

## **SOME ASPECTS ON THE MORE EFFICIENT USE OF WOOD IN THE INDUSTRIAL MANUFACTURE OF SINGLE-FAMILY TIMBER HOUSES**

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### **Abstract**

*The purpose of this study has been to identify and clarify the challenges to be faced in order to make more efficient use of wood in the production of timber houses in factories. This includes an example of the current payment capacity of the timber-house manufacturers in order to obtain wood for trusses and wall frames which is more adapted for their production. This article also describes the history and the outlook of the Swedish single-family timber housing industry. In brief, the article provides a basic understanding of the conditions of the single-family timber housing industry in Sweden. The companies in the case study reported very little waste related to quality discrepancies in the cutting of sawn timber for trusses and wall frames, achieving a volume yield of 93% or more. The study also shows that 2/3 of the cost of producing these components is associated with the raw material and 1/3 of the cost with processing. Companies should therefore maintain a high volume yield in their wood processing, and they should ensure that the quality specifications for the sawn timber used in the production are correctly related to the wood's intended use. These figures also suggest that a company's ability to pay for components is about 30% higher than the price of sawn timber.*

**Key words:** automation; robotization; timber properties; wood quality; cutting cost.

### **INTRODUCTION**

The industrial manufacture of single-family timber housing has a long tradition in Sweden and the market for these houses is an important trading area for wood-based materials. The majority of the on-site and prefabricated single-family houses built in Sweden have timber frames. This is not the case in the rest of Europe, where less than 10% of the single-family houses have a frame of wood (Dol & Haffner 2010). Nevertheless, this industry has developed weakly compared to other manufacturing industries (Bergström and Stehn 2005). Today's single-family timber housing companies do not fully utilise the materials and methods that would lead to the efficient manufacture of houses in a factory, and the companies' automation levels are as low as their productivity, leading to long lead times between ordering a house and moving in. If, in the future, wood is still to be a primary material for house production, it must be a material which tolerates comparison with other materials.

### **OBJECTIVE**

The objective of this study has been to identify and clarify the challenges to be faced in order to make the use of wood more efficient in the production of timber houses in factories. The study consists of two parts: a description of the history and outlook of the Swedish timber housing industry, and a cost study of wood material processing during the production of components for trusses and wall frames.

### **THE INDUSTRY OF SINGLE-FAMILY TIMBER HOUSING IN SWEDEN - A REVIEW**

The single-family timber housing industry in Sweden lies somewhere between the manufacturing industry and the construction industry (Malmgren 2010), and prefabrication in a factory is the dominant method of building single-family timber houses. Approximately 90% of the single-family houses in Sweden are built with timber frames (Bengtsson 2003). A single-family timber house

in Sweden usually has a floor area between 50 and 250m<sup>2</sup> and is seldom more than two storeys. The volume of wood in a normal-sized Swedish single-family house with a timber frame is, depending on the size and building method, between 9 and 27m<sup>3</sup> (Palm 1976).

The manufacture of prefabricated timber houses in a factory began in Sweden during the 1800s. A precursor to this method of manufacture was the activity of the architect Fredrik Blom (1781-1853). During the second half of the 1800s and the early 1900s, numerous timber-house manufacturers emerged in Sweden. The first decades of the 1900s witnessed a build-up phase for many single-family timber house manufacturers. In 1918, a comprehensive standardisation began within the field of residential construction and for construction materials, which meant a great deal for the industrialisation of prefabricated single-family timber houses. From 1930 to 1940, Swedish single-family timber house companies increased their production from 1,000 to 9,200 houses per year. During the years following the Second World War, a substantial part of the Swedish was exported to especially to Norway and Finland (Waern 2008). During the 1950s, the industry underwent a technological reorganisation, the major feature of which was to replace sawdust with mineral wool to insulate prefabricated building units. Mineral wool changed the production technique, because it compelled manufacturers to construct walls with studs that could hold the wool. These new walls used different panel materials as facings. Other influential and crucial changes were access to larger and better lorries for transport from the factory to the building site and a further standardisation of carpentry, windows and doors. The number of single-family timber-house companies increased even more, and by the mid-1980s, there were approximately 70 companies in Sweden. The period between 1945 and 1990 was a period of great success for the building of single-family houses with timber frames, with a peak in 1975 when approximately 46,000 timber houses were produced. Notably, half of these were produced in a factory. The building of single-family houses has decelerated significantly since its peak year of 1975, and the number of prefabricated single-family timber houses has essentially not exceeded 10,000 houses/year (Nord and Widmark 2010). Of the total on-site built and prefabricated single-family houses that have been erected in recent years in Sweden, 80-90% were timber houses (Bergström and Stehn 2005; Nord 2005; Lu et al. 2011).

