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THE BV2020 SOLUTION – GOING BIG WITH LIGHT TIMBER STRUCTURES

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ABSTRACT:

A growing population world-wide and a strong increasing trend towards more urbanisation calls for changes in the way we develop urban areas and cities. The building sector will play an important role in this development. Better utilization of land with more multi-storey buildings both for residential and commercial use is an important part of the solution. Climate change requires us to take action and substituting building materials with large CO_2 emissions with wood-based solutions which will make a huge positive contribution. Glue-laminated and cross-laminated timber are good alternatives. However, lightweight load bearing timber frame solutions will make an additional contribution to even more sustainable building construction due to less use of raw materials and the possibility to build on weaker ground. The BV2020 solution has the goal to develop concepts that enable mass customized production of prefabricated light timber frame, load bearing elements for buildings up to eight - 8 - storeys for the volume market.

KEY WORDS: tall lightweight timber buildings; wood-based building systems; mass customized production; prefab

1 INTRODUCTION

1.1 BACKGROUND

The challenge of designing tall and safe timber buildings has been a priority for the wood industry and researchers throughout several studies and projects [1]. Even though timber is one of our oldest and most traditional building materials, building codes have limited wide use in higher buildings due to fire safety concerns, amongst other issues [2].

The introduction of function-based regulations instead of material based regulations has played a key role in the use of wood in multi-story buildings with more than four floors. For instance, in Norway the function-based regulations regarding fire risk were introduced in 1997 [3]. This was important for the use of wood in big buildings, and therefore the development of techniques and systems for multi-story wooden buildings is rather new, and it is still a high potential for further development of effective production systems.

Until recently, the attention has mainly been on unique high rise, solid wood, signal-building projects. In later years, an increasing interest has grown also for lightweight timber frame constructions. All these projects have helped to identify and solve many of the fundamental obstacles that follows with an expanded use of timber in high-rise buildings. Now, time has come to realize returns of these findings and to go big, also with respect to volume.

1.2 OBJECTIVES

To really take advantage of the engineering developments that have been made within the timber building industry, one needs to convert all the good work that has been done into complete building concepts that can compete within the volume markets. This is the main goal of the BV2020 project, which paves the way for mass production of prefabricated lightweight timber frame load bearing elements for use in apartment buildings with up to eight storeys. In Figure 1, a typical example of a lightweight timber frame element is shown.

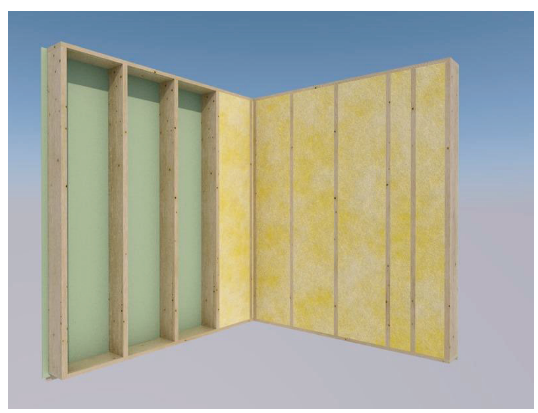

Figure 1: *Example of a typical lightweight timber frame element.*

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The project includes work packages that cover topics such as i) identifying the required material properties for light-weight timber structures, ii) solutions for the overall and detailed design of prefabricated constructions and their connections, iii) optimization and adaptation of the production process, as well as iv) verifying that all relevant aspects of the building as a whole and its solutions meet the required standards.

Støren Treindustri is a member of WoodWorks! Cluster (www.woodworkscluster.no), and the BV2020 project and concept fits well into the main work in the building sector in the cluster, with focus on:

- Transition of Industry 4.0 and Industry 5.0 in the wood based building industry.
- Effective use of digital information in the whole value chain, from raw material to end of life for the buildings.
- Increased industrialization of the building process – more performed in the factory and less at the construction site.
- Sustainability reporting, and the use of it to promote wood as a building material.
- Development of urban building concepts (multi-storey buildings) that are effective to produce, and eliminate the uncertainty among professionals to use wood as a building material for multi-story buildings.

