the contract construction that the building process imply, including both planning and implementation. For industrialized building especially, the implementation to a large extent comprises of manufacturing and erecting. The planning can be performed by architectural and engineering design consultants or by the manufacturing or construction company. Building construction comprises often of both main and sub-contractors or sub-suppliers, where the main contractor or supplier is the manufacturing or constructing company and the sub-contractors or sub-suppliers can be SME's.

An entrepreneurial culture is often said to an important factor of success for development of creative business operations within countries, regions and specific componies. Particularly successful company regions are usually defined as industrial districts or cluster. To understand how the culture in such a region is developed and how they are influencing – and influenced by – different conditions is important to study. How the culture is influenced by entrepreneurship depends on the perspective of

[1] Toppinen, A. et al. "The future of wooden multistory construction in the forest bioeconomy – A Delphi study from Finland and Sweden". *Journal of Forest Economics*, 2017.
[2] Swedish Entrepreneurship Forum, Stockholm, http://entreprenorskapsforum.se/.

the individual, on the organizational level and on the regional and national aspects. Social and cultural codes can have a greater impact on the decision of the individual than his or her own knowledge and capabilities. The culture of the organization can be looked upon as a strategic resource for the company and its climate a tool that governs and develops the organization concerning entrepreneurship and innovation. The explanation mechanisms behind successful regions are, in addition to the economical, the sociocultural environment regarding taking risks. All regions look different and carry their own history and, therefore, it is hard – if not impossible – to generalize when it comes to regional aspects on culture.

In this project a cooperation over the region and country borders need to be established and differences in regional company cultures be bridged. Culture or cultures are present where there are people who interacts. One needs thereby to take into account that companies are embedded in its local environment and that it is much that influence the culture in a company, among other things the local environment, the history of the company, the line of business, ownership, etc. This complexity needs to be considered when cooperating and in common activities and ambitions.

To foster entrepreneurial awareness and positive attitudes towards entrepreneurship is highly prioritized on many countries' business policy agenda. Individual, social and contextual factors, such as the function of the labor market and institutional laws and regulations, affect men's and women's entrepreneurial considerations concerning entrepreneurial operations. Through the years it has been proved that women's entrepreneurial activities in earlier stages vary significantly worldwide. These differences between countries mirror the differences in culture and tradition regarding women's participating in the economy, societal conceptions of the role of women on the labor market and within the trade and industry. However, such differences do not essentially exist between the Nordic countries. There are, however, differences: Men's entrepreneurial activities are usually what is called possibility motivated entrepreneurship, while women's more often are what is called necessity motivated entrepreneurship. New technology implicate that the small and new companies as well as the big ones become better equipped to broaden the markets for their operations, something that is especially important for countries with small home markets. There is no relationship between entrepreneurship and intrapreneurship, which indicates that it is institutional laws and regulations that govern how entrepreneurial talent is channelled in an economy. Securing the business skills is another key area in order for the entrepreneurs being able to grow and to maintain their innovative capability. Access to competence affects the level of (possibility based) entrepreneurship, but also what type of entrepreneurs that are established in an economy.

1.4 Entrepreneurship – industries and businesses in rural areas

Entrepreneurship in rural areas is a very little explored area, at the same time as it is a recognized societal challenge. The focus on entrepreneurship in rural areas is about conditions and driving forces for the emergence and growth of new industries and businesses that are partly built around "old resources" such as forestry, fishing and agriculture, in rural areas and partly those that are not normally associated with rural areas. Project initiatives therefore include to produce clear and practically workable proposals that strengthen the conditions for local entrepreneurship.

The question is what characterizes rural areas that are successfully able to develop new industries and businesses? How are the conditions for the local skills supply in terms of access to a skilled and matching workforce, the local attitudes to entrepreneurship and the infrastructure for communication and transport.

In the discussion about living countryside, it is sometimes emphasized that the "new economy" has given the countryside a number of new opportunities. The term "new rurality" is often used to describe the potential of the countryside. One argument is that the technological shifts that follow from automation, digitalisation and additive manufacturing have the potential to change the conditions for business operations and entrepreneurship in sparse environments outside the metropolitan areas. Another argument is that falling prices for long-distance travel and faster transport lift people out of their local contexts and enable integration between city and country, both in terms of work commuting and business activities. A third argument is that the new economy is characterized by rising demand for recreation, health, tourism and locally produced food, etc.

Common to several of the arguments about the possibilities of the new rurality is that they presuppose local entrepreneurship in order to be realized. Emergence as well as growth of new businesses and industries is directly linked to entrepreneurship; partly in the form of new companies in new industries, partly in the form of existing companies developing new areas of activity. It is therefore of great importance to understand the conditions and driving forces for entrepreneurship in new businesses in rural areas, not least in order to be able to produce evidence-based decision-making for policies aimed at strengthening entrepreneurship in new industries and business areas in rural areas.

A clear result from previous surveys is that entrepreneurship in a region has a supply and a demand side. The supply side is about access to factors such as inputs, labor, financial capital, knowledge and good business ideas. The demand side is about access to customers, purchasing power and niche markets. It has been shown that local institutions – both formal (laws and regulations) and informal (attitudes and norms) – play a role in local entrepreneurship.

Experience indicates that entrepreneurship in rural areas should focus on the industries and areas of activity that build unique resources of the rural areas on the supply side, and whose products can be sold in remote markets due to limited local market. Entrepreneurship in rural areas is generally low, and focuses on classical areal industries whose products can be exported to other regions (or countries) – the typical example goes back to forestry, fishing and agriculture. There are significant shortcomings and knowledge gaps regarding entrepreneurship in rural areas. This applies partly to differences in entrepreneurship between rural and urban areas, and partly to the specific conditions and driving forces of entrepreneurship in rural areas.

In order to understand which characteristics of the countryside that can explain and support a positive development, the overall studies must be supplemented with studies where successful rural areas are compared to less successful rural areas. Given the structural differences that exist between urban regions and rural areas, rural areas are likely to learn more from each other than from urban regions.

To address this shortcoming, one needs to identify rural areas that are successful in developing new industries and businesses through entrepreneurship and study the extent to which the successful rural areas differ from other rural areas in terms of

(i) local skills supply in terms of access to a competent and matching workforce;
(ii) local attitudes to entrepreneurship and
(iii) infrastructure.

These are among the most common factors that entrepreneurs and business representatives highlight in discussions about the conditions for start-ups as well as the growth of existing companies.

1.5 Indoor wood in buildings

It has been shown that visible wood indoor in buildings has an impact on the well-being of individuals with respect to health. For example, studies on end-user perceptions and the psychological effects of wood on human well-being indoors in hospital rooms can result in shorter duration of hospital stays by a couple of days.

It has also been shown that wood solutions even out the indoor humidity, retains heat energy, and emits no harmful levels of volatile organic substances. Wood in walls and floors then improves the room climate and energy consumption. For example, in newly built wooden houses in Stockholm the requirement for heating was reduced by 35 % because of these effects.

This positive effect of wood in interior solutions on the well-being of the occupant's health and impact on the environmental footprint of the building and room climate and energy consumption can mean great business opportunities for the wood industry.

2. Wood in buildings

2.1 Introduction

Wood plays an increasingly important role, especially in the building and construction industry, in order to meet the challenges with climate change, finite material resources and pertaining permanent adverse encroachments in nature, and energy consumption. It plays a significant role in environmental and climate effects on society as well as the well-being of its individual citizens.

The environmental and climate effects on society will here be exemplified by the conditions for Finland and the well-being of individuals by a recent European study.[3] Also, among the different applications of wood, multi-storey wooden buildings play a special role. The future need and potential for increased use of multi-storey wooden buildings will be presented as summarized in a recent Swedish study.[4]

Business models are fundamentally linked with technological innovation, yet the business model construct is often developed separate from technology.[5] This means that the connection between business model choice and technology is two-way and complex – something that has received little attention. In fact, business models and technologies regularly interact, which will be discussed and serve as a background and a starting point for the present study. Business models for industrialized construction of multi-storey wooden buildings are discussed later in section 4.3.

For multi-storey wooden buildings, the future challenges concerning the interaction of the different partners, the locomotives and the SME's, will be discussed. Also, some reflections on trends and challenges associated with multi-storey wooden buildings will be outlined. Especially, the status of the competence and skills of the working force, and the availability of design and planning tools for the consultants, manufacturers and entrepreneurs, will be discussed. In particular, these statuses for wood will be compared to the corresponding conditions for concrete and steel or, rather, the lack of access to these things compared to concrete and steel, will be in focus. These things will be exemplified by the conditions especially in Finland.

2.2 Potential for wood (exemplified by Finland)

The net growth of wood in Finland is about 30 Mm^3 per year (see Figure 1). Since 1960s the yearly growth has been bigger than cutting in Finland. There have never been so much wood in forests in Finland than today. This fact creates a potential for increased use of wood. Bio-forestry (use of wood) is one of the spearheads of economic growth in Finland.

---

[3] "Wood2New", Report EU-project, 2017.

[4] Brege, S., Stehn, L. och Nord, T., "Industriellt byggande i trä – nuläge och prognos mot 2025", Forskningsrapport LIU–IEI–RR–17/00263–SE, Linköpings universitet, 2017.

[5] Charles Baden-Fuller, Stefan Haefliger, "Business Models and Technological Innovation". *Long Range Planning* 46 (2013) 419–426.

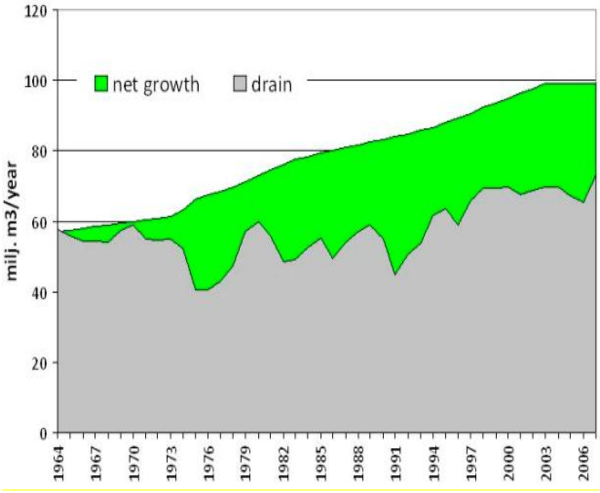


Fig. 1. Net growth of wood

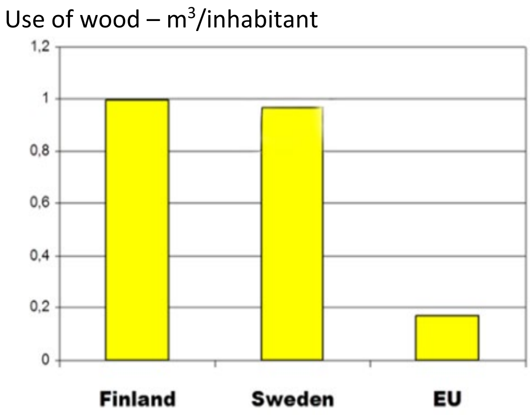


Fig. 2. Use of wood in constrution

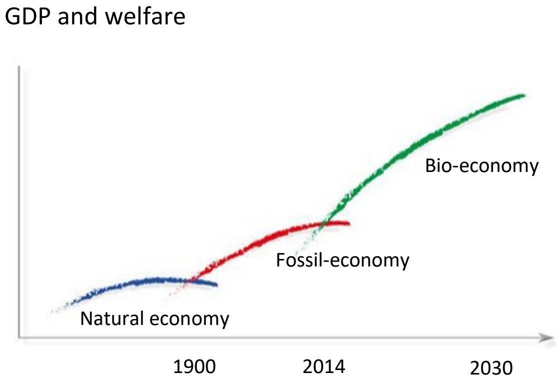


Fig. 3. Bio-economy next megatrend worldwide

There is a huge potential of increasing the use of wood in the construction sector in Europe. Finland and Sweden use much more wood in construction than the other Europe (see Figure 2; in m^3 per inhabitant). Building with wood is an ecological act. In Sweden the construction sector uses about 2/3 of the wood production. Sweden builds about 13 % of the multi-storey buildings in wood. Finland only about 0.1 %. There is a possibility for closing the gap by exchange and transfer of cross-border know-how and experience.

