Developing the Stavne Timber Block;

Life cycle design in practice

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Abstract

This paper reports on a development project where a prototype building component in massive wood [1] is being redesigned for full scale production. By utilizing reclaimed wood, the environmental efficiency of local material loops is improved. The component facilitates flexibility in construction and user phase, and also future reuse. Furthermore, the block intervenes with work adaptation in the production line as well as with life style and identity for the users. Through simplicity of construction, the block supports self-building and thus economic feasible dwellings. The paper describes the criteria for the development process, and discusses their influence on construction method.

Keywords:
Massive wood components, Carbon-neutral, Closing the loop, Work training, Self-building

1 INTRODUCTION

1.1 The Concept of the Timber Block

A building block based on stubs and reclaimed wood is introduced and described by architect Bjørn Berge as „Klimablokka" (The Climate Block") [1]. The building system aims at carbon mitigation by addressing life cycle design, low-impact material use and production as well as carbon storage. The prototype Timber Block is made up by cross-laid boards, fastened by wooden dowels. The construction method is described as a stacked system, where the components are joined by plugs.

In contrast to contemporary massive wood components that are usually provided in large-scale and often custom-made for each project, the Timber Block system aims at suitability for self-building. Also, future flexibility and reuse is facilitated. In the end, as wood-burning stoves are installed in as much as 80% of Norwegian dwellings, heat recovery is an obvious option.

Figure 1 The prototype Timber Block "Klimablokka" made of reclaimed wood. [1]

The prototype Timber Block is now being redeveloped for production at Stavne Gård Salvage Yard in Trondheim, where work adaptation for young people is a main target. The project is partly supported by *Innovasjon Norge* (Innovation Norway) and by the municipality of Trondheim.

1.2 Stavne Gård Salvage Yard (ReBygg)

Stavne Gård Salvage Yard is part of Stavne Gård KF, that is an institution but also business related organisation owned by the municipality of Trondheim. The employees at the salvage yard have ten years of experinece, cooperating with the largest regional entrepreneurs in the process of demolishing old buildings. The participants in the work adaptation programme at Stavne Gård are trained to disassemble and take out different building components (windows, doors, roof tiles etc.), furnishings and materials that can be prepared for sales and be reused. Stavne Gård Salvage Yard is in charge of 2000 tons of waste from buildings pr. year. This is about 2% of the total building and construction waste in the Trondheim region (middle part of Norway).

1.3 Scope of research

The Stavne Timber Block project can be described as an investigation process with many aspects related to environmental and social sustainability. Climate change mitigation is met through environmentally efficient material supply and producion processes as well as through carbon storage in wood. Adaptation is pursued through a flexible building system that can adapt to various technical and functional reqirements and that also facilitate changes and salvage. Furthermore, in the production line of the block, work adaptation is an important aspect. As for the final user of the Timber Block, the project aims to design a new self-building concept.

The investigation involves a number of practical and theoretical problems. It also involves a number of stake holders. The scope of this paper is to fold out the issues related to the project and to discuss viable options for the design of the block.

Every design process is unique and in many ways it resembles a research process. The investigations of the Stavne Timber Block are informed by a comprehensive list of criteria to guide the design. Furthermore, as this is not a closed industrial development but rather an open democratic process, the decision-making is made transparent to the stake-holders. Therefore, the process requires a level of systematization and dissemination that is not common in architectural or product design. The development process is thus reported as research - or more precisely as *research by design*. Four different construction systems for the block are outlined and discussed in relation to the given criteria. The aim is to inspire and aid similar development projects based on specific, local premises.

2 SUSTAINABILITY

2.1 Environmental efficiency

Wood is generally regarded as an environmentally sound building material, and it also has a range of end-of-life options. Wood components may be reused, shredded and recycled into fibreboards and paper products or it may be burned for heat recovery.

