This is the published version of a paper presented at 23rd International Wood Machining Seminar, 28-31 May, 2017, Warsaw, Poland.

Citation for the original published paper:


N.B. When citing this work, cite the original published paper.

Permanent link to this version:
http://urn.kb.se/resolve?urn=urn:nbn:se:lnu:diva-67488
Differences on automation practices in wooden single-family houses manufacturing: Four case studies

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ABSTRACT

In densely forested countries, forest and wood-based products are an important contributing factor to the country’s economy and also a valuable resource for house manufacturing. With rising demand for housing in Europe, wooden houses have become more of an alternative to concrete houses. Although wooden houses have always been popular in Nordic countries, higher demand puts more pressure on seemingly outdated production facilities and personnel in order to supply the market. Whereas many other industries strive to modern production concepts such as Industry 4.0 to adapt to new market conditions, industrial timber house building is still characterized by a high amount of manual labor.

In Europe’s highly industrialized countries, labor costs influence wooden house manufacturers rather negatively and exert great pressure on them to stay competitive. Some companies have chosen outsourcing of their operations and production as means to survive. Another way, already successfully proven in other industries, is the automation and digitalization of production processes. Effective implementation of automation equipment depends on several factors, e.g. production volume, applied material, chosen application or cycle times. It is not entirely clear which factors are contributing to the successful change to a more automated production.

Based on an Industry 4.0 readiness model, the purpose of this study is to seek out which dimensions correlate with each other in order to support improved production processes and efficiency for wooden single-house manufactures.

By applying a comparative case study approach, automation standards and practices in Sweden, Germany and Austria, are described and compared. Results of this case study reveal that a production strategy together with sound digital support and information sharing leads to the
INTRODUCTION
An increased demand for both single-family and multi-family housing units has emerged throughout the last years in Sweden. Sales of prefabricated wooden single-family houses in Sweden have increased from about 3780 units in 2012 to 5916 in 2016 (Möbelföretagen, 2017). The market share of all sold single-family houses was around 90% and has been quite constant during the last decade. However, the current production capacities of the available facilities are not able to manufacture the required amount of housing units in Sweden (Schauerte, 2013). Not only is the production capacity too low, but the production systems are also characterized by a low degree of automation (Eliasson, 2014) and digitalization (Hooper, 2015). The need for new production methods becomes evident.

Production strategies developed in the concept of Industry 4.0 provide new principles for production improvement and increased efficiency. In Europe, Germany followed by Austria are the leaders in the implementation of Industry 4.0 concepts in different industries (Acatech, 2016). Industry 4.0, encompasses various aspects, e.g. new business models, automation, production optimization, smart products and digitalization. By comparing different enterprises and similar production systems, the differences and ramifications of Industry 4.0 concepts in wooden single-family house manufacturing can be studied.

Objective
This study is based on four case studies of wooden single-family houses, whereof two of the participants are based in Sweden, one in Germany and one in Austria. The objective of this study is to compare those four companies in a cross-case analysis by means of their status of production and automation capabilities as well as their state of digitalization. By comparing those as well as the possible correlation between these dimensions, this research seeks to identify dimensions that need to be fulfilled in order to gain the most robust production system and prepare for future obstacles.

Theoretical framework
The International Academy of Production Engineering defines manufacturing as “a generally complex activity involving people who have a broad range of disciplines and skills, together with a wide variety of machinery, equipment, and tools with various levels of automation, including computers, robots and material handling equipment” (CIRP, 2014, p. 829). Manufacturing of products is comprised by the collaboration of people, machinery, computers as well as the flow of material and information through production. Figure 1 displays the
relations and interactions of the elements in a production system necessary to produce goods. The modified figure by Bellgran and Säfsten (2009) puts a stronger empathize on the material and information flow following each product in the system. Not all of the described elements need to be present in a production system to successfully produce goods. It is expected that with further development of technology, modern production systems will contain less human workers and more computers and robots. This kind of automation and digitalization of direct and indirect production processes is described with the concept of Industry 4.0 (Lasi et al., 2014). As motivation for industrial companies to move towards Industry 4.0, significant boosts of revenue and greater efficiency in production, as well as management systems, are projected (Lichtblau et al., 2015). This is often summarized as a higher market competitiveness for the enterprise.