The typical Swedish single-family timber house company is a small or medium-sized enterprise. It is often family-owned, and it manufactures mostly according to custom designs (Bergström 2004; Lu et al. 2011). A majority of single-family timber house companies apply production methods for the prefabrication of houses that do not differ greatly from those used in the on-site building of timber housing, except that prefabricated houses are manufactured in warm, dry premises (Johnsson et al. 2006; Johnsson and Meiling 2009).

The production costs for the single-family timber house manufacturer have increased year after year. To retain its profit margins, the single-family timber housing industry has raised the product price instead of becoming more efficient, e.g. by increasing productivity and introducing alternative materials that are better suited to the production and that contribute to make it more efficient. Of course, the former approach contributes neither to making the manufactory process more efficient nor to providing the customer with a cheaper and better house (SOU 2002; Brege et al. 2004). In recent years, however, some of the Swedish single-family timber house manufacturers have turned their attention towards the production process, and have sought to attain a more efficient production, following the principles of Lean Construction. During the implementation of Lean Construction, the companies have also realised that improved communication and greater collaboration with subcontractors are important for reducing costs. A computer tool for 3D modelling is an important instrument in this work (Schmidt 2009).

The dominant frame system for single-family timber houses in Sweden is based on timber studs; walls that consist of vertical studs with insulation material inserted between the studs and usually faced with gypsum- or wood-based panel materials inside and outside with some type of façade covering. The façade covering can be brick, plaster or solid timber. The level of completion in the factory varies depending on the choice of façade covering, because only timber façades can normally be prefabricated. The floor structure is prefabricated in the same way as the walls. Single-family timber housing businesses employ one of two strategies for the final stage: manufacturing plane elements in the plant and transporting them to the site for final assembly or assembling the plane elements in the factory and then shipping them as complete volumes to the final building site.

The level of automation is generally low among single-family timber house manufacturers, and the developments that have prevailed in other pervasive industries, such as the automobile industry, have not been adopted by timber-house companies (Eliasson 2014). During the 1970s, Japan took advantage of the experiences of the automobile industry regarding high quality work, reliability and investment in well-adapted production equipment. Japanese business then transferred this knowledge

to housing production via the Toyota Homes Company (Crowley 1998). During the last decade, a number of single-family timber house companies have invested in production lines for walls with partially automated functions.

Timber housing design relies predominantly on a two-dimensional CAD system, although the single-family timber house industry in general is moving towards design in 3D. The 3D program is a prerequisite for the efficient management of production equipment and for the generation of cutting bills (each bill includes a summary of the dimensions and number of pieces of timber to be cut). The companies rely on information technology less during the production phase than during the building phase (Johnsson et al. 2006). This means that when the production of the physical house begins, the drawings and supporting documents are printed on paper and distributed to the production personnel. The paper-based basic drawing has certain disadvantages, such as a deterioration in productivity. Specifically, a reliance on paper-based data increases the risk that late changes to a design may be lost and it increases the risk that various versions of the basic document may be circulating simultaneously in production. In the end, paper can lead to delays and additional costs.

The single-family timber house industries do not apply any "collective standard" for the dimensions and grades they use in their production of houses. This means that the needs for different cross-section dimensions and specific timber grades vary between individual companies. Moreover, the purchasers at the different companies make decisions according to their knowledge of the differences among local material properties. The single-family timber house industry in Sweden uses approximately 300,000m<sup>3</sup> of timber annually (The Swedish Forest Industries Federation 2013), which means that the volume of a single dimension and grade for individual companies is in general small. In practice, this has meant that it is troublesome for an individual supplier of sawn timber alone to satisfy the demands of a timber-house factory, i.e. each factory has several suppliers for sawn timber. Another factor that affects the purchasing of wood is the extent to which the timber-house manufacturer can rely upon the supplier's capacity to deliver according to the requirement specifications upon which they have agreed. Today, routines for monitoring the delivered material vary between the companies, ranging from a careful follow-up and compensation when necessary to an approach where comparatively large deviations from the specifications are accepted (Eliasson 2014).