Recycling is referred to as *down-cycling*, which indicates that a lower-grade material is produced. Down-cycling procedures often include industrial processes and long-distance transport, which demand energy and release emissions and waste. According to the “recycling hierarchy”, reuse is therefore a more preferred option because the material quality is retained at a minimal environmental cost [2]. Also, reuse is the only option that addresses carbon storage.

The production of the Stavne Timber Block can be described as an *up-cycling* process. By reusing waste material and developing a building block through product- and system-design, the material is given new functional and economic value.

2.2 Social empowerment

The project of development is based on Stavne Gård KF and their support-activites to young people for work adaptation, social training and personal develpoment. The production line and sales of the Timber Block will be important to Stavne Gård empowering the participants in their special programmes.

The building block aims for a self-building concept. Norway has a long tradition in self-building. This is an activity executed by the individual users and owners of the house. The tradition opens for exchanging knowledge about materials, construction and functions necessary to support a dwelling of comfort, and environmentally sound solutions. The self-building culture is often involving neighbours, friends and family in the building process as well.

2.3 Financial considerations

Although industrial recycling is becoming more common and is also profitable for some building materials, reuse and up-cycling of components are not commonly performed. One important reason is that the costs run high with the extra time use required.

Stavne Gård is in a special situation because the financial framework is based on work adaptation. Thus, the reuse activity can be performed at more ideal premises. In a future perspective, however, factors such as shortage of resources, environmental legislation and taxation policies may enforce more focus on reuse of materials in general. Therefore, the experiences gained today by Stavne Gård can become valuable also for enterprises operating in a building industry governed by pure market forces.

The original prototype of the Timber Block is considering the concept to be economically compatible with other building solutions of middle and high quality. Even though the production line at Stavne Gård to some degree is supported by the social working programme, the Timber Block concept must be further developed and evaluated in terms of work intensity. The goal is to establish a production line that can be cost-efficient and thus provide a building system that is economically feasible for first-time home buyers.

3 MATERIAL SUPPLY

The raw material supply is based on local and low-grade wood such as stubs and reclaimed waste (Figure 3). This material counts for approximately 17% of the total building and construction waste in Norway. The percentage is estimated to increase the next 10 years simultaneously with new prohibition against organic based waste to landfill by June 2009. The Stavne Timber Block will be produced of wood stubs and reclaimed wood from new building projects, rehabilitation and demolishing of old buildings (Figure 2).

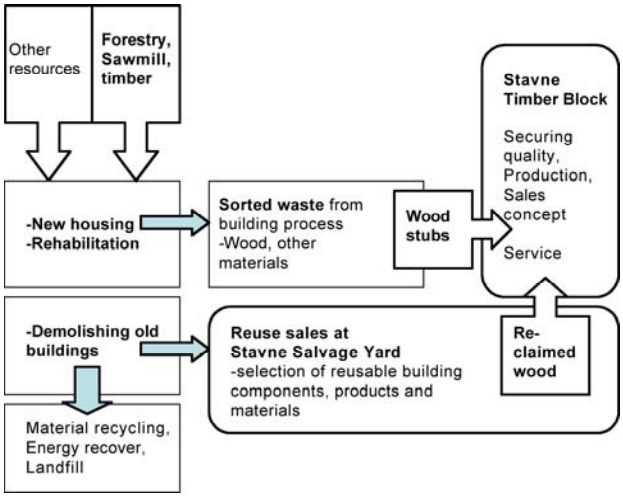

Figure 2. The production of the Stavne Timber Block integrated in local wood material loops.

Figure 3 Material supply at Franzefoss. (Photo: K. S. Wigum)

4 DESIGN CRITERIA

To reach the high ambitions regarding a full specter of sustainability targets, a comprehensive list of design criteria was worked out. As described in chapter 3, the raw material supply will be based on local and low-grade wood such as stubs and reclaimed waste. A second basic principle is to keep the environmental investments low throughout the production process. This regards energy use for processing and transport as well as choice of secondary construction materials. In addition, criteria are connected to four aspects of the block design.