We live in the age of bio-economics. Bioeconomy is the next big megatrend worldwide (see Figure 3). Bio-economy is the fastest growing megatrend, which will create growth and well-being to societies taking benefit of it. Scandinavian countries (Finland, Sweden, Norway) are superpowers in bio-economy, having a lot of renewable natural resources, know-how, innovation and flexibility to utilize them.

2.3 Climate effects of wood

It is a well known fact that wood stores carbon (see Figure 4). Every ton of wood binds almost 2 tons of carbon dioxide from the atmosphere. A medium-sized massive wood house has about 30 tons of wood. This corresponds to the same amount of carbon dioxide as generated by driving a car approximately 400 000 km.

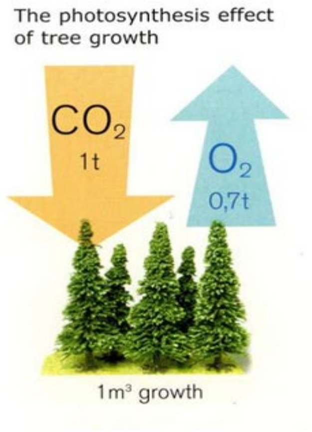


Fig. 4. Climate effects

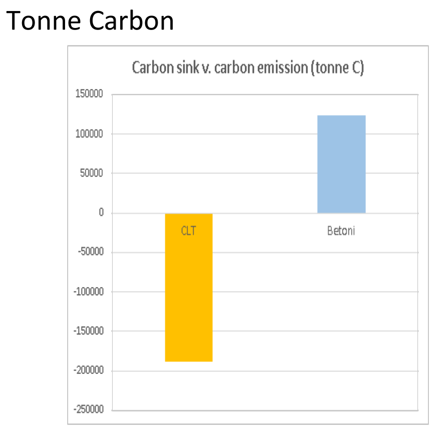


Fig. 5. Multi-storey building

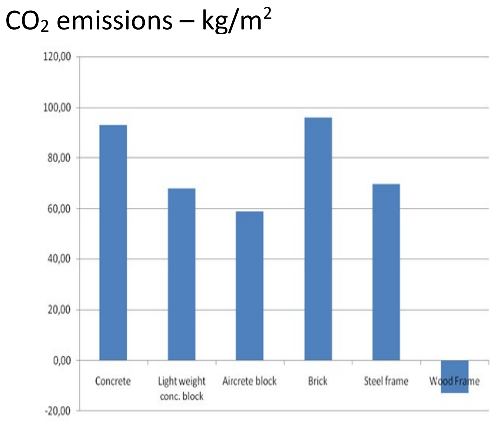


Fig. 6. Frames – exterior walls

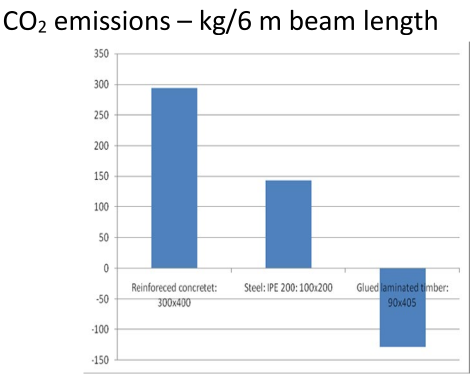


Fig. 7. Beam manufacturing

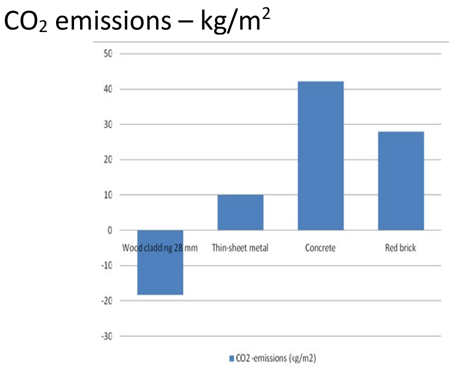


Fig. 8. Exterior cladding

As an example of the climate effects, a wooden multi-storey building, the apartment block Murray Grove, London, UK, 2009, is used. The carbon sink and carbon footprint of the manufacture of the frame of this tall apartment block were compared with a corresponding concrete building (see Figure 5). A massive wood (CLT) frame *stores* about 188 tonnes of carbon from the atmosphere (left bar). A similar concrete frame would *emit* about 124 tonnes of fossil fuel emissions (right bar).

As another example, wooden frames – external walls are shown compared to those of concrete, lightweight concrete, airconcrete, brick and steel frame (see Figure 6). The diagram shows carbon dioxide emissions caused by the manufacture of frames – exterior walls (kg/m^2). If wood frame is used, then the emission would be about *minus* 15 CO_2 kg/m^2 (bar far right), i.e. the wood *stores* that amount.

As another example, manufacturing of wooden beams is shown compared to those of reinforced concrete and steel (see Figure 7). The diagram shows carbon dioxide emissions caused by the manufacture of beams (kg per 6 m long beam). If glued laminated timber is used, then the emission would be about *minus* 130 CO_2 kg/m^2 (bar far right), i.e. the wood *stores* that amount.

As another example, exterior wooden cladding manufacture is shown compared to that of thin-sheet metal, concrete and red brick (see Figure 8). The diagram shows carbon dioxide emissions caused by exterior cladding (kg/m^2). If wood cladding is used, then the emission would be about *minus* 18 CO_2 kg/m^2 (stack far left), i.e. the wood *stores* that amount.

2.4 **Energy efficiency of wood buildings**

For massive (CLT) buildings, the energy consumption for a massive wood wall is 3 534 MJ/m³ wood (see table). The clean energy from the production waste wood is 7 000 MJ/m³ wood. This means a positive net energy of 3 466 MJ/m³ wood from using wood. This extra energy can be used for heating of homes in the city.

Energy consumption for a massive wood wall (MJ/m³ wood)		*Positive net energy from using wood (MJ/m³ wood)*	
* Harvesting	132		
* Production	2 644		
* Transportation	223		
* Construction	270	* Clean energy from the production waste wood	+ 7 000
* Service life 50 years	265	* Total consumption during a massive wall life time	- 3 534
Total	3 534	Extra clean energy from the process	= 3 466

As an example of the energy efficiency effects, a wooden multi-storey building, Trähus 2001, Malmö, is used. A wooden apartment block was built for the Malmö Housing Fair using a patented frame solution. The emissions from the frame manufacture, construction and demolition stages and the need for energy were compared between corresponding timber and concrete frames (see Figure 9; in relative percent). The wooden house alternative did require only 42.5 % of that for a concrete building.

As another example, the energy consumption in the manufacture of exterior walls is shown compared to that of concrete sandwich, red brick wall, timber frame with brick façade, timber frame and façade, and wooden log wall (see Figure 10). The diagram shows that the total energy consumption was negative in cases with timber frame and façade and with wooden log walls, i.e. the whole process results in access to extra clean energy.

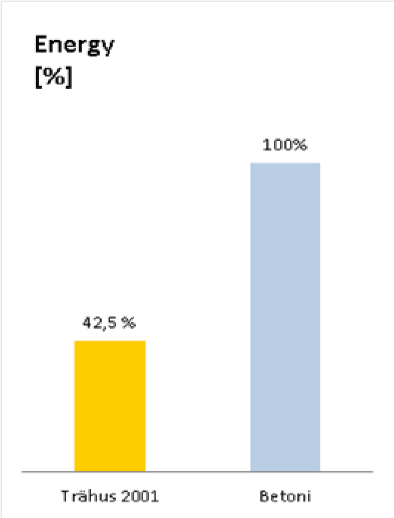


Fig. 9. Multi-storey building

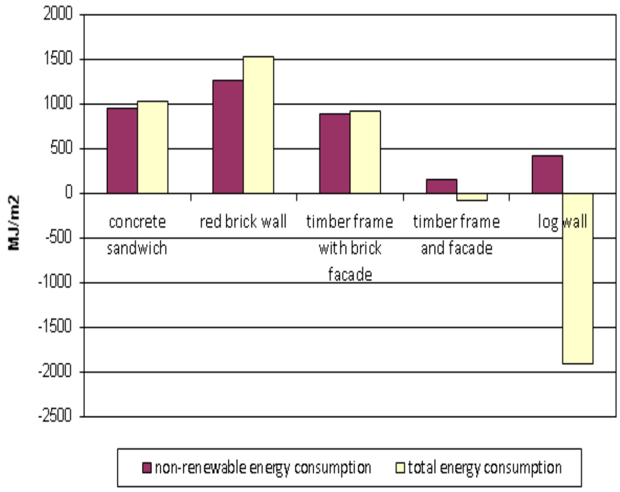


Fig. 10. Frames – external walls

2.5 Structural use of wood in multi-storey buildings (exemplified by Sweden)

A recent Swedish study[6] summarizes the prospects for industrialized wood construction and multi-storey wooden buildings as follows:

In view of the social challenges associated with demography (strong population growth together with a strong urbanization), climate (reducing the climate loading), employment (keep employment at a high level with a "reasonable" division of jobs between city and country) and resource efficiency requirements, industrial wood construction can contribute the following within a time perspective of up to year 2025:

- Build up a capacity for industrial wood construction that can deliver 50 % of the multi-family houses built on the Swedish market (17,500 apartments, of which 15,000 are produced in the country) and at the same time reach a 30-35 % material share in the segment of premises.

- In doing so, create 8,000 new jobs in prefabrication in the factory environment and help to move 6,000 jobs from the big city to rural areas. This could be a partial solution to the lack of domestic construction work force - to "move the jobs out to the countryside" and to "transfer work assignments from carpenters to machine operators". This could also be an opportunity for integration of newly immigrated labour (diversity).

- Utilize the wood's potential for reduced climatic load compared to other building materials. An industrial multi-family house has 40 % lower CO_2 emissions than a comparable concrete house (in the material part of the construction phase). The corresponding number for premises is minus 35 – 40 %.

- Reduce climate load with 0.3-0.4 million tons of CO_2 equivalents by substituting from concrete to wood (multi-storey houses + premises) - a saving of about 1 % of the total emissions that Sweden's trading and non-trading sectors will adapt to until the year 2030. If the carbon storage of wood is added to the substitution effect, the calculatory savings will be 0.6-0.9 million tons of CO_2 equivalents. The target for 2030 could further be turned up to 0.5 million tons savings in substitution from concrete to wood and to over 1 million tons if carbon storage was added (based on the assumption of a static concrete industry in terms of climate adaptation).

[6] Brege, S., Stehn, L. och Notd, T., "Industriellt byggande i trä – nuläge och prognos mot 2025", Forskningsrapport LIU–IEI–RR–17/00263–SE, Linköpings universitet, 2017.

- Construct more resource-efficient buildings by using industrialized construction and, above all, take advantage of the potential for continued efficiency improvements as a result of increasing the volumes. Industrial construction has better control over the refining processes, which includes subcontractors, consultants and material suppliers and can through the creation of better integration and partnerships be dampening in a volatile market.

- Industrial wood construction aimed at multi-family houses and premises also has the potential to be a future export success. Experiences from the domestic market, which is considered to be an "early market", may be included in various types of business models in a successful export business.