Single-family timber house manufacturers will produce timber waste when the timber lengths are not optimal or when the sawmill-graded wood does not meet the actual needs (Grönlund 1990). The sawn timber delivered is, in most cases, sorted in accordance with traditional sawmill timber grades (e.g. CEN 2000). Sawmill grading is usually not performed with the final use of an individual piece of sawn timber as the starting point, but rather from practical considerations of the sawmill production. These methods result in a grading of sawn timber that does not fulfil the requirements set forth by the sawmill customers.

Several of today's timber-house companies manufacture building elements, such as roof trusses, joist floors and wall units, themselves. In contrast, they almost always purchase the doors, windows and carpentry ready-made from external manufacturers. For their own production, the single-family timber house companies can purchase sawn timber only in the dimensions and lengths offered by the sawmills and timber product wholesalers. Therefore, the single-family timber house industry has no common requirement specifications for sawn timber, and each company formulates its own requirements and qualities (Weinfurter and Hansen 1999). A relevant question to ask is why the work of standardisation within the single-family timber house industry, which began in 1918, has advanced no further. The single-family timber house industry has, on several occasions, expressed a desire to purchase ready-made material, i.e. sawn timber cut to specific lengths and of a specified quality (Bergman et al. 1997; Nord 2005). Quality can be defined as "meeting the customer requirements" (Oakland 2000) or as "the suitability of wood for a particular end-use" (Jozsa and Middleton 1995). The properties of the purchased material begin with the customer's requirements, given that it is the customer who bears the responsibility for the requirement specifications (Kliger et al. 1994). The single-family timber housing industry's desire to increase the purchase of important quantities of components has not, however, been followed by a willingness to pay for the increased level of service, so that the actual development in this respect has been only modest (Eliasson 2014).

The cost of the timber material constitutes only a fraction of the total cost of a house. Brege et al. (2004) have shown that building materials constitute 25% of the total construction cost for a single-family timber house and that the timber itself accounts for only a small percentage of the total construction cost. These figures indicate that the price of sawn timber has a minor influence on the house's final price and that manufacturers could afford to pay a higher price for prepared wood material or could add other types of products to the construction, such as engineered wood products. The costs associated with sawn timber that does not meet the requirements of the single-family timber

house factories as a consequence of deficiencies in timber properties are significant, but few, if any, recent studies of these costs are available.

**METHOD FOR THE COST ANALYSIS OF THE PROCESSING OF WOOD MATERIALS**

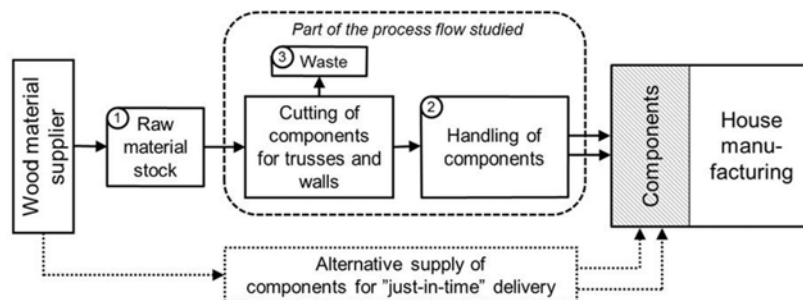
In this study, the costs of cutting timber into components for trusses and wall units were determined for two single-family timber houses companies. Some comparative figures for the production in the two companies are presented in Table 1.

*Table 1*

**Comparative figures for the companies studied**

Key data	Company A	Company B
Production [number of houses/year]	120	700
Total number of employees	47	400
Number of employees in factory production	27	145
Volume of sawn wood purchased [m <sup>3</sup> /year]	9,000	19,000

Both companies prefabricate plane elements with timber studs and joists. Custom designs offered by both the companies mean that successive houses in the production differ from each other and that it is difficult to save time by coordinating material production. Company A customises designs to a higher level than Company B, which means that Company A is less able to combine the processing documents for several houses when cutting material in larger batches. The designs of the building units at the two companies are similar, so the processing costs for the cutting operation are directly comparable between the two companies. The general materials flow and manufacturing process is illustrated in Fig. 1.