The design criteria are given as general performance standards. The first aspect regards environmentally efficient use of materials in the lifecycle, or *salvageability*. The second aspect considers the various *user needs* through the lifetime of the house. The third aspect regards utilizing the specific *material properties of wood* in a best possible manner. The fourth aspect regards designing the blocks so that the *production line* and distribution systems can benefit.

4.1 Salvageability

Environmentally efficient use of materials must be pursued throughout the lifecycle, addressing:

- *Reuse and recycling.* Relevant design criteria to achieve this are: *Limited Material Selection, Durable Design, High Generality, Flexible Connections, Suitable layering* and *Information and Access.* These criteria are further detailed in [2].
- *Heat recovery.* After the components last service life, the blocks should be suitable for heat recovery in standard wood-burning stoves, without the need for flue gas cleaning.

4.2 User needs

The product must adapt to demands for design and construction, as well as for the use-phase of the house.

- *Self-building.* The blocks should facilitate self-building, which regards simplicity of building method, weight of components and safety of work. Point of sale should introduce instructions to the concept and support the idea of healthy and sustainable living, both as an urban and rural solution.
- *Adaptability.* The building system must adapt to various design needs. Also, changing life situations in use phase must be met in simple ways so that self-building is still a viable option.
- *Economy.* The blocks should facilitate economic feasible dwelling solutions. The final housing should also be a cost effective dwelling in terms of low energy demand for heating, easy maintenance and flexibility in reconstructing the building.

4.3 Material properties of wood

The development of the Stavne Timber Block aim at utilizing the specific material properties of wood in a best possible manner:

- *Indoor air quality.* Wood's capacity to regulate humidity as well as heat should be maintained, and its' thermal insulation qualities should be utilized in the construction.
- *Thermal insulation*. Preferably, the blocks should achieve existing thermal insulation standards with only a complementing layer of fibreboard sheeting and aerated cladding. For low-energy buildings, auxiliary insulation can be an option. This must be investigated through model testing.
- *Carbon storage.* The issue of carbon storage in the wood material should be maintained. This presupposes long-term management of the blocks.

Technical properties of wood such as shrinkage/ swelling capacity, moisture transport capacity, thermal insulation capacity and structural strength are variable according to the direction of the wood fibre cells. The main principles are summarized in figure 5. The properties of wood with regard to the choice of construction methods are further discussed in chapter 5.

4.4 The production line

Important design criteria are posited by the production line at Stavne Gård, where work adaptation for young people is the main objective. Also, the building process is addressed:

- *Simplicity of production.* The blocks must be suitable for uncomplicated, local production, possibly at movable plants.
- *Logistics.* The blocks should be designed with regard to ease of handling, transport and storage.

4.5 Potentials for improving the prototype

The design process is now in the phase of exploring the possibilities of the original concept in the perspective of the four areas of design criteria presented.

The prototype Timber Block is made up by cross-laid boards, fastened by wooden dowels. As wood shrinks and swells depending on the relative humidity of the ambient air, cross-laying of the boards helps achieve stabilization of the wood. The construction method is described as a stacked system, where the components are joined by plugs. Stabilization is further achieved by an exterior layer of wallboard sheeting.

Figure 4 The prototype Timber Block as a stacked construction system using plugs. [1]

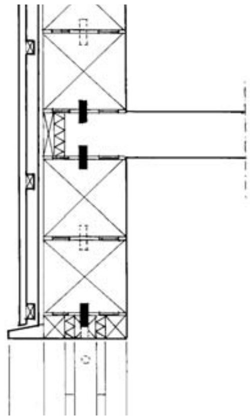

Figure 5 Sectional drawing of the prototype. [1]

After analyzing the prototype regarding the comprehensive list of design criteria, potentials for improvements were pointed out. Thus, the block was more or less taken apart and new designs emerged.