Figure 1: Structural perspective on elements of a production system (adapted from Bellgran and Säfsten, 2009)

Figure 2: Dimensions of Industry 4.0 (Lichtblau et al., 2015)

In Lichtblau et al. (2015) a readiness model for organizations to investigate their possibilities and capabilities for Industry 4.0 maturity is presented. It comprises six dimensions, as depicted in figure 2, to achieve Industry 4.0 readiness. Four of those six dimensions, employees, strategy and organization, smart factory and smart operations are directly linked to production systems, and they are therefore used in this study as the baseline for analysis. The dimension of employees refers to human workers, both in production, but also in production related processes and administration. In addition, it reflects as well to working attitude and how it contributes to the company’s culture. Strategy and organization refer to, e.g. existing manufacturing or automation strategies, how the company is organized and how investment decisions are made Smart factory includes elements of information technology (IT) and the production equipment. Smart operations apply among others to how information is shared inside the organization and with its suppliers/customers. Smart products and data-driven services relate to products and their capabilities itself. They are not the focus of this study and therefore not included. Nevertheless, they might have an impact.
in future wooden single-house manufacturing when the goal is to make houses smarter, e.g.
smarter electricity management in order to save electricity (Zipperer et al., 2013).

METHODS
The paper is based on case study research design with qualitative data in order to analyze
contemporary events (or current states) of the four cases (Yin, 2014). By studying the four
dimensions described in the theoretical framework and using each of them as an embedded unit
of analysis in each case, an explanatory comparison is conducted.

Selection of respondents
The selection of the respondents in Sweden was based on a registry provided by the Swedish
Federation of Wood and Furniture Industry (Möbelföretagen, 2015). The record includes over
30 of the largest Swedish single-family house manufacturers. Two of those 30 were selected
due to their geographical position located in the main cluster of all Swedish wooden single-
house manufacturers and their averaged production volume. The selection of the German and
Austrian companies was based on their estimated company size, turnover and production
volume. In addition, both companies were known in their industrial branch by having modern
production facilities, having invested in new production equipment to some extent in the last
five years and performing change management. If the companies own more than one production
site or brand, only the visited production site (with the main brand) is analyzed, and an overview
is presented in Table 1. All four wooden single-family house manufacturers are specialized in
customized houses with an engineer-to-order manufacturing strategy.

<table>
<thead>
<tr>
<th>Case number</th>
<th>Location</th>
<th>Interviewed person</th>
<th>Total # of employees / whereof in production</th>
<th>Ownership</th>
<th># manufactured single family houses in 2015</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Sweden</td>
<td>Head of production</td>
<td>80/74</td>
<td>corporate group</td>
<td>100</td>
</tr>
<tr>
<td>2</td>
<td>Sweden</td>
<td>Technical director</td>
<td>115/65</td>
<td>family business</td>
<td>200</td>
</tr>
<tr>
<td>3</td>
<td>Germany</td>
<td>Head of production</td>
<td>300/100</td>
<td>family business</td>
<td>250</td>
</tr>
<tr>
<td>4</td>
<td>Austria</td>
<td>Technical director</td>
<td>280/70</td>
<td>family business</td>
<td>250</td>
</tr>
</tbody>
</table>

Data Collection and Analysis
Data was gathered during 2016 by semi-structured interviews where all respondents were asked
the same questions, either in person or via telephone (Fowler, 2014). Besides general
background information about the companies, the questions covered topics of production and
assembly systems, material handling, investment decisions, production and automation
strategies as well as an overview of the competence of the employees. In addition, a visit to the
production sites expanded the data collection with actual observations of the manufacturing facilities. The combination of interviews and observations allows for high quality in qualitative research methods (Merriam and Tisdell, 2016). Follow-up questions were asked when suitable, both during the interview but also during the study visit. The length of the interviews varied between 60 and 90 minutes. All interviews were recorded for the purpose of transcription. The transcript was sent out to each of the respondents for correction and approval. Only the final transcript was then used for data analysis.

By ensuring that the interviewed personnel did meet the qualifications and had the knowledge necessary to answer the questions, the internal validity was upheld (Yin, 2014). Therefore, all participants were directly responsible for the production processes (e.g. head of production) or heavily involved (e.g. technical director) in them and can be considered as experts in their business area. This together with reviewing the original transcript drafts strengthens the results. Reliability is ensured by appropriate step by step documentation of the research process.

RESULTS

Employees

When comparing the numbers presented in Table 1, it first seems that case 3 and 4 are larger in the total number of employees. However, this is not the situation due to marketing and sales strategies of case 1 and 2. Both companies use external sales offices, which are not included in the listed numbers of employees. It is therefore only of interest to compare the number of people involved in the production or related processes, i.e. personnel working in production, logistics, purchase or information technology (IT) departments. Additionally, design and development are not included in the figures. All companies work in one shift of eight working hours, five days per week.