Final comments concerning the future availability of capacity in the Swedish housing construction market

- If the greatly increasing need is to be met, then we are talking about significant capacity expansions.

- At the same time, the Swedish forestry and wood industry currently appears to be the only operator to emerge with far-reaching and advanced plans for large capacity expansions.
  * For example, we estimate that the uncertainty regarding the climate issue is (at present) too great for the concrete industry to consider embarking on major expansion plans.
  * In addition, the large construction companies seem to separate themselves regarding ownership from the concrete production and are therefore less attached to the traditional construction in concrete.

The expansion of industrial prefabricated timber construction has a great potential that can be utilized by both the Nordic forestry and wood industry, by the construction industry as a whole and by the society at large.

2.6 Indoor use of wood in buildings (exemplified by EU project Wood2New)

Research results show that visible wood indoor in buildings has an impact on the well-being of individuals with respect to health and that wood in walls and floors improves the room climate and energy consumption. This positive impact on both health and environment also means great business opportunities.

2.6.1 Impact on health

Now it is scientifically proven, as many in the construction industry already know: wood in buildings, furniture and on walls is good for our health and our well-being. Studies on end-user perceptions and the psychological effects of wood on human well-being indoors have been conducted (the European project "Wood2New"). Four types of facilities were studied: (1) hospitals; (2) offices; (3) day care centers and a care home for elderly.

- Hospitals: The results indicate that there is a connection between architecture, materials and health. There is indicative evidence that wood used in hospital rooms can result in improving healing processes and health outcomes, such as shorter duration of hospital stays by a couple of days.

- Offices: The results of this survey indicate that furniture has the biggest effect on the perception of the space as such, when general comfort factors are otherwise satisfactory and equal.

- Care centers: Interior materials influence both the visual and sensory environment. These aspects were generally appreciated by the users of the presented cases. The use of wood was generally perceived positively; ninety percent of the end-users would recommend wood material for interior spaces in care environments. User experiences of the log building were slightly better than on average concerning all features, except the indoor air temperature. It was also perceived as the most logical.

2.6.2 Impact on environment

The Wood2New study also shows that wood evens out the indoor humidity, retains heat energy, and emits no harmful levels of volatile organic substances.

- Wood evens out indoor humidity: Researchers have shown how the wood absorbs and emits moisture, thus contributing to a better indoor climate. When we shower or cook food on the stove, the humidity increases, the wood sucks up the moisture and then releases it when the air becomes drier again. This process has been studied with a thermal camera and shows that when the moisture is absorbed by the wood, heat is released that heats the room.

- Wood retains heat energy: This humidity process mentioned above has been studied with a thermal camera and showed that when the moisture is absorbed by the wood, heat is released that heats the room. A practical illustration is the newly built wooden houses in Sundbyberg, where it was estimated that 74.6 kWh per m^2 and year would be required for the heating. The result after occupancy was 49.2 kWh per m^2 and year. One reason for the low consumption can be the wood's inherent properties to keep energy over the day.

Thus, results show that even wood in interior solutions has an impact on the environmental footprint of the building as well as on the well-being of the residents. This positive impact on both health and environment means great business opportunities.

2.7 Business models and technological innovation

The business model construct has become attractive to many academics, taking on its own momentum as is evidenced by the fact that the publications have increased rapidly in the last years.[7] However, the construct has also attracted criticism because there appears to be a diverse set of business model definitions and a diverse set of approaches to classification. The key questions is "what are the components of a business model and how does business model innovation occur"?

It is important to explore one clear emerging view of the business model construct, namely the relationship between business model innovation and technical innovation. How do technology and business models interact? Technology development can facilitate new business models. But, business model innovation can also occur without technology development, as occurred in 1980s when the Japanese pioneered the "just in time" production system. In fact, business models and technologies regularly interact. Some have applied well-known business model constructs and developed them in new contexts.

There are key relationships embedded in the business model construct, and new business models are related to new technologies. The question is whether business model innovation is potentially separate from technological innovation even though business model possibilities often rely on technology or is there an inevitable relationship between the two.

2.7.1 Building the framework

There are two lines of classifying business models. Some see the business model concept as part of the strategy lexicon and intertwined with technology. Others see the concept of the business model as potentially separable from technology and strategy and examine how understanding business models and business model innovation might shed light on core strategy and technology questions. This latter approach has the potential to answer the long-standing challenges concerning when a novel

[7] Charles Baden-Fuller, Stefan Haefliger, "Business Models and Technological Innovation". Long Range Planning 46 (2013) 419–426.

technology requires a novel business model, and when the combination of a novel technology and a novel business model lead to competitive advantage.

A typology with four dimensions can be developed: customer identification, customer engagement, value delivery, and monetization, and what this typology does for our understanding of business model innovation and its relationship to technical innovation.

2.7.2 Refining the innovation performance link

Strategy scholars have underplayed the role of business model choice in their search for establishing a link between technology innovation and competitive advantage. The typical assumption that a radically improved product or service offering will over time automatically lead to increased profits for the innovating firm, ignores the enormous problems that firms face in working out the interdependencies between business model choice and technology effectiveness.

A given technology seldom operates in isolation from other technologies; interoperability is required in order to create the intended value. This is a well-recognized relationship, but it recently has become more intense, dynamic and uncertain, due to the arrival of sophisticated information technology and greater availability of platform technologies. Those who assume a simple relationships between technology development and the performance outcomes for a firm ignore the moderating influence of business model choice. Business model choice determines the nature of complementarity between business models and technology and the paths to monetization. A poor choice can lead to low profits, a good choice to superior profits.

2.7.3 Developing the right technology

We highlight two important factors in the business model that influence development: the role of openness, and the role of users. Openness refers to the permeability of the company boundaries. It may be valuable for users or even competitors to share technology without asking for compensation, because sharing may lead to learning and to the establishment of communities with similar, professional interests. It is not just openness that matters in determining technological trajectories, but the connectivity between openness and user engagement – again a business model choice. There is an interaction between business model choice and the direction of technology development.

Thus far we have somewhat discussed the way that business model choice influences technological and firm development, but it is pertinent to ask if technology also acts on business model possibilities.

2.7.4 Management agenda

Managers need to be creative in the face of this complex interplay between technological innovation and business model elements. They can recognize the value of involving developer of technology in the design of the business model. This is what sometimes is called the “architecture of participation”.

Managers need to decide who should be involved. Different stakeholders perceive different domains as more central or dominant. Technology developers understand the agenda and possibilities for a technology to be used, but may miss the implications for monetization or market demand. On the other hand, marketing experts may hold deep insights into customer behavior, but may not understand what a given technology could be expected to deliver.

Taking an ecosystem perspective may also help because it focuses attention on how the systems integrators need to form expectations about the scientific and technological fields underlying the components and sub-systems. Even where innovation is not “open” beyond the specification of interfaces, the supplier needs to understand and link to the technological and organizational environment within which their components are sold in order to understand the market.
Systems integrators, platforms, and multi-sided markets share what is sometimes referred to as a business ecosystem. For managers, the ecosystems perspective holds the promise of opening up the

wider entrepreneurial and collaborative space that a new technology affords – and provides room for novel business models to succeed.

2.7.5 Reflections

In summary, business models are fundamentally linked with technological innovation, yet the business model construct is essentially separable from technology. The business model relationship with technology is formulated in a two-way manner. First, business models mediate the link between technology and firm performance. Secondly, developing the right technology is a matter of a business model decision regarding openness and user engagement. The deciding questions concern both technology management and innovation, as well as strategy.

It is first noted that choice of business model influences the way in which technology is monetized and the profitability for the relevant firms. We then noted that the business model frames managers, entrepreneurs, and developers hold in their heads also determine the way in which technology gets developed – and that these connections are capable of being very powerful. This means that the connection between business model choice and technology is two-way and complex – something that has received little attention. And it is also recognized that technology will itself influence business model possibilities.

This means that technology from other sectors such as information technology influences the way in which a business model can be created and adapted. Performance improvements often rely on both process innovation and business model changes.

There is a need to model the link between technology development and firm performance, taking into account competitive dynamics, the influence of technology on business model innovation, and the organization of technology development. The business model may have to change in order to appropriate features of a technology that create customer value. Also, elements of the business model may change in order to allow technology to be developed that fits customer needs or that emerges from the customer directly.

A larger theoretical issue behind this observation is to what extent the organization of technology can and should mirror the structure of the underlying technology. The question is known as the "mirroring hypothesis". It has been demonstrated that for large engineering projects an alignment of team structures with technical modules enhances development effectiveness and saves costs. This points to an important open question, to what extent business model elements can and should map the modularity of the technology applied and under development, and vice versa. Modularity has a long history in strategy and innovation, and, both cognitively and practically, it offers insights that link the stage of technology development with the organization of innovation and customer engagement. Modularity is a model of technology development that could help explain technological development and the joint implications of changing customer demands and technological evolution for the business model.

2.8 Future challenges concerning interacting partners for construction of multi-storey timber buildings

- Techniques for tall wood building construction are under strong development. Combinations of different structural principles open up for different ways to optimize tall structures. Wood industry companies develop systems and methods to meet the new challenges that society's specifications put on the market, and the interest of the consulting companies has been raised, both among architectural and structural engineering offices.

- The most obvious thing that lags behind is the contractors' interest in and their inclination to develop their skills and their operations into the wood sector, but here too, the change is now beginning. There is also a too large gap between main and sub-contractors.

- What is needed in particular for the next phase of the development of wood construction is closer cooperation between the various players in the market.
  * When Stora Enso launched its concept "Building Systems by Stora Enso" on the Swedish market in November 2016, it was intended to showcase opportunities that different applications of the company's different products offer. It was therefore not a ready package, no given optimum solution, but just a demonstration to raise the interests of different market players - and hopefully unite those interests.

- Because it is precisely there, in the synergy between the manufacturer's experience, the architect's visionary ideas, the structural engineer's commitment to good solutions that enable the visions and the entrepreneur's ability to put that into practice in an efficient process, that element deliveries can be transformed into new groundbreaking construction works.

- The large wood companies have extensive expertise in materials and products, and this knowledge must meet the development needs of subcontractors in order to streamline the supply chains towards the end product to partly respond to market conditions, and partly knowledge of consultants and contractors concerning the properties, functions and applications of the products in systems and building objects.

- It is thus about a cross-fertilization between producer and consultant teams, including SME companies, in order for the products to be implemented on a broad front and in order for the construction on the market to be developed.

- On the engineering side – involving both consulting companies and contractors – increased investments in education and training regarding wood material and wood construction are needed, and among architects there is a need for increased knowledge of materials and regarding production conditions.

- At present, uncertainty exists in many of the market players due to ignorance and lack of experience, an uncertainty that can be remedied, inter alia, by increased interaction with the major wood companies and the practical application of existing solutions already available.

- In many cases, SME companies have the requirements for taking the lead regarding the development and to show, for example, the major consultant companies and contractors on the big potential of wood construction.

- For multi-storey buildings the focus is on industrial wood construction. Some companies operating in the field are from the manufacturing industry, while others from the construction industry. Here, both types need to learn from each other.

- Some companies strive to systematize their products, elements and systems, and use configurators to offer variants of the basic design. Others are still working on just designing individual building objects. Here, too, there is a need to bridge the gap between further developed industrialization and traditional or habitual approaches to the process.

- There is also a too large gap between main and sub-contractors. An important effort is to create coordination and collaboration between different suppliers, for example, those supplying the primary frame structure, secondary structural elements, and wood manufacturing products, respectively.