The network in WoodWorks! Cluster exists of R&D organizations and companies covering the whole value chain from forest to building operations, and is used as a resource in the performance of the project work.

2 IMPACT OF BV2020-CONCEPT

The BV2020-concept, by using light framework construction, has potentially several beneficial impacts on the building industry concerning greenhouse gas emissions and cost efficiency. However, this has to be calculated and proven when the concept is fully developed, but in the following sections the most important motives for developing the building concept are discussed.

2.1 Use of wood – the substitution effect concerning greenhouse gas emissions

In the European Union, building construction consumes 40% of materials and 40% of primary energy, and generates 40% of waste annually [4]. The potential to benefit the environment by replacing reinforced concrete structures with timber is illustrated by Skullestad et.al [5], where a 34-84 % reduction in climate change impact has been calculated for 3-21 storey buildings. However, an essential prerequisite when comparing two products is that they can fulfill the same function in a building. In the LCA language, this is referred to as the "functional equivalent of the object". There is a quantification of the technical characteristics and functions required by the object (product). The functional equivalent makes it possible to derive a reference unit used to produce results from calculations (e.g.: per m², per year, per employee, per m² per years).

Comparisons of greenhouse gas calculations should only be made on the basis of the functional characteristics of the objects equivalent. This requires that the functional requirements are described together with the intended use and relevant technical requirements. The functional equivalent of a building or part of a building shall include factors as:

- Building type
- Technical and functional requirements
- Required lifetime
- Total area
- Total heated utility floor space

The BV2020-concept is based on a lightweight construction, and therefore it is not a material intensive construction. This is positive due to greenhouse gas emissions per kg. material. However, the BV2020-construction involves several materials, and in the development of the concept effort to minimize the total greenhouse gas emissions is a priority. Calculations on how the various materials influence the total account of greenhouse gas emissions of the whole building will be important in the BV2020-concept, not limited to parts of the building or single materials.

In [6] it is shown examples of variations in the greenhouse gas emissions dependent on which materials, and the amount of each material, that are used in a wall construction. The difference between the construction systems is rather high, also within the wood construction systems. However, the example of lightweight framework system shows a rather low value in the example. The development to reduce the greenhouse gas emissions is currently very intensive, and therefore it is important to perform dynamic calculations to take this into consideration consecutively. For the BV2020-concept this will be important to optimize the construction due to the total greenhouse gas emission for the whole building.

2.2 Urban nodes

In Norway, residential buildings represent 37 % of the total building mass [7]. Even though multi dwelling buildings constitute a small part of these today, it is evident that the demand for this type of buildings will increase in the years to come. Due to a general population growth, increased urbanisation, and the need to preserve more agricultural area, the call for higher apartment buildings will grow significantly. It is a policy making process in progress in EU to establish urban nodes for effective transport and infrastructure [8]. This development is also reflected in smaller scale, e.g.

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establishment of small cities in connection with railway stations.

A compact building mass is cost effective due to infrastructure, and multi-story buildings will be important in this development. It is therefore of great importance that concepts for timber buildings represents a competitive alternative. To exploit the potential of timber as a CO_2-sink, we need to provide the market with competitive timber alternatives within the segments that constitutes the largest volumes. A new normal must be to go big with timber, and the goal for the BV2020-project is to develop a flexible concept and solutions both for construction, fire safety and acoustics that can be manufactured and built in an effective, economical and also environmentally sustainable way, ready to be used. These are on-going activities that will be presented on the WCTE-conference in Oslo 2023.

There will be increasing demands to utilise today's building stock to a much greater extent than has been the case so far. Extensions in the height of existing buildings can therefore be socio-economically advantageous and at the same time contribute to sustainable management of existing buildings. In addition, it will increase the value of existing buildings. In [9] these aspects are described more in detail.

A limitation is what existing buildings can withstand from the extra load from building at top. Some buildings are already planned for this, while most are not. However, due to the relatively low specific gravity, load-bearing structures in light-weight framework constructions of wood will be well suited as a load-bearing system for extensions on existing buildings – and thus it may also be possible on some buildings that were not originally intended for this.