In case 1 no employee holds a university degree. Most of the employees have a high-school diploma or equivalent professional qualification. In case 2, ten employees involved in production hold a university degree, whereas the remaining employees have high-school diplomas or vocational qualification. In case 3, ten people in production hold a university degree; the remaining workers are comparable to case 1 and 2. In case 4, about 25 employees hold a university degree while the remaining workers have the same formal education level as in the other three cases. None of the companies is interested in hiring unskilled labor.

Case 1 states that they have no personnel with the skills to e.g. implement new production or assembly technology. They solemnly rely on external consultants. Their head of production (HP) describes that the workers are not afraid of new methods and technology, but they have a negative attitude towards change. In case 2, the technical director (TD) mentions that they have the competence to execute smaller technological projects on their own. For bigger acquisition of equipment, they rely on external consultants. According to the TD of case 2, the workforce is often differentiated when the company acquires new equipment. About half of the workforce is reluctant, and the other half is in favor for it. In case 3, the HD describes that they have a
mixed competence in regards to production development. They have not experienced any problems when they have conducted projected in regards to machinery or other equipment. However, in regards to digital or IT infrastructure, e.g. computer-integrated manufacturing (CIM) or computer-aided manufacturing (CAM), they have not the necessary competence in-house. The TD of case 4 describes that the company hired a lot of personnel for their IT department for about ten years ago to develop their CIM, CAM and building information model (BIM) systems as well their information flow through their supply chain. In recent years they have also hired more educated and experienced personal in their production facilities.

All four cases mention that it is hard to hire skilled and competent personal, both with a university degree, but also with a professional degree. The HD of case 3 states that they ‘value their employees’ weight in gold,’ empathizing the difficulty in finding and hiring the right new employee.

**Strategy and organization**

In case 1 the company group, i.e. their investor, gave money to invest in new equipment. This investment took place just a two to three years back according to their HD. However, in the beginning, they had problems installing the new machinery despite many external consultants. During 2015 they have experienced problems with integration of the new equipment in their material flow and production process. The HD is responsible for production and automation strategy but states to rely on consultants in which way it should be carried out. Case 2 is a family owned company with a small investment capital. Their investment strategy was during the last years focused mainly on implementing smarter solutions in their production, e.g. laser guiding systems or tablets instead of print-out of drawings. The goal was to simplify and speed up production processes and to free personnel from easier tasks to let them support more complicated tasks. Case 3 is also a family owned company, and they have not invested in new “big” production equipment, e.g. new computer numerical controlled (CNC) joinery machines, but in smaller handheld tools to improve working conditions. The HD mentions that they rely very much on their experienced workforce to have a well-functioning production process. Case 4 started for about a decade ago to invest in new personnel to develop their IT infrastructure, mainly their computer-aided design software (CAD), CIM and CAM systems. About five years ago they invested in entirely new equipment, mainly new CNC machines. The investment and production strategy decisions in the family owned cases 2, 3 and 4 are developed by their owners together with responsible production employees.

Case 3 and 4 differ decisively from case 1 and 2 in regards to their supply chains. Case 1 and 2 mainly consist of production sites and manufacture single-family houses with minimal extra subassembly for individual parts. They use suppliers for their e.g. raw material, windows, floors. In comparison to the Swedish companies, case company 3 is also responsible for distribution and building of the prefabricated house on the actual site. Case company 4 is unique and owns a saw mill delivering the necessary wood, manufactures its own windows, staircases, doors,
and has an own district heating plant utilizing the sawdust from the sawmill and joinery machines. Furthermore, they also distribute and build the houses on site with own personnel.

**Smart Operations**

In regards to IT systems, case 1 uses a CAD system for drawing up the houses. However, they do not have a material handling system nor CIM/CAM software to control the new machinery. Data input at their new CNC cutting machine has to be entered manually. Operators in production use print-outs for the construction of e.g. wall elements. Furthermore, data sharing of their enterprise resource planning (ERP) system has to be executed manually, i.e. ordering goods from suppliers is not occurring automatically. The HD states that they have lead times of several weeks for delivering a house. Case 2 uses CAM files derived from their CAD program in order to control their support systems, e.g. laser guiding, or cutting machines. In addition, all work orders appear on tablets. The ERP system automatically orders pre-cut timber for construction of roof trusses from a nearby sawmill. The raw material is then delivered in packages. Other components are also ordered automatically by the ERP when a housing project is entered into the system from the CAD manually. In case 3 the company generates CAM files automatically from their CAD system to control some of their equipment. CAD data from the houses is entered manually into the ERP system, which after that generates orders for components of the houses automatically. Their HD mentions that lead times for ordering are only one to two weeks because of good relations with their suppliers. They use a material handling system to overview the flow through production. All employees have to some extent access to the ERP allowing them to get an overview of the current state of a house construction project. Work orders are print-outs and are available at all workstations. The TD in case 4 indicates that the company is sharing all their data with their suppliers by their ERP. However, since most of those suppliers are internal, and they have good relations with the external suppliers. CAD drawings from houses are automatically compiled to BIM and CIM creating lead times of only one to three days in production itself. According to the TD, the whole production is controlled automatically to create the best material flow through production. Work instructions are directly sent and shared at each workstation with computers.