The prototype measures 374 mm each way in a cubic volume. The generality of the prototype can be improved by adapting directly to the 6M (600 mm) norm, which is implemented as an overall standard for construction materials. Secondly, smaller dimensions of the block would result in easier handling (important for both the production line and for self-building) as well as improved architectural flexibility: A smaller block could be used in a variety of constructions; both interior and exterior walls with different thermal insulation requirements. Also, a smaller block could easily be burned in standard stoves after its' last service life.

The flexibility can be further improved by choosing connection points that are visible and easily accessed. A method for joining the blocks that also allows for parallel disassembly could be investigated. Finally, a method for tagging product information - concerning manufacturer, material quality and production date - directly on the blocks could assist decision making in a potential second (or third etc.) service life.

Thus, the two main issues for the redesign are 1) smaller dimensions of the blocks and 2) flexible joints that are easily accessed. An additional desire is to design a block that also utilizes the potential for architectural articulation of the components. The lay-out of the blocks as well as the detailing of the joints can be used to support component-bound ornamentation of exposed surfaces. Addressing the architectural flexibility as well as its' inherent potential for articulation could add value to the new building system.

5 CONSTRUCTION METHODS

The two main issues for the redesign - smaller dimensions of the blocks and easily accessed flexible joints - both affect the construction in new ways, and challenges are posed. When decreasing the size of the blocks, cross-laying of boards becomes less practical. Stabilization must therefore to a greater extent be achieved in the joining of the components. After some initial sketching, the design ideas for the new block were divided in four groups, according to their constructive principles.

In the following, these four constructive principles will be discussed. Although different formats for the blocks have been proposed, a point of departure for the discussions is a block with gross measures 1x2x3 M (100x200x300 mm). This format can adapt in a number of ways to the 6M norm, and is highly flexible in meeting various architectural demands. The joining of the blocks is thus the variable input and the main issue for the discussions.

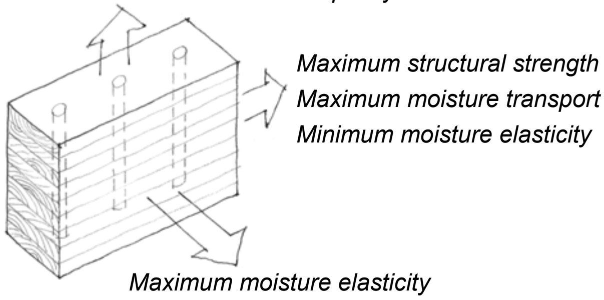

Figure 6 Proposed timber block (1x2x3 M), shown with basic technical properties, variable according to the direction of the wood fibre cells.

Technical properties of wood have been determining for the development of various vernacular building methods in wood. Aiming at using these properties cleverly in the new design, a side look to traditional building methods can be worthwhile. Also, comparisons with various contemporary building techniques, in wood as well as in other materials, can be relevant.

5.1 Node connection

The first ideas evolved around developing a type of node connection which is fully reversible and easily accessed from all sides. This would give full flexibility of the blocks which could be used to build up not only walls with different thermal insulation requirements, but also could be used in a variety of bonds to give architecturally interesting patterns.

The connection points are localized at the corners of the block. Either a tongue and groove system - as used in vernacular log constructions (Figure 7) - or separate fasteners can be specified.

Figure 7 Node connection in vernacular log construction (Photo: A.S. Nordby)

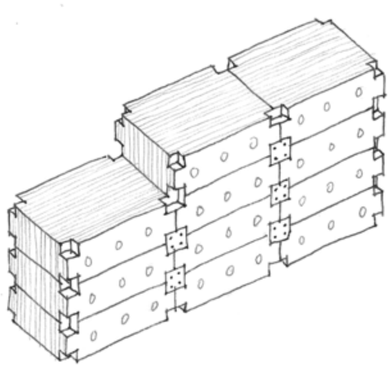

Figure 8 Node connection of the Stavne Timber Block

Although this construction alternative would optimize flexibility, the method raises some problems: The transfer of loads is depending on the precision of the blocks and joints. A high precision of the block measures can be hard to obtain as an important criterion for the production line is simple tools and operation. Also, movements of the wood caused by moisture could represent problems. Moreover, in the building process, the many node connections could result in a complicated and time-consuming construction period.