In many existing buildings made of heavier materials such as concrete, masonry and steel, there may be reserve capacity compared to an extension. However, it is an advantage that the extension and load-bearing system do not impose excessive loads on existing buildings. Heavier building systems on extensions may limit the number of additional floors that can be built on. By choosing a "light" extension and lighter load-bearing structures, there are greater opportunities to get more floors and increased usable square meters for the extension.

2.3 Pre-fabrication and industrialisation

For timber constructions to be a truly sustainable and viable alternative, the economic side of it must also be competitive. An effective production process is crucial to attain to be competitive with other building systems. The BV2020-concept is based on prefabrication of elements (Fig. 2), that means fabricate as much as possible in the factory, and then put together on the construction site.

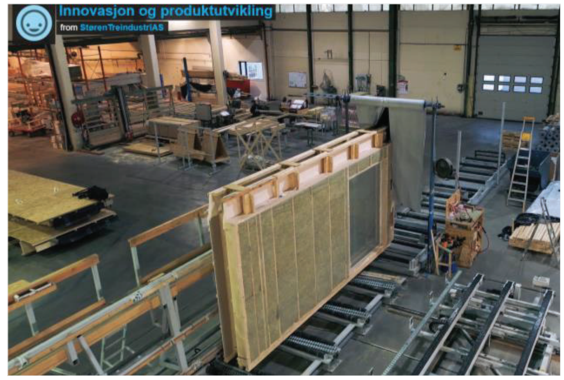

Figure 2: *Production line for elements at Støren Treindustri AS (https://storen-treindustri.no/produkter/).*

There are benefits by performing the building operations in a factory, and are also discussed by [10]:

- Better quality of the wood building product.
- Lower cost compared to performing the operations at the construction site.
- Shorter construction time.
- Independent of weather conditions, which will reduce the risk for humidity in the constructions.
- Reduction of on-site accidents.
- Reduction of waste

A range of variables influence the costs. Even though the direct material costs of wood can be slightly higher than others, the total cost of a finalized mid-rise wood building will often be lower compared to a concrete construction (6 % for eight storey buildings according to [11]). Prefabrication and mass production are key elements to achieve necessary competitiveness of this alternative, and thus even more projects can make the environmentally friendly choice and increase the total use of wood in buildings. This will heavily affect the ability of the building industry to achieve a noticeable reduction in climate change impact, and by doing so, contribute to the crucial global climate goals.

In the life cycle of a building, the operation phase has been dominant concerning energy use and green house gas emissions, but emissions that occur during the operation has declined dramatically over time due to existing substantial energy saving codes or other policies, and thus, the relative contribution of construction stage emissions and impacts becomes more dominant and significant. Therefore, green house gas emissions or impacts in the construction stage must be analysed [12]. The choice of material is the most important at the construction stage concerning green house gas emissions, but also the way of producing the buildings is of importance.

The building industry based on conventional on-site construction approach is by [12] characterized as labor-

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intensive, wasteful, and inefficient, and that it is need for more introduction of lean production and prefabrication in the building industry.

In [13] research concerning the development of productivity in industrial wood building sector and conventional building sector has been performed in Sweden. It is the period from 2014-2018 that has been investigated. The results show that the industrial approach has increased the productivity expressed as cost per area of 30 % compared to conventional building processes, and that the lead time for the building process has been reduced by 3,3 months.

Through an Internet survey [14] of hundreds of AEC professionals (Architecture, Engineering, and Construction), data were gathered on the impact of prefabrication and modularization on key industry productivity metrics including project schedules, costs, safety, quality, eliminating waste and creating green buildings. It is reported that some of the most significant productivity findings from prefabrication and modularization users include the following:

- 66 % report that project schedules are decreased – 35 % by four weeks or more.
- 65 % report that project budgets are decreased – 41 % by 6 % or more

Further, [14] report that productivity is the top driver of prefabrication/modularization use among all firms. It is described that time savings and even small cost reductions make a big difference for players in the construction industry, where profit margins are slim due to the labour-intensive and expensive nature of on site construction. In the investigation it is found that 92 % of contractors see productivity as a stronger driver to use prefabrication/modularization, compared to engineers (70 %) and architects (68 %). Competitive advantage (85 %) and generating greater ROI (70 %) (return of investment) are stronger drivers for contractors than they are for architects and engineers [14].