2.9 Trends and challenges concerning multi-storey timber buildings

2.9.1 Reflections on some trends

- There are many good, robust solutions for multi-storey wooden houses. Many of the initial issues have been resolved, and certainly replaced by new challenges, but the visions of the number of achievable floors have also steadily risen – challenges change as the visions become more bold.

- The Wälludden project in Växjö, which was completed in 1997, was the first modern wooden house in Sweden that broke the boundary between four and five floors. In 2004, there were still shortcomings in the field of wood expertise and systems in the wood field to increase the proportion of tall wooden houses on the market (according to a Government investigation), but today several barriers have been passed and, for example, work is going on with respect to Skellefteå's new culture house, which is going to be 19 storeys high when it is completed in 2021.

- In Canada, cross-laminated wood (CLT) is considered today most competitive for buildings with six to twelve storeys, considering the economic situation in the market there, but the market is different in different parts of the world, and increasing land prices in urban environments easily drive up the expectations on what is being built.

2.9.2 Reflections on some other challenges

- In several of the tall wooden building visions so far – both inside and outside the country – wood plays a decisive role, but in combination with other materials. In this respect, CLT offers a key feature. The rigidity and strength of the CLT elements make their applicability extremely versatile, and they are already used in addition to panel-plate systems, also in wood-based column-floor systems, as floors in steel frames, as suspended roof and floor structures for increased spans, etc.

- The combinations open up for many ways of optimization, both from architectural and structural engineering design perspectives.

- Architecturally, the design potential of the tall wooden houses has just begun to be explored and developed, exemplified by the work of the Canadian architect Michael Green in theory and practice.

- The design process should preferably be driven by the digital design environments that computer-aided design enable.

- Also, a thesis for wooden house construction is that woodworking technology provides for or controls the possible future shape of the industrialized timber construction. In this respect, CLT is a very clear example and where also the digital design and planning tools is beginning to give their clear imprints.

2.10 Status in comparison with concrete and steel concerning competence and tools for constructing multi-storey wooden buildings (exemplified by Finland)

2.10.1 Lack of competence and skills

Structural engineers working with concrete, steel and wood are shown in Figure 11. Those knowing and working with wood are very few compared to those working with concrete. Only 30 higher-level structural engineers are educated per year in Finland (Diplomingenjörer & byggnadsarkitekter). This should be tripled!

Construction managers working with concrete, steel and wood are shown in Figure 12. Those working with wood are essentially non-existant compared to those working with concrete. Lahti Univeristy of Applied Sciences offer a degree course in wood engineering with 30 opening seats per year.

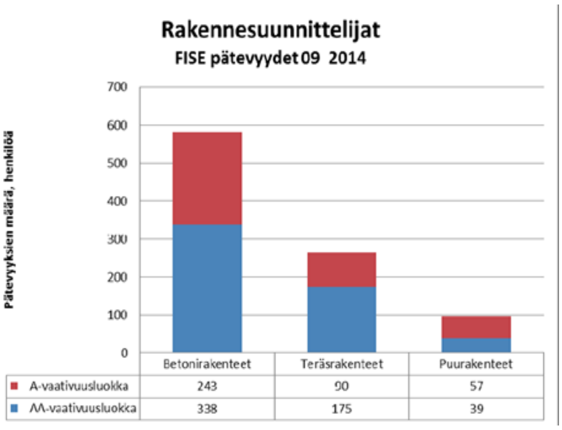


Fig. 11 Structural engineers

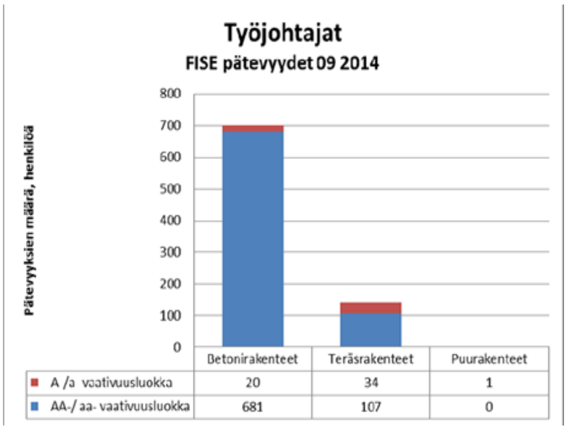


Fig. 12 Construction managers

y-axeln: Number qualified persons
x-axeln: Concrete, steel and wood
Red and blue: Higher and lower level education

2.10.2 Lack of design and planning tools

- Concrete and steel industries have complete sets of design and planning tools, but not the wood industry
  * Concrete and steel designs are based on extensive research and development work
  * Wood industry, therefore, lags decades behind the concrete and steel industries

- The effects are:
  * Architects and engineers are less educated and trained in wood construction
  * Architects and engineers do not have the same access to design support for their work with wood
  * Clients are less prone to choose wood for buildings projects

- This causes:
  * Reject to achieve high energy efficiency
  * Unnecessary excessive expenses, low quality and extended schedules in building industry including renovation and life cycle maintenance

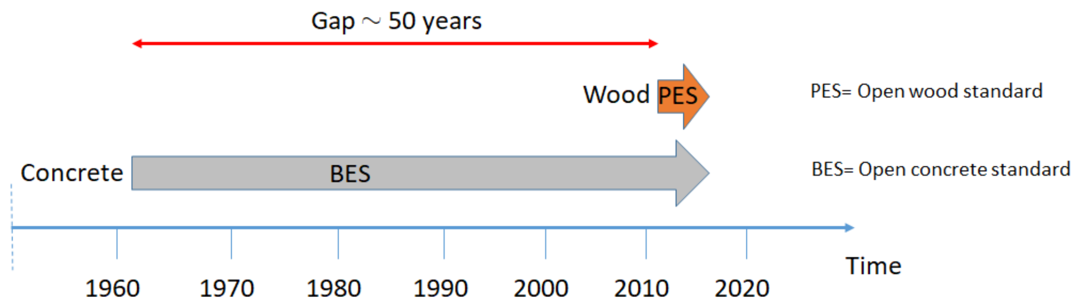
- Building regulation differences in the northern countries, especially concerning multi-storey wooden buildings, will obstruct cross-border services and industrial co-operation.

2.11 Gap between planning tools for timber buildings compared with those for concrete and steel (exemplified by Finland)

Due to building regulations concrete has been the most popular material in multi-storey buildings for decades. Education system has also responded to this requirement by training concrete expertise. Concrete has a long history in multi-storey buildings and both designers and contractors are familiar with the material.

In the 1960's and 1970's an open prefabricated standard for concrete (BES) were developed in Finland. The system was based on standardized elements and standard joints between the elements. An open system made designers work easier and contractors were able to invite several suppliers to submit bids. Because of the system, a great number of small concrete prefabrication factories were established around the country.

The open system for wood is just set up and the experience of the designers and the contractors is low. A lot of research and development work is required in order to make the new system attractive. More research and development is required, especially in stiffening and horizontal movement, i.e. horizontal stabilisation and oscillations of the whole building, and robustness of the higher multi-storey buildings (4-5 storeys and up).



Picture 1. Open standards in use for concrete and wood in Finland

Fig. 13

As described above in Figure 13, the gap of 50 years in standardizing building modules and joints between concrete and wood as structural material has lead the industry to a very favourable position for concrete. In this respect, wood is far from competitive as building material for multi-storey buildings. It is urgent to close this gap.

2.12 Interest groups

The primary target group is companies in the SME sector (up to 250 employees) that build multi-family houses in wood, are in the process of building such, or have development potential and their own ambitions, to be able to build multi-family houses in wood within a reasonable time. Through a thorough review, a number of companies in this category have been identified, all of which have expressed an interest in participating in the project.

The secondary target group includes smaller companies that can be developed by doing business with, and in other ways collaborating with companies that are part of the primary target group, and partly with large companies that build multi-family houses, or components for such. Such larger companies have been called "locomotives" as they can offer growth opportunities for smaller companies in the secondary target group.

The secondary target group also includes carpentry companies, consulting companies in, for example, construction, and companies that supply components to the larger companies.

The demand for multi-family houses in wood is greater than what the region's companies are currently able to meet. The companies that are active and build according to the industrial principle (which is considered to be the only possibility for delivery of significant volumes) are extremely few, and have all been established for a long time. There are only basically four companies in the northern region; Martinsons Byggsystem, Lindbäcks Bygg, Derome Plusshus and Masonite Beams. In the debate on SME growth, growth barriers are often raised, which is why so few of our SME companies manage the journey towards growth. Because there are several companies that have the potential to grow, and it is these companies that we want to stimulate in this project.

Important holdbacks for growth in this industry can be summarized as:

1. Technically verifiable solutions and effective tools to meet the technical requirements: Unfortunately, it is much easier to build houses with a framework in concrete or steel, as there have been good structural aids for these materials for decades. Simpler aids for managing wooden houses with at least up to four to six storeys are important to obtain.

2. Business models: Although small businesses can demonstrate good solutions and good technology for building multi-storey buildings, larger customers (not least public customers, such as municipal housing companies) are reluctant to try new suppliers and new technical solutions. In addition, procurements often require that the supplier has both a high financial strength and a large staff, which SMEs do not have.

3. Ability to lead their companies, as well as appropriate financing: Here, the project can provide advice, even if the questions are too extensive to be directly addressed by the project. These issues can be further processed through the project's partners.

4. Skills supply: Here, the project will support the start of an education towards "Industrial wood construction and wood manufacturing" which is largely aimed at underrepresented groups, women and immigrants.

3. Technical development – Basis for planning tools for wooden buildings, especially multi-storey timber buildings

3.1 Building systems for timber buildings

Today's building system has been adapted for traditional site construction. Today it is important to create conditions for industrial construction and high prefabrication. It is crucial for the building company's continued development to establish products adapted to element construction, which provides increased rationality and quality as well as shorter and "drier" production. In addition to the development of the components themselves, great care must be taken to connect them through effective connections to a complete building system as well as manufacturing and assembly techniques.

In order to streamline the design process and the integration of the building parts, so-called product configurators need to be developed. They are computer-based tools for architects and engineers by which they design, analyse and construct virtually the actual building on the basis of the developed predefined regulations and the scientifically verified design principles for the different building parts.

There is a need to develop different types of design tools that industry needs to produce and build multi-storey buildings in wood. Mainly within the areas (1) architecture and building design; (2) structural engineering – building systems, stabilization, components and connections; (3) building acoustics - sound and vibration; (4) building technology - climate envelop, energy, fire and installations; as well as (5) construction engineering and management processes.

3.2 Future challenges for multi-storey timber buildings

In order for multi-storey wooden buildings to be able to secure their position in the industry, on the market, in consultancy and in management, efforts are needed to synthesize and further develop the building systems. In order to offer the market such rational and efficient, complete building systems that meet the required functionality and safety, a basis is required from systematic R&D work on the technical features of the above areas.

It is important to have an overall perspective for developing the area of multi-storey wooden buildings, in order to take into account all aspects of their construction. This perspective covers the entire chain, as well as the above-mentioned disciplines. For example, this includes the following perspectives.

3.2.1 Architecture

Architectural option, variety and quality include design, building systems, detail design and planning tools. The building system should offer architects and clients a system that allows great flexibility in the choice of design, in the case of, for example, planning, floor spans and making holes. However, this must be done within certain frameworks for cost-effectiveness and production-friendliness. Tools for the architect and structural engineer to use in designing need to be developed.