**Fig. 1.**

**Flow in the processing of timber components for trusses and wall elements, also showing an alternative supply of components. The numbers 1,2 and 3 refer to Table 2**

Both companies have their own specifications based on the actual needs of the company and on the standardised sawmill grading rules. The sawn timber suppliers to the two companies consist of a number of sawmills that are located mainly in southern Sweden. The stations for cutting components for trusses in the two companies are essentially the same. The main difference is that in Company A the operator personally carries the timber from the stack to the saw table, whereas in Company B the timber is fed automatically. Company B's feeding equipment ensures that the next piece of timber arrives on the saw table while the operator is still cutting the first piece of timber, and the material that the operator has just cut is being removed to the depot. At both companies, information from databases is automatically sent to the cutting operator regarding the geometry and the number of components. During the period of the study, Company B cut components for three houses simultaneously with the same truss design. Similar coordination was not possible at Company A. The effective operator time at both companies consists only of the time the operator is working on the material processing. Disturbances, such as conversations with colleagues and private needs, were deducted from the operator's time so that a fair comparison could be made between the companies.

Both companies produce wall frames consisting of studs. The frame produced by Company A consists of solid wooden studs, built as a crossed stud frame with insulation in two crossed layers to minimise thermal bridges. The wall frame produced by Company B includes a light stud instead of a solid wooden stud. The light stud is insulated to hinder thermal bridges. The differences in the wall constructions at the two companies mean that the quantities and dimensions of the timber differ.

In order to calculate the manufacturing costs, the authors have used equivalent costs for raw materials, personnel and expenses. The equivalent costs are based on direct materials costs for sawn timber, indirect materials costs, direct labour costs, and indirect labour costs as shown in Table 3. The capital cost for the equipment used for cutting was low (less than 2 € per m<sup>3</sup> cut timber) and about the same for the two companies, so it was excluded from the manufacturing cost presented here.

The *processing cost* is defined as the difference between the total manufacturing cost for a given volume of cut material (timber components) and the cost of purchasing the timber. The processing cost was studied by measuring the material waste and the consumption of time and material. The present study covers only the material waste due to timber differing in length from the specifications. The loss of entire pieces of wood due to quality defects, which both companies sort prior to the cutting operation, is not included in the waste. The study has been limited to the cutting part of the operations partly because both companies are considering basing their production on components purchased from a supplier that would offer them just-in-time delivery. To calculate the cost of components, a standard model has been used. The model includes *material costs and manufacturing handling costs* consists of 20% material costs and 60%, salary costs. Costs for salary and materials were valid at the time of measurement.

## RESULTS

Table 2 shows the material consumption during processing when the sawn timber was cut into components. It can be concluded that the material utilisation during cutting is high with only 3-4% waste at both companies. This means that their processing costs consist mainly of manufacturing costs.

**Table 2**  
**Volume of sawn timber and components, and operator time during cutting of components.**  
*Positions 1-3 are shown in Fig. 1*

	Position	Company A	Company B
Volume of raw material for cutting [m <sup>3</sup> ]	1	7.01	9.05
Volume of cut material (i.e., components) [m <sup>3</sup> ]	2	6.78	8.76
Volume of waste material, length discrepancies [m <sup>3</sup> (% of raw material)]	3	0.24 (3.4)	0.29 (3.2)
Total efficient operator time [h:min]		12:19	10:11

Table 3 shows a cost calculation for cutting the sawn timber into components. The processing cost is about 20% higher per unit volume of components at Company A than at Company B. A decisive reason for this is that Company B cuts its sawn timber for more than one house at a time, whenever this is possible. Another reason for the greater efficiency of Company B is its handling equipment, which automatically ensures that the timber products reach the operator.

The cost differences between the companies are not large, and the processing costs amount to approximately one third of the total manufacturing cost. In general, it is important to note that all the supporting documents for the operator at the cutting saw must have complete, correct information. When the operator is forced to stop working on the material processing to locate the supporting documents, this leads to an increase in price.

