Industrialised Timber Frame Housing

Managing customisation, change, and information

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Department of Civil and Environmental Engineering
Division of Structural Engineering – Timber Structures

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Preface

This thesis is the visible result of a research process, which for me has meant many interesting insights, increased knowledge, and lots of hard work. I hope that the product at least in part can match the process. Most important for me during this process has been the interaction with the many competent and interesting persons I have had the opportunity to meet. It would not have been possible to accomplish this thesis without the support from these persons sharing their insights and knowledge. I am very grateful for this support and although not everyone can be mentioned I would especially like to thank:

Professor Lars Stehn, head of the Division of Structural Engineering – Timber Structures and initiator of the research project, for showing a real and genuine interest and knowledge in my research and for always providing good constructive ideas. I have really enjoyed all of our discussions, and chats, regarding different aspects of research and other matters.

Ass. Professor Mats Westerberg, Division of Management Control, for, during interesting discussions, sharing his knowledge of areas which I previously was not familiar with at all.

All of my colleagues at the Division of Structural Engineering – Timber Structures, you have all made this journey interesting, pleasant, and enjoyable.

Without the companies, which have participated in the case studies and the survey and provided valuable empirical data and industrial perspectives, performing this research would not have been possible.

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Jessica, meeting you is the best that has ever happened to me and you are always my greatest inspiration. Every day with you is a meaningful, exciting, and rich day full of beauty.

Göteborg, November 2004
Max Bergström
Abstract

The overall aim of this thesis is to develop an increased understanding of industrialised timber frame housing (timber frame housing construction fully or partially conducted in a controlled environment utilising industrial processes and machinery). Of specific interest is how industrialised timber frame housing companies manage customisation, change, and information.

Three single case studies (at a medium-sized industrialised timber frame housing company), one multiple-case study, and one survey were conducted. The first single case study investigates how production can benefit from integrating a customer-oriented design and production. The second single case study illustrates the shift towards an enterprise resource planning (ERP) approach through a change process. The third single case study describes the ERP system implementation. The multiple-case study investigates the prospects and pitfalls among four small and medium-sized industrialised timber frame housing companies that manufacture complex products utilising advanced prefabrication. The survey, conducted among the vast majority of industrialised timber frame housing companies in Sweden, presents the industry structure and investigates the benefits and disadvantages of ERP.

The results demonstrate that matching customer requirements and an industrialised building system is facilitated through product and process development. Other findings suggest that ERP can meet the needs of industrialised timber frame housing, promote an organisation to be re-engineered through comprehensive change, and act as a driver for a more efficient internal and external supply chain. However, a lack of history regarding information technology (IT) systems for production processes and the timing of the system selection in the overall ERP adoption are both critical for the ERP system implementation outcome. With no previous history of IT systems for production processes, an ERP system implementation is a big step even if it is carefully conducted. Industrialised timber frame housing has increased in popularity on the market over the last years. An important reason for this is the increased customer focus. However, blind customer focus leads to poor utilisation of resources. By balancing customer orientation with internal efficiency, achieving an effective construction process seems possible. Communication between different actors in the construction process, finding a reasonable level of customer focus, and capacity limitations are current problem areas with the potential for improvement. Possible ways of improving the construction process are an increased integration between actors, a gradual increase in IT support, and finding the balance between project and process orientation. The survey demonstrates low ERP usage in industrialised timber frame housing with a low degree of strategic importance, while there are operational and managerial benefits. The results also show the potential of the ERP approach.
for industrialised timber frame housing, while its use is favoured by an increased maturity in IT.

The overall results show that customer orientation, change, and information management are important ingredients in industrialised timber frame housing. Customer orientation can act as a driver for change and for improved information management. Changes in business processes are needed to facilitate customisation and information management. Information management has a key role in the entire construction process to facilitate customisation, while the need of efficient information management can act as a driver for change.
Sammanfattning

Det övergripande syftet med denna avhandling är att utveckla en ökad förståelse för industrialiserat trähusbyggande (trädhusbyggande som helt eller delvis utförs i kontrollerade produktionsmiljöer med hjälp av industrialiserade processer och maskinell utrustning). Av speciellt intresse är att undersöka hur industrialiserade trähusföretag hanterar kundanpassning, förändring och information.