3.2.2 Structural engineering

Structural engineering comprises complete building systems such as, for example, light-frame systems, CLT systems, post-and-beam systems, hybrid systems and volume element systems. System solutions are due to robustness, horizontal stabilization through, for example, shear wall action, bracing and frame stiffness or stabilizing shafts. The systems are based on systems of building components including floors, walls, roofs, elevator shafts and stairwells as well as secondary components, with their connections and joints. Connections and joints are central to wood-based building systems, for floor suspension, wall joints, anchorages and joints, and in modern wood construction, always involve some form of material combinations with steel, where knowledge about material properties and likewise combinations is crucial. Connections and joints are essential for the required system performance, as well as for effective constructability - handling, transport, logistics, assembly and, possibly, substitution of parts or future dismantling of the building are due to well designed and effective junction solutions.

Robustness is an important property especially for high rise timber buildings since there is not much long-term experience of structural behavior in general and robustness in particular of such buildings. Robustness can be defined in various general or precise ways but in general may be described as a property of a structure to resist global failure due to a limited but destructive load. Other ways to describe robustness are resistance to disproportionate collapse or progressive collapse. Methods to treat robustness analyses of timber buildings are needed and experience from buildings made of materials such as concrete and steel should be taken into account for this. However also special considerations must be taken into account for timber buildings since timber is in many ways very different from other materials, e.g. when it comes to its low weight and special types of connections and joints.

Evaluation of robustness for buildings is necessary and important for all buildings, but maybe especially for high-rise buildings which may contain a large number of people and effects of lack of robustness may be very detrimental. High-rise timber buildings have not been constructed for long and for such buildings evaluation of robustness is demanding since tools, methods and requirements for evaluation (e.g. computer simulation methods) have not been developed and are today lacking to a great degree. Steel and concrete high-rise buildings have been in use since long and for them the situation is the opposite, methods, tools and design standards for evaluation of robustness exist and are established and experience of results from robustness analyses exist. Timber as a building material is to a great degree different from steel and concrete since timber is lighter but still stiff and strong. It can be said that high-rise timber buildings are lagging behind at least 50 years in this respect.

The Swedish authority for building regulations, Boverket, (National Board of Housing, Building and Planning) have some established rules for evaluation of robustness adopted for mainly steel and concrete high-rise buildings. It can be suspected that such methods are not appropriate for timber buildings mainly because of the low weight of timber but also because of other reasons (e.g. other types of joints between structural parts). Existing rules may have too strict requirements that are not suitable for timber. It is necessary to develop and test new methods for high-rise timber buildings that will result in sufficiently robust buildings but that are not too strict. Using too strict evaluation methods will result in overly robust buildings and thus be negative for timber buildings (with respect to cost). Boverket are working on rules and may very well be interested in results from new studies in this area. Cooperation with them are aimed for in this project.

Closely related to structural engineering and architecture are design and planning tools, there are digital interfaces between architecture and structural engineering. The digital tools for the architectural and structural engineering design have in recent years become closer to each other and in the development of configurators. Coordination of the digital tools is required for the design, modeling, dimensioning and simulation, and wood related design programs need to be developed for the new developed wood products. Additionally, integration and adaptation of the construction process to computer-aided production processes, not only for optimized chain from material refined processing, design and dimensioning to production and assembly, but also for optimized resource economizing (materials and energy) to further reduce environmental and climate impact.

3.2.3 Acoustics

Building acoustics primarily include air-borne and footfall sound insulation, flanking transmission, and springiness and vibration, and has long been a major challenge in wood construction. Structural and acoustic requirements are often contradictory. In many modern buildings you wish to have large open spaces for flexible room planning, which means that the floors with long spans are needed. The floors with long spans are therefore critical components that must meet challenges with vibrations and footfall sound in addition to strength and stiffness.

For rational construction, the connection details between floors and walls are crucial. They need to be easy to assemble and must meet high demands on strength and stiffness while being favorable from an acoustic point of view. Heavy and conflicting requirements are therefore imposed on the connections. In order to achieve high interaction between the components in the entire building system, high strength and stiffness are required, while the reverse is valid for limiting the flanking transmission.

3.2.4 Building technology

Building technology primarily covers the areas of building physics design and quality assurance of the climate envelop and pertaining energy efficiency of the building as well as fire safety, installations and life cycle analyses.

Installations must be integrated into the building system, e.g. sprinkler system, ventilation, water and sewer system. Installation technicians should be involved in the development of the building system. In particular, the interconnection between different parts of the system, which allows fast assembly with high demands on precision and work environment, needs attention.

The design of the building system and its roof and wall elements shall be adapted to the new energy directives from the EU and, in the best possible case, even future energy requirements (energy efficiency).

3.2.5 Construction engineering and management and business processes

Building production and building processes cover the areas of prefabrication and manufacturing, assembly and logistics, industrial construction and its processes, as well as management, operation, maintenance and business processes (see further section 2.7). For the industrial construction, building production and building processes are increasingly important, as well as pertaining business models (see further section 4.2). Prefabrication, assembly and logistics are central to contemporary construction and building technology manifests the possibilities and limitations of the construction process.

The construction system must have a high level of prefabrication for industrial construction and require a minimum of completion on the building site to ensure high quality. Entrepreneurs must be involved in the development of the building system's manageability and safety during erection. Assembly and completion are critical factors. In particular, the interconnection between different parts of the system, which allows fast assembly with high demands on precision and work environment, needs attention. The goal is that only the assembly of the various components of the complete building system needs to be done at the construction site by special installers.

An advantage to industrialized building is, among other things, that it establishes a factory milieu with a high degree of stability in production and coordination with subcontractors, suppliers, and designers. The potential drawbacks to industrialized building are reduced design flexibility and the need to intervene with clients and architects/designers at an early stage in the design phase to guarantee proper building specifications and to enable the efficient use of the prefabricated building systems. This balance between prefabrication (standardization) and customization is one of the most studied trade-offs.

Despite the growing academic interest in industrialized building, studies are needed that link industrialized building to overall company business models. Putting industrialized building into a broader business context could lead to a better understanding of its potential for competitiveness and profitability.

It is concluded that there is a need to study how industrialized building fits into overall company business models. It is also acknowledged that there is a need for the opposite perspective in a two-way process, i.e. industrialized building as a driving force in forming new or altered business models.

4. Business development – Basis for business models for wooden buildings, especially multi-storey timber buildings

4.1 Industrialized building

The term 'industrialized building' is the Swedish version of what is known in other countries as offsite construction, offsite production, system building, or non-traditional building.[8] From a technical point of view, industrialized building is defined as the prefabrication of components for elements and complete houses in a factory milieu with product development to support these building systems as products. The advantages to industrialized building are that it reduces the impact of project orientation and establishes a factory milieu with a high degree of stability in production and coordination with subcontractors, suppliers, and designers.

Reliable and fast delivery times are regarded as the most important characteristics of industrialized housing. Generally, competitors implementing traditional, onsite, and project-oriented building are unable to offer these tight time frames that yield fast returns on investments for clients who opt for industrialized building. In addition, lead times for onsite work using volume modules can be reduced to approximately 2–3% of the complete project time (ranging from sales and design to completion of the interior).

The potential drawbacks to industrialized building are reduced design flexibility and the need to intervene with clients and architects/designers at an early stage in the design phase to guarantee proper building specifications and to enable the efficient use of the prefabricated building systems. This balance between prefabrication (standardization) and customization is one of the most studied trade-offs.

Annual average production of multi-storey house apartments between 2006 and 2011 in Sweden was approximately 15 500, out of which between 10 % and 15 % were from industrialized building. Multi-storey housing accounted for approximately 40 % of total housing investments and 1.2 % of GDP.

---

[8] Staffan Brege, Lars Stehn and Tomas Nord "Business models in industrialized building of multi-storey houses". *Construction Management and Economics*, 2014, Vol. 32, Nos. 1–2, pp. 208–226, http://dx.doi.org/10.1080/01446193.2013.840734.

Consequently, offsite prefabrication accounted for nearly 0.2 % of GDP (with approximately 500–700 persons employed).

Specifically, the empirical context is the industrialized building of multi-storey wooden houses with wooden frames in the Swedish market. Since 1994, the market share within this particular market segment has grown from 0 % to nearly 15 %. Before 1994, building wooden-framed multi-storey houses was prohibited. In Sweden there are five dominant wooden companies that produce prefabricated timber building systems (most of them in the Nordic region), which have brought about this development (and which accounted for more than 90 % of accumulated production from this market segment).

4.2 Business models

Despite the growing academic interest in industrialized building, studies are needed that link industrialized building to overall company business models. Putting industrialized building into a broader business context could lead to a better understanding of its potential for competitiveness and profitability. A business model perspective could also help improve the understanding of why the take-up of industrialized building has been slower than expected.

It is concluded that there is a need to study how industrialized building fits into overall company business models. It is also acknowledged that there is a need for the opposite perspective in a two-way process, i.e. industrialized building as a driving force in forming new or altered business models.

Here, we focus more specifically on different business models that have industrialized building (in the various stages of value added in prefabrication) as a basis. The business model construct is used as an analytical tool, providing a holistic perspective on how a company does business and which activities and resources are mobilized.

Concerning business models for industrialized multi-storey wooden buildings, the following approaches can be considered:

(1) Adapt a general business model construct to the industrialized building setting and choose the major business model elements.
(2) Empirically identify the most frequently used business models and model elements.
(3) Analyse the requirements for a good fit between the environment, the business model, and its business model elements.

There is a need to establish important theoretical cornerstones for industrialized building and business model constructs. Design business models where the business model elements are adapted to industrialized building. Viable business models need to build up strong marketing push mechanisms to ‘create’ a market for industrialized building.

4.3 Business models for industrialized multi-storey buildings — Business model construct

The business model construct has been widely used during the last decade, partly because of its popularity among business managers and partly because of its potential to provide a holistic view of how companies do business. The holistic business model construct has a high degree of descriptive detail and analytical potential that can be reached by combining different theoretical perspectives. The business model construct is a very efficient analytical tool.

The business model construct includes three major building blocks: (1) market position; (2) offering; and (3) operational platform. The market position defines and distinguishes the roles taken in the marketplace and is closely connected to strategic effectiveness (‘are we doing the right things?’). Strategic effectiveness can be measured in terms of market share, brand equity, customer satisfaction and profit margins from premium prices. The operational platform is the resource base and how it is organized and is closely connected to operational effectiveness ('are we doing things right?'). Operative effectiveness can be measured in terms of cost development, quality improvements and lead times to customer and market. Finally, the offering is a sort of intermediate building block that connects the resource base with the market position.

The offering is perhaps the most important part of the business model because it ends up in a 'value proposition' directed toward customers. Market position is often described in terms of the segments and relationships through which the value propositions are communicated, negotiated, and adapted/developed. Because value propositions are often the result of cooperation in company networks between suppliers, partners, and so forth, market positioning must also include the company's position in a broader value network. The operational platform consists of the resources and competences of the company, together with complementary external resources from suppliers and partners, and the manner in which these are organized and used. From a technology perspective, the solution lies in the development of product platform portfolios and component product platforms.

In the context of industrialized building and the advancement of operational platforms for different prefabrication levels, lean production philosophies are being systematically introduced. Some of the initial problems related to moving from onsite production to factory-based production (offsite) settings are essentially cultural. Factory building strategies rely on repetition, which leads to standardization and product platform thinking in design and production, stable organizations with multi-task workers, and pre-planned flexibility.

Five business model elements are identified: (1) prefabrication mode (operational platform); (2) role in the building process (market position); (3) end-user segments (market position); (4) system augmentation (offering); and (5) complementary resources for design and onsite construction (operational platform).

The starting point is the prefabrication mode or building system level, which is part of the operational platform. To construct a business model based on prefabrication level, the other four elements are needed as complementary.