**Smart factory**

All four cases use similar conveyor systems for construction and transporting of the wall elements.

The level of automation is very low in case 1. Most of the work is done manually with handheld power tools and with work instructions shared on print-outs. New investments have among others led to a new cutting machine. This new piece of equipment is working properly from a technical point of view. However, the HD remarks that they have problems fully integrating and utilizing the machinery. They have not measured capacity utilization of it, but estimate it to be under 10%. Also, case 1 has no material handling system, resulting in high stock levels of timber.
and other components Personnel is picking what they need on their own according to their working instructions. The TD of case 2 mentions that their smaller investments into support systems have made a good impact on production and they were able to increase production efficiency by over 10%. Older machinery is working properly, and they have analyzed bottlenecks in production. They are preparing to acquire new equipment in order to increase productivity even more. Case 3 carries out most of the work manually with the help of handheld power tools. Existing equipment is working correctly, and they have not planned to invest in new automated systems in the next years. In case 4 a whole new production line was installed, and most of the production steps are executed automatically. A few skilled workers overview the processes and first in finishing operations, e.g. plastering of walls or wiring of electrics manual labor is used. Delivery of goods to workstations is planned with the help of software. Although the production processes have improved drastically during the last couple of years, they still want to become better according to their TD.

**DISCUSSION**

When comparing the four companies, case 4 has shown the best scenario for increased production efficiency. This can be related to a clear production strategy with a focus on digitalization at first. For this, new and qualified personnel was hired as a first step and after that new machinery and automation equipment were implemented. Case 1 acquired heavy equipment with neither a clear strategy nor skilled personnel at this particular machinery leading to a suboptimal performance in their production system. To some extent, it can be described as a bad case example for investing and implementing of new machinery. Case 2 shows that with little investment, but a clear strategy, production efficiency, and working conditions can be increased. An analysis of case 3 demonstrates that relying on skilled and dedicated personnel can also lead to well-working production systems. However, this strategy does not seem very robust for the future. Table 2 depicts how the four dimensions influence each other with an either positive (+) effect, a negative (-) effect, or no correlation (0). Each column illustrates which effect one dimension has on the other one. As most crucial dimension in this case study, strategy and organization have been identified.

| Table 2: Type of correlation for the four dimensions in the case studies |
|-----------------------------|-----------------------------|-----------------------------|-----------------------------|
| Employees  | Strategy and Organization  | Smart factory  | Smart Operations  |
| Employees  | X  | +  | 0  | 0  |
| Strategy and Organization  | 0  | X  | 0  | -  |
| Smart factory  | +  | +  | X  | +  |
| Smart Operations  | +  | +  | -  | X  |

The obvious success of case 4 in regards to their production system is very much contributed
by their well-working internal material flow and supply chain integration. It is a big advantageous for case 4 to almost own the entire supply chain from raw material production to final construction of the houses. This allows them optimal control of their supply chain. Often, wooden house manufacturers suffer also bad data sharing in supply chains because of many other wood product industries, e.g. windows and door manufacturers or saw mills are not that digitized either in comparison to many other industries.

CONCLUSIONS AND FUTURE RESEARCH
Although this study only includes four cases, it gives a clear indication that a proper production strategy is the best point of origin when improvement in the manufacturing processes is the goal. Based on the production strategy, it is then often advantageous to first develop a better IT infrastructure in order to support automated equipment. If the goal is only to acquire production support tools, smart operations are not that important. Skilled workers are necessary for smart equipment and smart operations. Differences in their strategy and the working culture depend on very much the type of ownership. If the company is family business owned, facilities are often in better shape and employees more motivated (Löfving et al., 2008). However, it is not a necessity to make large investments into new production equipment. A smart and clear production strategy with improvements of the material flow, supply chain and control of the bottlenecks can lead to the right enhancements, too.

Future research will enlarge the study to cases in different wood product industries, e.g. furniture or joinery industries to analyze if the four dimensions correlate in the same way.

ACKNOWLEDGEMENTS
The authors wish to express their sincere gratitude for financial support from The Knowledge Foundation (www.kks.se) through ProWOOD, a doctoral programme on wood manufacturing, Linnaeus University and Jönköping University.

REFERENCES