De övergripande resultaten visar att kundorientering, förändring och informationshantering är viktiga ingredienser i ett industrialiserat trähusbyggande. Kund-
orientering kan verka som en drivkraft för förändring och förbättrad informationshantering. Förändringar i affärsprocesser är nödvändiga för att underlätta kundanpassning och informationshantering. Informationshantering har en nyckelroll i hela byggprocessen för att främja kundanpassning och behovet av effektiv informationshantering kan verka som en drivkraft för förändring.
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**Appendix A – Mail questionnaire**
## Abbreviations in sections 1-5

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>CE</td>
<td>Concurrent engineering</td>
</tr>
<tr>
<td>ERP</td>
<td>Enterprise resource planning</td>
</tr>
<tr>
<td>IS</td>
<td>Information system</td>
</tr>
<tr>
<td>IT</td>
<td>Information technology</td>
</tr>
<tr>
<td>MRP</td>
<td>Material requirements planning</td>
</tr>
<tr>
<td>MRP II</td>
<td>Manufacturing resource planning</td>
</tr>
<tr>
<td>R&amp;D</td>
<td>Research and development</td>
</tr>
<tr>
<td>ROA</td>
<td>Return on assets</td>
</tr>
<tr>
<td>SCM</td>
<td>Supply chain management</td>
</tr>
<tr>
<td>SME</td>
<td>Small and medium-sized enterprise</td>
</tr>
<tr>
<td>TOC</td>
<td>Theory of constraints</td>
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<tr>
<td>QFD</td>
<td>Quality function deployment</td>
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1 Introduction

This section presents the background comprising of an overview of the housing industry in Sweden, leading to: the scientific relevance and research motives, aim and some central concepts, limitations, disposition, and research questions of the thesis.

1.1 Background

An extensive governmental evaluation of the Swedish construction industry shows higher productivity in the manufacturing industry than the construction industry as well as the possibility to reduce production costs in housing construction (SOU, 2000). To increase productivity and reduce costs, industrialisation, customer orientation, and a more efficient construction process are mentioned as important factors. A following governmental evaluation shows the Swedish construction industry as having a low degree of competition yielding high costs, low productivity and quality, and small incentives for change (SOU, 2002). For example, only a few companies are active on the market for multi-family dwellings. A strategy to increase competition in Swedish housing construction, developed on behalf of the government, suggests increased use of timber in housing construction (Ds, 2004). According to the strategy, an increased knowledge of timber housing construction among housing construction actors, more developed building systems for multi-storey (> 2 storeys) houses, and one-family house manufacturers acting as catalysts for increased industrialisation in housing are ways towards the overall goal. A comparison shows the efficiency development for the construction of one-family houses to be better than for multi-family dwellings, due to the higher degree of process-orientation in one-family housing construction and the advantages arising from industrialisation (SOU, 2000). A further analysis of Swedish timber frame house manufacturing, conducted on behalf of a governmental department, also suggests that industrialised timber frame housing systems have the potential to reduce costs in housing construction (VA, 2004). The cost of timber material does not make the most significant contribution to potential cost savings; rather, the main reasons for the cost reducing potential are, e.g. possibilities to increase prefabrication, improve logistics, and improve the construction process. Hence, the importance of developing market-oriented prefabricated building systems for multi-family dwellings in multi-storey houses to possibly utilise similar advantages as in one-family housing is pointed out in both Ds (2004) and VA (2004).

Both opportunities and obstacles are identified in recent Swedish development projects regarding construction industry and implementation and use of information technology (IT). Examples of opportunities are possibilities for improved communication, working methods, and decisions. Lack of standardised classification systems, difficulties of integrating IT systems throughout the construction
process, inadequate forms of contracts, and lack of knowledge are identified as current obstacles (Wikforss, 2003).

The manufacturing industry has gained substantial improvements in efficiency through concepts like supply chain management (SCM), lean and agile production, and comprehensive planning methods. These concepts and methods are often supported by information systems (IS). Logistics, SCM, and lean and agile production are demonstrated as disciplines with the potential to also increase efficiency and flexibility in the housing construction process (Naim and Barlow, 2003; Roy et al., 2003). Methodologies provided by SCM, e.g. for control, can resolve many construction supply chain problems (Vrijhoef and Koskela, 2000). Through case study research of a Swedish low-cost housing concept, it is shown that adopting an SCM philosophy in housing has the potential to, e.g. develop new markets and increase revenues (Olsson, 2000). Two obstacles for SCM adoption in the housing industry are the project focus and project culture (Olsson, 2000), i.e. adaptation is needed due to the differences regarding these obstacles (Riley and Clare-Brown, 2001). Typically, the project-focus, i.e. the production of one single new product utilising temporary supply chains with separation between design and production, negatively impacts construction supply chain management, thereby leading to instability and fragmentation (Vrijhoef and Koskela, 2000).

Industrialised housing (tentatively described in section 1.3 and positioned in section 2.2) both resembles and differs from the manufacturing industry, implicating both possibilities and limitations in the potential transfer of concepts from manufacturing to housing and that real lessons can be drawn from the manufacturing industry (Gann, 1996; Gibb, 2001).