4.3.1 Prefabrication mode (Fig. 14)

Three prefabrication modes (or levels) of building systems are identified: module elements, floor/wall elements, and component systems. A building system based on module elements is at the highest prefabrication level (approximately 80 % offsite and 20 % onsite), component system operate at the lowest prefabrication level (an inverted ratio of 20 % offsite and 80 % onsite), and the prefabrication level of the floor/wall elements is in between. This categorization follows praxis on Swedish market.

The three prefabrication modes differ in (in-built) knowledge, intensity, and complexity in terms of coordination. They are different in a technical sense in maintaining and developing the building system and in a business sense in conducting business as projects or as recurring building projects in a process. Each prefabrication mode has pros and cons. For example, the volume module has the advantage of a high degree of factory production but also the lowest flexibility in design adaptation to building specifications, which places demands on early involvement in the design process. Consequently, in-house capability or long-term cooperation with architects/designers is needed, which is why volume element builders display high technical/coordination complexity in maintaining their building systems and, consequently, the highest complexity in the operational platform.

4.3.2 Role in building process (Fig. 15)

The low flexibility of the different prefabrication modes, combined with a traditional building process and general or design-and-build contracts that favour onsite construction with a high degree of flexibility, indicate that coordinating many subcontractors and adapting to varying client conditions are major obstacles. Therefore, the prefabrication strategy must be complemented with a strategy for the role that industrialized building companies aim for in the building process.

For volume element producers, a high degree of control in the architectural design phase and total onsite control are particularly important, making the main contractor role the most appropriate. The producers of floor/wall elements offer higher flexibility in meeting client demands and building specifications, which enables them to enter the building process as specialized (frame) subcontractors. Prefabricated element manufacturers have a medium level of onsite coordination and responsibilities in the design phase.

4.3.3 End-user segments (Fig. 16)

The literature together with the empirical findings on the behaviour of industrialized housing companies and the strategic behaviour of Swedish developers show that the following interconnected dimensions are important: (1) level of living and architectural standard/quality; (2) attractiveness of the location; (3) category of living as family, elderly, students, etc.; and (4) tenure of the dwelling as rental or condominium.

When end-user segments are linked to prefabrication mode, these segmentation criteria could be condensed into two variables: (1) the level of living and architectural standard; and (2) the degree of customer adaptation (or potential for larger volumes of standardized deliveries). The module element mode delivers primarily standardized solutions, which logically leads to a choice of a low to medium standard. The floor/wall elements producer normally targets a higher standard and customer adaptation in high and medium locations and the producer of component systems is able to cover the entire market.

4.3.4 System augmentation (offering) (Fig. 17)

The offering element in the business model is defined as system augmentation (increased value added in the offering) and could be analysed as a combination of the degree of prefabrication of the building system and the role of the company in the building process. The offerings are expressed in functional terms. A turnkey offering is often accomplished by combining a main contracting responsibility and a volume element prefabrication mode. When the industrialized housing company combines the main contracting role with a developer role, the outcome is a build-operate solution, or long-term ownership by the company. When a subcontracting role is combined with a floor/wall element prefabrication mode, the functional result is a climate-proof structural frame or even a complete climate shell with cladding erected on site. Finally, the combination of a supplier role (subcontractor or sub-subcontractor) and a component prefabrication strategy results in a component systems offering.

4.3.5 Complementary resources (Fig. 18)

Complementary resources are those directed toward the design and onsite production phases, such as architectural resources, design capabilities, and assembly teams and resources (for example, onsite machinery, cranes). The turnkey (and the build-operate) offerings demand the highest degree of complementary resources in both the design and onsite production phases. The floor/wall element offering (climate-proof structural frame) is in the middle of the three types, whereas the component system offering demands the lowest complementary resources. However, the problem for frame systems suppliers, depicted in the middle of Figure 18 is that elements can come complete with technical installations, indicating that a customer may request, or the company may offer, liability for functional performance. This possibility implies risk taking in terms of contracts and a capacity for onsite assembly and coordination in the design phase with other technical sub-consultants. Such a situation creates tension in terms of the responsibilities in both design and onsite production in the frame system producer’s business model.

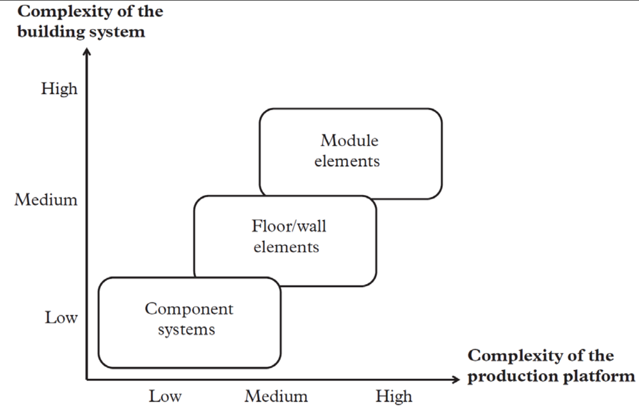


Fig. 14. Prefabrication mode as the degree of complexity of building system and production platform

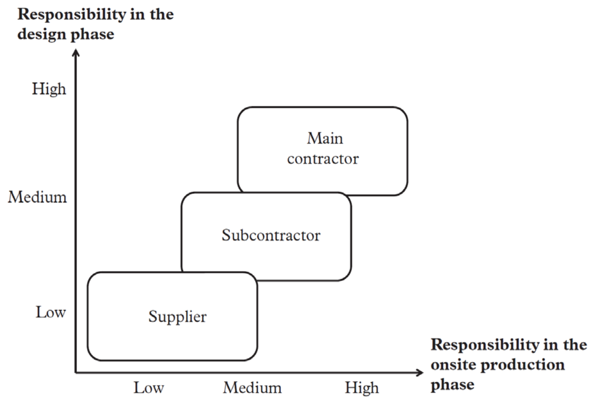


Fig. 15. Role in the building process based on degree of responsibility

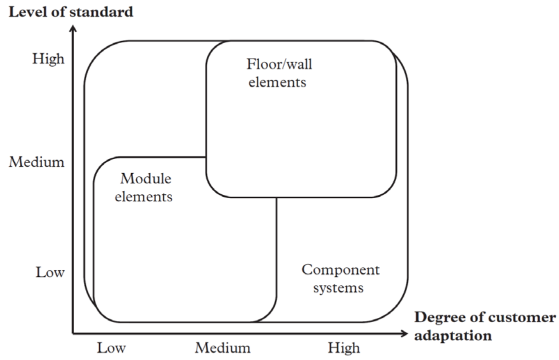


Fig. 16. End-user segments are the combination of level of standard and degree of customer adaptation

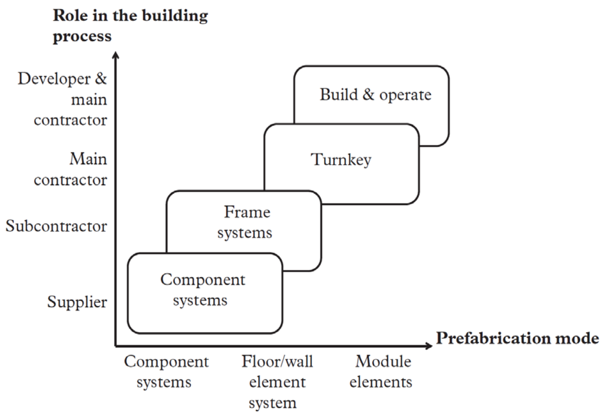


Fig. 17. The offering combines the role in building process and type of prefabrication mode

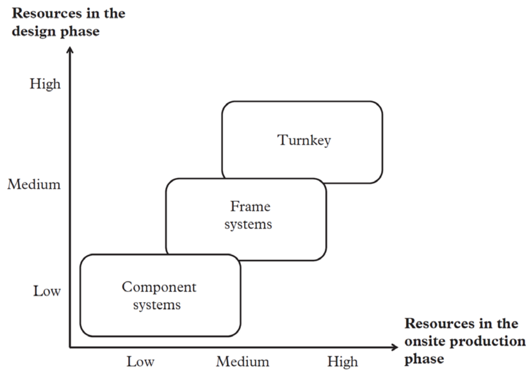


Fig. 18. Complementary resource base indicates the degree of control of resources for design and onsite phases

4.3.6 *The entire model*

In sum, when the prefabrication mode (Fig. 14) was expanded into a business model construct, it was broadened using four business model elements (Fig. 15-18). Together, these elements formed theoretically possible configurations and myriad combinations.

4.4 The business model construct — Present experiences

Studies have been made on the five dominant Swedish companies and their production of prefabricated multi-storey timber houses and their different business models.

4.4.1 *The cases of Lindbäcks, Moelven, and Setra – volume element producers*

The modules consist of wall, floor, and ceiling elements assembled into a closed three-dimensional structure. The modules are as complete as possible, including interior finishing, before being transported to the construction site, where they are assembled. The prefabrication degree (that is, the amount of money and time spent inside the factory, including transportation, compared with that spent on site) is approximately 75–85 % for all three companies. The building system is based on timber studs or solid wood, and the typical size of the modules varies between 4 x 3 (width x height) and 8 or 12 (length) cubic meters.

In recent years, consultants have been more closely connected to companies through long-term agreements. Moreover, a considerable proportion of traditional subcontractors (electricians, heating, ventilation, and air conditioning (HVAC) installers, carpet layers, and others) is now found in-house or is engaged through long-term contracts.

All companies aim for the main contractor role and exclusively work with design-build contracts. The obligations and rights sections of these contracts are sometimes modified through a performance-based contract adaptation.

Early involvement in the conceptual phase of a building project is crucial because design decisions affect the ability to efficiently use the module building system. All companies devote resources and are able to enter into discussions early in the design and planning phases of a project. Effective interaction between sales and design is a core skill for our case companies; however, the companies vary in terms of their organizational solutions and the manner in which they approach customers or the customers' architects.

A key complementary resource is architectural design. Therefore, significant effort goes into communicating the pros and cons of building systems to architects. In fact, all three companies work with universities on research and development to verify, present, and develop methods to facilitate the design of their building systems and collaborate closely with selected architectural firms. Setra has a long-standing practice of cooperation with a larger architectural firm and bases its development on a scientific approach to construction and architectural engineering.

Other key resources that the three companies identified, maintained, and developed are transportation, logistics, and onsite construction work.

4.4.2 *The case of Martinsons Building System*

Martinsons Building System manufactures solid wood floor/wall elements combined with glulam. These elements constitute the frame system for multi-storey dwellings. The elements themselves are prefabricated to approximately 90–95 %. The system offers high structural performance and the open span length is approximately 12 m, which provides a large degree of freedom for the floor layout. Depending on the overall contractual agreement and the client, the elements can be delivered complete with cladding and with all technical installations. Technical solutions are available for both factory and onsite completion of installations. A climate-proof structural frame, or even the complete climate shell with cladding (for example, facade, windows, doors), can be transported to the site and sometimes even erected on site. Transportation and some assembly are subcontracted.

Martinsons works exclusively through design-build contracts. The company's role varies, which can strain the business model. For most of its projects, Martinsons acts as a specialized frame subcontractor to the main contractor, which means that the company's responsibilities are prefabrication and transportation, design, design coordination, and onsite assembly of a complete climate shell.

The building system is general and open (unlike the closed and company-controlled volume modules), enabling any architect or structural designer to work with it. To support the work of architects, Martinsons must maintain, develop, and promote handbooks.

4.4.3 The case of Masonite Flexible Building System (MBF)

The Masonite Flexible Building System is an open/general system solution based on three elements: (1) Masonite's own prefabrication of different types of I-beams; (2) lightweight floor/wall elements prefabricated separately by a project-specific manufacturer or through longer-term agreements; and (3) design and assembly instructions. The building system company is part of the Masonite Group, which also produces commodity I-beams and engages in general building projects. The manufacturing of I-beams is highly mechanized with a high volume output. Lately, the company made efforts to increase efficiency and planning by implementing lean production techniques and tools.