5.2 Prestress bonding

A second alternative for bonding small wood components is prestress. Rods are set in holes in the blocks and used to compress the blocks by nuts. This system would enforce stability and be less dependent of the precision of the block measures. However, it would be less flexible in construction and for later adaptations than using node connections.

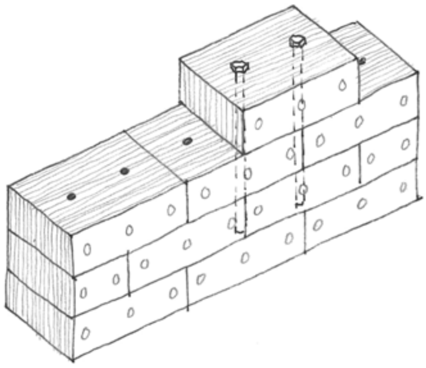

Figure 9 Pre-stress used in the Stavne Timber Block

The pre-stress bonding method could be used to connect whole walls and also sub-partitions. Furthermore, the method could be used to construct beams and columns.

Pre-stress is commonly used in concrete beams with steel rods. Steel is also commonly used in wood constructions. However, as a basic principle is to keep the environmental investments for production low, the use of steel should be avoided. Therefore, other construction materials for the rods should be considered.

5.3 Independent load bearing structure

A third alternative construction method is to separate the load bearing structure from the filling. This step would simplify the considerations regarding the structural calculations. The different constructional members could then be optimized according to the more specific requirements.

Various two-level structures in wood are known from vernacular buildings. “Stavverk”, “sleppverk” and “skjelterverk” are some known Norwegian methods. In all these constructions, the structural strength in the longitudinal direction of the wood is utilized in the load-bearing members. In the infill-parts, the moisture elasticity works independently so that the movement of the wood does not disturb the structure. Rather, the movement assures tightness of the construction in different weather conditions throughout the year.

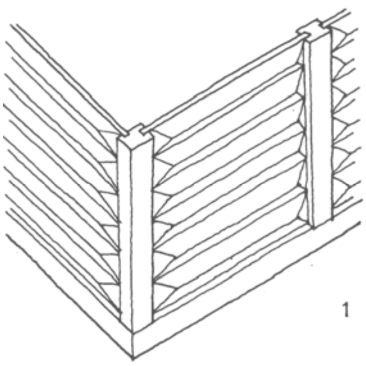

Figure 10 Vernacular “Sleppverk” (Drawing by Dag Nilsen)

The division in two separate member types could represent a more complicated production at Stavne Gård. However, it would make it easier to optimize the design according to the specific material properties of wood. Also, the infill partitions would be architecturally flexible to suit different demands.

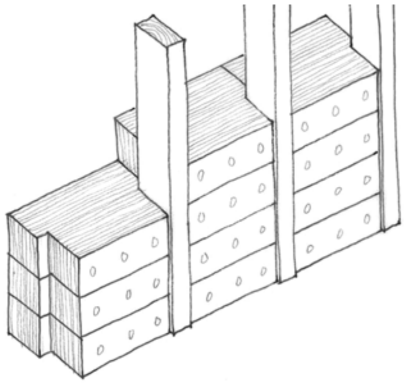

Figure 11 Load bearing members and in-fill system using the Stavne Timber Block

5.4 “Timber masonry”

The last alternative that will be discussed here is bonding of the blocks by using mortar. *Timber masonry* (or *cordwood masonry*) in various shapes is known from both vernacular buildings and from experiments performed the last 10-30 years by self-builders.