In the research of [12], models and case- studies were performed to calculate the reduction of green house gas emissions when increasing the prefabrication level. It was found that the reduction was 2-5 %, but that it can be even more reduced by higher degree of pre-fabrication.

In the investigation of [14] "green aspects" were not a major driver to prefabrication and modularization adoption. However, when they asked about environmentally aspects, including site waste and amount of materials used, a different story emerged. 76 % of respondents indicated that prefabrication/modular construction reduces site waste – with 44 % indicating that it reduced site waste by 5 % or more. In addition, 62 % of respondents believe that these processes reduce the amount of materials used – with 27 % indicating prefabrication/modularization reduced materials used by 5 % or more [14].

In the development of the BV 2020-concept, and in the WoodWorks! Cluster, the industrialization of the building process has high priority, including the logistic from raw material sources to transport and assembling at the construction site. To optimize the use of raw material and reduction of waste through the whole value chain is important together with high productivity. It is, however, impossible to eliminate the waste totally, but the side streams that the waste represent can be raw material for other types of industry in the region, ant it is on-going activities to study these possibilities.

2.4 Mass customization

To produce buildings effective in an industrial way, it is a challenge to combine it with high variation in the products to meet the customers requirements. Mass customization is, according to [15], a manufacturing paradigm that enables customized and personalized design at a cost near mass production, and that mass customization's ability to lower unit cost, increase quality, and shorten project duration for customized offerings is considered highly relevant for tomorrow's house building industry.

Støren Treindustri has ongoing activities concerning mass customization of the production of buildings up to four floors, and it is possible to adopt it into the BV 2020-concept for buildings up to eight floors.

In [15] it is concluded that a great potential exists for applying mass customization in the house building industry. However, despite its potential, research on mass customization in the house building industry is sparse. In particular, research on developing the solution space and choice navigation tools is limited in this industry.

Several challenges for implementing mass customization in the house building industry have been identified and reported in the literature review of [15]:

- "The requirement for changing the supply chain setup. At the moment, supply chains in the house building industry are structured to fit engineer-to-order building projects and thus lack standards necessary to cope with builders and suppliers of mass-customized offerings."

- "To align what customers want with the internal capabilities of the company, that is, to define the solution space offered to customers."

The last bullet point has high priority in the development of the industrial building process in the BV 2020-project and in WoodWorks! Cluster. The variation in the product spectre has to be limited to the limitations in the factories for maintaining high productivity, but at the same time offer more variations where the industrial limitations are lower.

3 FURTHER WORK

To verify the interaction between both technical solutions, fire safety, acoustics, design for efficient manufacturing/ prefabrication, environmentally friendly material use and production and finally a profitable concept for all parts of the value chain, the BV2020 solution must be tested in full scale with a pilot project, preferably an 8 storey residential apartment block.

Furthermore, the concept is also applicable for other building types such as offices, etc., which is also planned for, even though not being part of the initial project description.

For fire safety, the project has developed loadbearing prefabricated floor slab elements of lightweight structural wood with the ability to withstand the complete duration of a fire, including the decay phase, according to Eurocode 1 [16]. This has been possible by taking advantage of products with improved material properties during fire and focus on fire performance in the design of the construction.

With regards to acoustics, the developed concept for the floor elements for spans of approximately 8 meters has shown very good test results both with regards to airborne sound and step sound.

Similar development and tests will be carried out for load bearing walls and transitions. Several other aspects of the concept also need to be managed, ensuring the required flexibility of the entire building.

4 CONCLUSIONS

By substituting building materials with large CO_2 emissions with wood-based solutions, we can make a huge positive contribution to the necessary actions against climate change. The BV2020 solution has the goal to develop concepts that enable mass customized production of prefabricated light timber frame, load bearing elements for buildings up to eight - 8 - storeys for the volume market. The development of the concept is well under way. A concept also for load bearing walls and transitions is under development, and both fire safety and acoustics will be studied this year.

Further development of the design for manufacturing, establishing cost-effective production processes and optimalization of the carbon footprint will be carried out.

Pilot project(s) will hopefully confirm achievement of the projects overall goals and give positive contribution to the reduction of green-house gas emissions.

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