Depending on the prefab element manufacturer, the Masonite open building systems offer good- to high-structural performance, and six storeys are now technically possible. Structural composite floor solutions with a span length of approximately 10 m provide architects with a large degree of freedom to design an open floor layout. The complexity of the system is deliberately kept low by using standardized components and design/assembly guides that enable architects and structural engineers to combine them as they see fit.

Masonite has the knowledge to act as a building component supplier (excluding assembly) to a specialized frame subcontractor. The company's main competence is manufacturing of tailored I-beams and coordination of floor/wall elements manufacturers' delivery of 'building kits' with assembly instructions to the main contractor.

The company's role is categorized as a specialized and versatile subcontractor that assumes technical responsibility to architects, contractors, and developers for handling its system. However, from a contractual perspective, the company assumes both the risk and the low design responsibility of a traditional subcontractor or materials supplier under several forms of general to design-build contracts.

Masonite has few key complementary resources. Drawing on the group's selling/marketing resources, tendering and selling are maintained as a whole. Masonite does not operate the onsite work. However, to facilitate assembly, the company includes practical training for the contractors' onsite personnel on a test building that can be assembled or de-assembled before the site work.

The second key aspect is sustaining and updating the design and assembly instructions. This aspect includes assuring the quality of the open building process using decision-making checkpoints and 'what if' scenarios. The instructions are co-developed by academia and through close cooperation with key manufacturers, architects, and designers (primarily small and medium-sized enterprises (SMEs)).

4.5 Emperically identified business models

The empirical data have identified seven business models in terms of configurations of the five parameters presented in the frame of reference (Figs. 14-18).

4.5.1 No. 1: Systems supplier with turnkey offering

The dominant business model is the system supplier with volume element prefabrication and a turnkey offering mode. This business model accounts for approximately 80 % of the total deliveries of our five case companies (including in-house ownership; see business model no. 3). The configuration is built around the module element prefabrication mode; additional business model elements are the main contracting role in the building process, a turnkey offering toward volume end-user segments such as medium-quality family houses in medium acctractive locations, dwellings for the elderly and students, and, finally, a highly upgraded resource base with complementary resources. The three case companies producing module elements (Lindbäcks, Moelven and Setra) all developed this business model and Setra also attempted to assume the additional role of developer.

The case descriptions show that, during the introduction of prefabricated timber solutions on the multi-storey housing market, taking the main contracting role in the building process was extremely important. This position was vital to persuade clients to use timber frame solutions and to gain control in the design phase. To a large extent, the three case companies were forced to 'create' this market segment by themselves, which would have been more difficult to accomplish from other positions in the building process.

4.5.2 No. 2: Systems supplier with free factory offering

This system supplier business model takes the position of selling free factory. Apart from some technical assistance in the design phase, the business model remains 'inside the factory'. The end-user positioning is the same as the system supplier/module business model. To date, selling the prefabricated module system free factory has been used very infrequently and with questionable results. Moelven had bad experiences with inexperienced customers that could not handle the onsite assembly, resulting in discussions about which party bore the responsibility.

In contrast, this business model is very successful within the Swedish market for small houses and for selling construction barracks. The immature status of the market is a key explanation for the difficulty encountered when this model is implemented in the multi-storey segment. No widespread knowledge exists within the industry (or in the university system) on designing and building using prefabricated wood elements.

4.5.3 No. 3: In-house developer and systems supplier with the build-and-operate offering

Among the case companies, the only in-house developer was one of the module element producers (Lindbäcks). The in-house developer strategy was estimated to account for approximately 15 % of the total market for prefabricated (wooden-frame) multi-storey houses. This business model is well suited to the early stages of market introduction because the contractor produces for its own real estate company, but also as a possible way to level off fluctuating market conditions. A company that produced for itself may offset low demand and keep the factory going.

4.5.4 No. 4: Frame system supplier with climate-proof structural frame offering

The frame system with a climate-proof floor/wall element prefabrication strategy was used in less than 5 % of the total building volume of our five case companies. The business model configuration built around the floor/wall element prefabrication mode is the subcontracting role in the building process, together with a functional offering in terms of a climate-proof, structural frame directed toward the higher quality segment of family multi-storey houses. The need for complementary resources is medium to high regarding both the design phase and the onsite production (assembly) phase. One case company, Martinsons, was 'forced' into this business model to 'get things done'. However, Martinsons now attempts to avoid this business model because the profitability was not high enough relative to the risks involved in the subcontracting (close to main contracting) position.

4.5.5 No. 5: Frame system supplier with free factory offering

The frame system supplier business model could also take a selling position free factory. This model has been used more frequently than the module element free factory business model (no. 2), accounts for an estimated 5 % of the total market volume, and produces more positive results. This business model avoids the responsibilities and risks involved with a subcontractor position in the building process (as mentioned in business model no. 4).

4.5.6 No. 6: Component system supplier with technical support offering

The component system supplier business model is built on delivering a customer-adapted component system that is sold with additional technical assistance in design and onsite assembly. This component system is widely used and customers from all market segments could be viewed as potential customers (and customers from other markets, such as detached houses). This business model can be viewed as an adaptation from the supplier (Masonite Beams) to meet customer demand and an adaptation to the low level of knowledge and understanding among architects regarding the system's technical requirements/obstacles. This business model represents approximately 5 % of total volume.

4.5.7 No. 7: Component system supplier with a material supplier offering

This business model with a material supplier offering sells customer-adapted components free factory. In all other respects, the model is similar to the component system supplier business model (no. 6). It is a relatively viable model and represents approximately 7–8 % of total volume. A supplier (Masonite Beams) prefers this business model, with its lower risk profile and the potential for highly standardized and scale efficient production and delivery.

4.5.8 Reflections:

The successful implementation of industrialized building depends on business models with industrialized building as a basis or a starting point. Thus, an important conclusion is to take the prefabrication mode as the starting point for business model design and then adapt the other model elements to a good fit with industrialized building. All of the dominant industrial builders in the Swedish market viewed themselves primarily as producers of prefabricated building systems. To do business successfully, they had to design entire business models to 'complement' their prefabrication mode.

In marketing, successful companies often manage to create a combination of push and pull effects. Push effects are built through effective sales and distribution and a high degree of availability when the customer is willing to buy. Pull effects come from customers' own demand for a company's offering, which could result from a high degree of brand awareness and brand loyalty.

Concerning the push and pull mechanisms that promote industrialized building, one could argue that only weak pull mechanisms exist at the institutional level. Regulatory changes are creating opportunities for industrialized building in the UK and Sweden (function-based codes and government support for pilot projects), but these changes are comparatively weak. Strong pull mechanisms are also lacking at the corporate level, partly because of mental barriers and a lack of knowledge among architects and other decision makers in the building process.

Therefore, a need exists for strong push effects when introducing industrialized building as an innovation. And as a consequence, a second and very important business model element to promote industrialized building was the role taken in the building process. The empirical data show that, in four out of the five cases, the industrialized builder also took the main contractor role in the building process. Such a role is particularly important for volume element prefabrication, which is specifically required for early involvement in the design process.

A long-term perspective and a more mature market for the use of industrialized building of multi-storey houses may result in stronger pull mechanisms at the institutional and company levels, which reduce the need for the main contractor role to execute such strong push mechanisms. However, Sweden seems to have a long way to go.

Important barriers to industrialized building are high capital costs and lack of economies of scale and scope. The challenge lies in the ability to combine a standardized offering from the operational platform with a relatively homogeneous demand from the customer base. Industrialized builders of module elements have the greatest need for high volume market segments, whereas producers of component systems could achieve economies of scale and scope by selling a standardized product range to a large and more heterogeneous customer base. In both cases, lean thinking and development of standardized modules are important tools to achieve operational effectiveness.

Immature markets within the construction sector, in other countries and in other construction segments, are also believed to need strong push mechanisms to successfully promote the introduction of new technologies and business models need to be adapted to this new technology.

To better understand the pros and cons of industrialized building and its extension into viable business models, conducting comparative studies between different housing and construction segments and between different countries with different institutional structures would be fruitful.

5. Application – Demo and pilot projects for wooden building systems, especially multi-storey timber buildings

5.1 Follow-up of pilot projects

Wood is perhaps our oldest building material. In the Nordic countries, wood has been used extensively for our buildings throughout history. We can divide wooden houses/structures into three main types; (1) pure wooden houses; (2) houses of wood joined by the use of steel (screws, nails, bolts) and (3) houses that are stabilized with concrete core for stairs, lifts and other service areas.The variants are many and include composite floors with wood and concrete, semi-conditioned zones behind glass facades etc.

Using wood for high-rise buildings requires not only special attention to these issues, but also challenges the methods we use to build or wooden houses. For example, in Bergen, a 14-storey wooden house was erected in 2015. The house uses a number of diagonal struts with large dimensions (cross-girders) which takes up a lot of valuable space inside the apartments. The erected house in Bergen proves that there is still a way to go before frameworks for high-rise wooden houses are sufficiently rigid.

In order to study the various methods and solutions of wooden buildings, there is a need of following selected pilot projects to study and evaluate the whole building with respect to business models and the construction process. The purpose is to gather the current technology level, identify the solutions applied to the projects, and record the challenges and problems experienced in the projects, including technical, planning and business aspects. Also, to evaluate the pilot projects from a perspective of industrialization, digitization, and energy efficiency.

5.1.1 Business models and development

Concerning the business models for industrialized multi-storey wooden buildings, the following items could be studied (see further details in Section 5):

(1) Is there a general business model construct to the industrialized building project and what choices are made concerning the major business model elements.
(2) Identify empirically the most frequently used business models and model elements.
(3) Analyse the fit between the environment, the business model, and its business model elements.

Evaluate the business model construct with respect to the following three major building blocks: (1) market position; (2) offering; and (3) operational platform.

Identify the following business model elements:
(1) Prefabrication mode (operational platform);
(2) Role in the building process (market position);
(3) End-user segments (market position);
(4) System augmentation (offering); and
(5) Complementary resources for design and onsite construction (operational platform).

The starting point is the prefabrication mode or building system level, which is part of the operational platform. To evaluate the business models, include the prefabrication level (cf. Section 5.1.2), and to study the other four elements as complementary.

5.1.2 Construction and planning process

Concerning the construction process for industrialized multi-storey wooden buildings, the following sub-processes could be studied:

(1) Planning;
(2) Manufacturing;
(3) Erecting

and

(4) Project managing – interaction between partners; and
(5) Following-up on the function of the building.

Especial focus could be on critical issues as:

(1) Horizontal stability, robustness and building oscillations, and also on sound and vibrations of floors and flanking transmission, and on energy efficiency;
(2) Planning, management and interaction between participating partners (consultants, wood companies, entrepreneurs) and between main supplier (big wood companies and other "locomotives") and subcontractors (SME's) and cross-border exchange and learning, etc.; and
(3) Industrialisation and digitalisation of the different processes.

One purpose is also to identify strong and weak items and pick up problems and challenges in the project that need supplementary or in-depth study.

5.2 SME perspectives

To study the projects in order to find out what parts of the building process (as subcontracting, planning, manufacturing, erecting), structural components (as floors and walls, balconies) and manufacturing products (as woodwork, flooring, installations) that could be suitable for SME's to be involved in. For what parts could the SME's act as sub-contractor, sub-supplier, sub-sub-supplier and/or designers. To evaluate what types of business models could be applied for such sub-supplier work.

Also, evaluate why SME's are not requested to take part in the building process of wooden multi-storey buildings to a greater extent than at present. Why are some developer and contractor doing most by himself? What parts could more effectively be performed by a specialized sub-supplier? How to make the building process more efficient and economical by involving SME's more?