The mortar works as a bonding agent as well as a supplementary fill between the timber pieces. Clay mortar is preferred because it adapts to humidity in similar ways as wood does. Often the clay is mixed with sawdust, which may increase the homogeneity with the wood as well as the mortar’s thermal insulation capacity. [3]

Figure 12 Vernacular “Log masonry” used in a barn from 1840 at Ner-Skjørstad in Oppdal, Norway. [3]

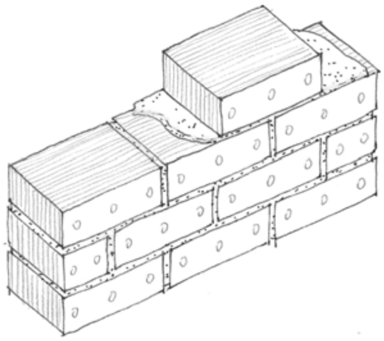

Figure 13 Timber masonry using in the Stavne Timber Block

Since wood has a higher thermal insulation capacity than clay, the mortar fillets generally represent cold bridges in the construction. Another challenge with this alternative is that the building process may be more complicated because the construction involves a second material and also - when not self-building is the case - the second profession of a bricklayer.

At the advantageous side, as the mortar works as a supplementary fill between the blocks, the precision of the block measures is not critical.

6 DISCUSSION

6.1 Material supply

The design process and research so far has shown that Norway, with a majority of wood-based housing construction, needs a variety of solutions for salvage of wood in the near future. However, building traditions from the twentieth century is not including the flexibility and easy disassembly qualities that is required for reuse. The handling of nails and metals in the reclaimed wood is a challenge both for machines and work participants. This is both an economic and time consuming barrier, as well as a question to human safety in the work situation.

6.2 Design methodology

As a part of an iterative design process, we might want to return to some basic discussions concerning the Timber Block's principle of reusing wood. To press grounded wood in blocks is an example of a totally different approach to the solution. However, in the meaning of playing along with the qualities of the wood as such, this solution is not as suitable. Every decision must however include an evaluation stage in the process regarding the design criteria set up.

6.3 Construction methods

Today, massive wood is usually provided in large-scale components that are often custom-made, and structural calculations are performed for each project. The small scale of the Timber Block, however, generally poses more complex considerations for the structure than the larger components. The block has to provide structural stability locally within each block and globally within the system. Independent of which one of the four constructive principles that will be pursued, some basic aspects must be considered:

- *The direction of the structural stress on the system.* As the structural strength of wood is significantly higher in the longitudinal direction of the cells, the system would benefit if the blocks could be stacked so that this property is utilized.
- *The wooden dowels.* The fastening of the dowels is critical for the stability of the single block. The stress on the ambient wood caused by the dowels varies according to the direction of the wood fiber cells. Also, the moisture elasticity could cause problems for the fastening in the long-term.
- *The boards.* The fastening of the boards depends on precision in production, use, structural stress as well as on moisture in the wood.

A combination of construction methods could be functional. E.g. in a two-level structure, the load-bearing members could use pre-stress bonding to assemble blocks into columns and beams, whereas in the infill parts the blocks could keep their architectural flexibility and respond to various requirements such as thermal and noise insulation, moisture transfer (particularly relevant in e.g. cow barns) as well as to different visual expressions.

7 ACKNOWLEDGMENTS

As many architects, engineers and builders have been involved in developing the ideas for the design of the new block, there is a large group of people who contributed along the way. Discussions have basically taken place informally over work desks and during breaks. The idea of designing a building component based on stubs and reclaimed waste seems to trigger creative minds. Also moral support as well as sceptical questions has been welcomed. Thanks to all who contributed in one way or the other, and in particular to Jan Siem.

8 REFERENCES

[1] Berge, B., 2006, Klimablokken, Gaia Lista.

[2] Nordby, A.S. et al., 2007, Salvageability of building materials, Proceedings for the SB07 conference, Braganca, L. et al. (eds.) pp. 593-599, IOS Press, Lisbon.

[3] Hemmingsen, C., Stensen, E., 2004, Kubbevegg-teknikken. Studentoppgave, NTNU