**Table 3**  
**Manufacturing costs during the cutting of components**

	Company A	Company B
Direct material costs, purchase of timber (220 €/m <sup>3</sup> )	1,542	2,118
Indirect material cost (20% of material cost)	308	424
Direct labour costs (30 €/h)	369	339
Indirect labour cost (60 % of salary)	222	203
Total cost (€)	2,441	3,084
Sales of waste material (25 €/m <sup>3</sup> )	-6	-8
Total manufacturing cost (€)	2,435	3,076
Total manufacturing cost (€/m <sup>3</sup> cut material)	359	351
Processing cost (€/m <sup>3</sup> components)	132	110

## **DICSCUSSION**

Following tradition, the majority of single-family houses in Sweden are built with timber frames. Many of these wooden homes also use wood in their façade coverings. Using wood can give housing manufacturers a competitive advantage compared to using other materials, especially environmental advantages. Any advantage on the European market is especially valuable to Sweden, because the Swedish single-family timber house industry is weakly represented on this market. The arguments for the use of wood cite this material's greater inclusion of carbon and reduced emissions of greenhouse gases. Nevertheless, the costs of sawn timber and assembly for the housing manufacturer must be the same as or lower than the equivalent costs for alternative building materials in order for these arguments to be compelling. Unfortunately, the single-family timber house industry in Sweden is currently facing numerous financial challenges, and the overriding question is how to produce houses at an attractive price.

The development of production technologies and methods which began during the first decades of the 1900s has not shown the same continuity as the development in many other industries. One hypothesis for this lack of development is that quality discrepancies in incoming sawn timber lead to increased costs due to material waste and extra work in the factory as well as productivity losses. A general problem (but not a universal problem) in the Swedish single-family timber house industry is that the house manufacturers cannot specify their own production costs in detail (Eliasson 2014). Therefore, it is impossible for them to assess the costs that arise due to wood that does not fulfil requirement specifications.

The case study revealed that the waste that arises from quality discrepancies in incoming sawn timber was very low, and the volume yield in cutting sawn wood to components for trusses and wall frames was greater than 93%. This study shows that two thirds of the cost of producing a given volume of components is related to the raw material, and that one third is related to processing. It is extremely important to maintain a high volume yield in the sawn timber processing. This prerequisite has been difficult to accomplish for sawn timber at a sufficiently low cost. It is vital to note that the low percentage of waste in the study does not reflect the general pattern of the industry. One reason for the high volume yield in this case study was that the authors included only the sawn timber rejected at the cutting station and gave no consideration to waste due to quality deficiencies in the delivered product or to sawn timber that was rejected before or after the cutting station. In total, the wood waste in single-family timber house companies is much greater and arises during several operations in the production process, such as stocking, material processing, assembly in the factory and assembly at the building site. Waste can also result from complaints about ready-made houses. Waste during the assembly process in the factory may depend not only on poor timber quality but also on assembly errors. Errors in assembly can arise from deficiencies in timber qualities, incorrect instructions and supporting drawings, poor concentration and carelessness. Moreover, the operators do not always know about the requirement specifications during assembly. The dismantling of already assembled material always leads to rejection and the need for substitute material.

Swedish manufacturers of single-family timber houses have a long tradition of prefabrication, but the companies exhibit a low level of automation. Increased automation may be one way to reduce the cost in the prefabrication of single-family timber house manufacturing, as suggested in this study. The expected cost reductions have not, however, been investigated in this study. Compared to on-site building, prefabrication provides numerous advantages: lower production costs through rational, multiple manufacturing, less risk of negative influences from the weather during construction and fewer errors in each building's body.

## **CONCLUSION**

This study illuminates the fact that the Swedish manufacturers of single-family timber houses generally have production means that are technically less developed than those of other manufacturing industries in spite of the fact that Sweden has a long tradition of manufacturing prefabricated single-family timber housing and that timber housing dominates the market in Sweden for this product category. To increase or at least maintain the same level of their utilisation of wood as a building material during the construction of single-family houses, Swedish companies must make their production more efficient by refining *the* technology, production methods and materials that lie on the leading edge of technology. A prerequisite for this is that extra costs for more precise timber specification plus extra capital costs for automation is offset by savings in reduced waste and savings in other processing and labour costs. They must also engage in the system-component-based purchase of timber.

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