5.3 Digitization (exemplified by Norway)

The building and construction industry has experienced stagnating productivity in recent years. In Norway this has got national attention through parliamentary reports and national measures (eg Stortingsmelding nr. 28 / 2011-2012 Good buildings for a good society, the Building21 strategy in Norway - Together we build the future, Roadmap for digitization - for a fully digital, competitive and sustainable industry (BNL 17/2 2017)).

The main report from the Norwegian research council co-funded innovation project SamBIM (ended November 2016) gives a good overview of the background for the productivity stagnation in the industry in Norway, why the challenges are linked to digital transform, changed interaction processes in the value chain and what new knowledge, technology, forms of interaction and types of contracts that are necessary to increase productivity in the industry.

In summary, the SamBIM report shows that the industry is dominated by numerous and small to medium sized players who traditionally organize design, planning, construction and operations differently from project to project, and who struggle to spread innovations because the composition of participants from project to project is changing. New digital technologies are now entering the industry, creating need of change for all stakeholders. However, without the standardization of processes, methodology, tools and contractual forms, players cannot take out the potential gains. In an industry with a large proportion of small local and regional actors, local, national and international cooperation is required to boost the productivity of the industry.

Successful digitization throughout the entire value chain will result in lower costs in the planning and construction phase, reduction of planning and construction times, reduced amount of errors in the construction process and more efficient operation and maintenance of the building throughout its life.

In conjunction with the follow-up of demo and pilot projects, focus is also on the development of cooperation forums/meeting places where industry and research community identify specific problem areas, where research and development projects can be established. Such projects are linked to future real projects in the region where “Digital construction site” and “digital twin” will be central. Implementation of BIM requires participation from the entire value chain, and there is a need for significant development of interaction processes in this work. UiT The Arctic University of Norway, Alta, has a complete, state of the art BIM cave to be used to visualize and demonstrate possibilities concerning technologies, methods and pilot projects.

In Alta, Smart Construction Cluster (SCC) was established in 2015, where UiT is also a member, and approximately 25 companies in the construction industry. The Cluster aims to position Alta as the leading Testlab and Lauchpad for Digital Construction and specificly for implementation of the national “Roadmap for digitization”.

5.4 Demo and pilot projects

Examples of real building projects that can be studied and evaluated are given in the following:

5.4.1 Sara kulturhus, Skellefteå

The Sara building is a cultural centre and hotel. The area is 25.000 m^2, of which 15.000 m^2 for the culture centre. The building include a City library, Art gallery, Museum Anna Norlander, Västerbotten county theatre, and a Hotel/Congress centre.

Fig. 19. Sara Cultural House in Skellefteå – A nineteen storey timber building.

5.4.2 Soksbo Modulohus, Skellefteå

Modulohus is a new wooden building concept for multi-family houses. The system is smart building, cheap and sustainable. Modulohus lowers the price per square meter of multi-family homes by up to half or more.

Modulohus has opened the door to smart Swedish construction technology. The very cost- and energy-efficient solutions come from the company's many years of experience in electricity and real estate. The first complex with 38 apartments was ready for occupancy in the autumn of 2015 on Bockholmsvägen in Skellefteå.

Modulohus prefabricated modules enable short assembly times. The dimensions are optimized to avoid unnecessary building material waste. Modules can be joined or divided depending on the desired living space, which means that the house can easily be adapted to different groups of tenants. The construction also allows the construction of high-rise buildings and housing complexes, and that finished houses can be moved relatively easily. Thick exterior walls, attic corridors and wastewater recycling, just like the dishwasher and washing machine in each apartment, provide the conditions for controlled energy consumption.

The construction method is by prefabricated modular volumes, high prefabrication in a controlled factory environment, and site assembly with crane, quick and easy.

Fig. 20. Modulohus – A new wooden building concept using prefabricated modules.

5.4.3 Ör-projektet, Sundbyberg

The Folkhem's Ör-project is a city block of wood with social, ecological and economic sustainability. In the new block, a total of 209 new homes will be created with a mix of, tenancies, condominiums, senior housing and intermediate housing. In this way, the neighborhood gets a nice mix of different types of housing, ages and needs. The neighborhood offers new meeting places in the form of a new grocery store, café, workshops, coffice, culture house, gym, bicycle workshop, etc.

Fig. 21. Ör centrum i Sundbyberg, Stockholm – A block with multi-storey timber buildings.

5.4.4 Cederhusen, Stockholm

Another multi-storey timber building of interest is Cederhusen in Stockholm.

Fig. 22. Cederhusen in Stockholm – A "block" with multi-storey timber buildings.

5.4.5 Alta Care Center, Alta, Norway

Using wood in construction has long tradition in Norway. Most buildings in the country are made of wood, either using solid timber or frame structures. Lately, due to the advantages of wooden materials, also high rise wooden buildings have appeared. The Alta Care center will have a combined massive wood and concrete structure. For this structure, the building process and the use of BIM is of interest.

Fig. 23. Alta Care Center.

5.4.6 Mjösa Tower, Brumunddal, Norway

Mjøsa Tower is a 18-storey, 81 m high wooden building in Brumunddal, and was at the time of completion the world's tallest wooden structure. The structure is supported by concrete in the upper storeys to stabilize the the tower from swaying. The building process of the tower and, specifically, the methods and solutions used for erecting such a tall wooden building.

Fig. 24. Mjøsa tower, Brumunddal Norway – 18 storey wooden house.

5.4.7 "Treet" in Bergen, Norway

"Treet" in Bergen is a timber-framed multi-family wooden building. "A key challenge when erecting the building was to have sufficient horizontal stability, and preventing the building from swaying in strong winds. To solve this, the glue-laminated frame was reinforced with diagonal glulam braces. In addition, concrete elements were added on the top of the 5th and 10th floors to bring more weight to the building.

Fig. 25. Treet i Bergen – 14 storey and 51 m high timber building.

6. Summary – Areas of research and development

6.1 Background

Wood plays an important role in the construction industry to meet the challenges of the climate, finite natural resources and energy consumption. It plays a significant role in environmental and climate effects on society as well as the well-being of its individual citizens. Among the different applications of wood, multi-storey wooden buildings play a special role. The positive effect of wood indoors on the health of residents and building environmental, can mean great business opportunities for the wood industry.

Multi-storey wooden buildings in the Nordic region have proven to be the main business opportunity in the new bioeconomy, see Toppinen, "The future of wooden multistory construction in the forest bioeconomy", *Journal of Forest Economics*, 2017. However, it is emphasized that the technical challenges must first be overcome and access on design tools come to the same level as the equivalent for concrete and steel.

The future potential for increased construction of multi-storey wooden buildings has also recently been studied, see Brege, "Industriellt byggande i trä – nuläge och prognos mot 2025", 2017. It emphasizes that based on demographics (strong population growth and strong urbanization), climate (climate impact reduction) and employment (keeping employment at a high level with a "reasonable" distribution of jobs between urban and rural areas), industrial timber construction can contribute as follows until 2025: (1) Build capacity for industrial timber construction to be able to deliver 50 % of the multi-storey houses in wood on the Swedish market; (2) Create 8 000 new jobs in prefabrication companies and help relocate 6 000 jobs from big cities to the countryside.

Business development focuses on identifying opportunities and developing resources for new, expanded or changed business operations. For the construction industry, this means a need to create business models and business strategies for the building process, which include design, manufacturing and construction, and involve consultants, contractors and small and large suppliers.

Business models are linked to current technical activities, see Baden-Fuller, "Business Models and Technological Innovation", 2013. When business models and technologies interact, this connection needs to be a starting point. We need to link industrial construction with companies' business models, as emphasized by Brege, "Business models in industrialized building of multistory houses", *Construction Management and Economics*, 2014. Business models for industrialized construction of multi-storey wooden houses that are in focus can provide a better understanding of its potential for competitiveness and profitability. Industrialized construction is also a driving force in shaping new or changing business models.

For multi-storey wooden buildings, it is important to address the challenge of the interaction between different parties in the building process, between the larger wooden companies, the "locomotives", and the SME companies. In order to reach the next phase in the development of wood construction, it is important to develop closer cooperation between the various players in the market. The forms for SMEs as subcontractors need to be developed.

There is a great demand for multi-family houses in wood, and it is expected to increase. The few large companies that exist cannot be expected to be able to meet this increasing demand. There is a great opportunity here for SME companies that have the ability to develop to be able to contribute.

6.2 The focus of the R&D work

The work is based on technical and business aspects on industrialized construction of multi-storey wooden houses. Here, the business forms for collaboration between large and small companies, and to create forms for how SME companies can function as subcontractors play a crucial role. An important aspect is the digitization of the various modeling tools. An important prerequisite for business development is a parallel development of the construction process and its technical and organizational design tools so that consultants, wood companies and contractors have access to them on the same terms as for the competing materials concrete and steel. Current building projects must be carried out in parallel with the intention of studying, applying and evaluating the business and technical principles and tools that are developed.

It is important to provide small and medium-sized companies with knowledge based on process-oriented learning ("learning by doing") and by exchange including both technology ("how we build – what can we learn from each other") as well as business models ("how we sell – what can we learn from each other"). Learning also takes place through studying and evaluating demo and pilot projects.

6.3 Three main areas of activities

The work comprises of three main activity areas: (1) the technical part, (2) the business part, and (3) the application part.

Technical part: There is a need to develop different types of design tools that the industry needs to produce and build multi-storey buildings in wood. Mainly within the areas (1) architecture and building design; (2) structural engineering – building systems, horizontal stabilization and sway, robustness, components and connections; (3) building acoustics - sound and vibration; (4) building technology - climate envelop, energy, fire and installations; as well as (5) construction engineering, planning and management processes. Here we focus on the first two areas. There is a need for filling the gap concerning planning and design tools for the construction of competitive wood building systems compared to those existing for the concrete and steel industry. Here we focus on the first two areas.

Business part: A rather undeveloped area is business and management models for wood building projects, especially for multi-storey wooden buildings. There is a need of developing business models for wood building systems, for industrialized manufacturing and construction processes, for the integration of SME's into big wood construction projects, and for the interaction between the different market players.

Business models for industrialized multi-storey wooden buildings could include to adapt a general business model to the industrialized building setting and choose the major business model elements, identify frequently used business models and model elements, and establish a good fit between the environment, the business model, and its business model elements. Five business model elements are identified, prefabrication mode, role in the building process, end-user segments, offering, and resources for design and onsite construction.

Application part – demo and pilot projects: It is important to follow up on real wood building objects under and after construction, to identify weaknesses and challenges for learning and further study from technical and businesslike aspects. There is a need for studying the industrialization of the wood construction process from manufacturing to erecting and the digitization of the wood construction process including planning and design.

Critical issues to evaluate are:

(1) Horizontal stability, robustness and building sway, (and also on sound and vibrations of floors and flanking transmission, and on energy efficiency);

(2) Business models and business elements; planning, management and interaction between participating partners (consultants, wood companies, entrepreneurs) and between main supplier (big wood companies and other "locomotives") and subcontractors (SME's); and

(3) Industrialisation and digitization of the different processes.

Acknowlegement

Discussions with and input from colleagues in Norway and Finland are much appreciated.

The authors would like to express their sincere appreciation for the financial support from the Regional Council of Västerbotten, the County Administrative Board in Norrbotten, and the European Union: European Regional Development Fund – Regional Structural Fund (Ärendeid: 20203193) together with Skellefteå and Piteå municipalities, The Swedish Federation of Wood and Furniture Industry (TMF), and the private companies Soksbo, Derome and Folkhem.