1.1.1 Industrialised timber frame housing in Sweden

The construction of timber frame houses has a long tradition in Sweden. Most one-family detached houses in Sweden have timber frames (lightweight frames) and are prefabricated by industrialised housing companies (approximately 74% from 1990 to 2002). Of predominance are the build-operate/own-transfer forms of contract including the responsibilities to fulfil performance requirements. The companies own and perform design and production processes (factory and on-site) as well as possess factory buildings including industrial machinery. The total annual production value of Swedish industrialised timber frame housing is approximately €730 M, with the annual export value at approximately €140 M (from 1999 to 2003). The major export markets are Denmark, Finland, Norway, Japan, and Germany. With the introduction of the performance based Swedish 1994 building code, multi-storey timber frame houses were again allowed to be built. Prior to 1994, multi-storey timber frame houses were not allowed to be built according to late 19th century fire regulations due to a number of great city fires. However, the production of multi-storey timber frame houses is still small
compared to the total production of timber houses and multi-storey houses in Sweden. On-site built houses with steel and concrete frames built by a few large contractor companies dominate the market for multi-storey houses. Industrialised timber frame housing companies manufacturing one-family detached houses and multi-family houses up to two storeys have not yet shifted focus very much towards multi-storey houses. Experiences from the one-family house market indicate that an industrialised production approach could also have potential for multi-storey timber frame houses.

1.2 Research motives

The construction industry is made up of multiple parts and can be defined in several ways. Within the scope of this thesis industrialised timber frame housing is regarded as a subgroup of industrialised housing, which is a subgroup of the housing industry, which is a subgroup of the construction industry (see also section 2.2 and Figure 2.2). Is industrialised timber frame housing an interesting and relevant area for research? Based on the demonstrated difficulties and opportunities in housing construction it is here argued that it is:

- In Sweden, the construction industry represents roughly 10% of the labour market and the built environment is of great importance for the welfare for society. Ideally, buildings should be functionally, economically, sociologically, environmentally, and aesthetically acceptable and attractive for long periods of time (SOU, 2002). The state of the art of housing construction (section 1.1), its development potential (section 1.1), and its importance for society makes empirical data collection and research findings within housing construction scientifically relevant, with the potential for practical implications.

- By definition, industrialised timber frame housing is industrialised and performs parts of or the entire construction process utilising industrialised processes and machinery. Research findings are thus based on an area within housing construction with a history of industrialisation. Experiences from the detached housing market in Sweden, which has had open competition for a long time, demonstrate that an industrialised timber frame production approach is highly competitive. Hence, industrialised timber frame housing is a source of empirical data collection that when analysed can contribute with scientifically relevant findings.

- Similarities to the manufacturing industry make industrialised timber frame housing interesting for research, because of the learning aspects regarding utilised concepts within the manufacturing industry.

- An increased knowledge of industrialised timber frame housing is relevant for current and potential actors on the multi-storey housing market, primarily regarding alternative production methods (increased industrialisation).
1.3 Aim and central concepts

Sections 1.1 and 1.2 imply that improvements in housing construction are possible and that there is a learning potential from manufacturing to housing construction as well as from industrialised one-family house manufacturers to industrialised multi-family and multi-storey house manufacturers.

Possible improvements in housing suggest that there is a potential for an applied or normative research approach, i.e. identify “solutions” or ways to possible “solutions” of existing problems within housing (described in section 1.1). The learning potential also suggests a potential for a more theoretical or descriptive research approach, i.e. increase the existing knowledge base regarding industrialised timber frame housing.

The origin of this thesis is the need for improvements in housing construction. However, it is not within the scope of a thesis to only provide directly applicable “quick-fix solutions” to existing problems. Instead, it is to increase knowledge of a scientifically relevant area (section 1.2). The research presented in this thesis has an applied research orientation due to the practical origin of the thesis and the interest of the researcher, see also section 2; and while in the search for new knowledge, practical implications have emerged due to this orientation. The research findings might thus be used for increased, developed, and normative insights, also for non-scientific target groups, of a previously uncharted area such as industrialised timber frame housing. Both the research findings and their implications can thus be used at scientific and practical levels, Figure 1.1.

![Figure 1.1. Relations between empirical data collection and research contributions.](image)

Hence, the overall aim of the thesis is twofold – one scientific and one practical oriented aim:

- The overall **scientific aim** is to develop an increased understanding of industrialised timber frame housing and how industrialised timber frame housing companies are aiming for construction process and supply chain improvements.

- The overall **practical aim** is to create an increased understanding of industrialised timber frame housing from a practical perspective while providing pos-
sible ways towards “problem solutions” more closely and directly related to industry needs.

To increase existing knowledge regarding industrialised timber frame housing, a multi-scientific research approach has been applied. By doing so, several ingredients of industrialised timber frame housing have been covered rather than focusing on separate and isolated ingredients. A concept such as industrialised timber frame housing can be multi-definitional, covering multiple aspects. Tentatively and schematically, the complexity of industrialised timber frame housing can be illustrated as in Figure 1.2, where possible ingredients influencing and defining industrialised timber frame housing are shown. The ingredients shown in Figure 1.2 represent broad terms, for example “information” can include e.g. information management, IS, and IT. Each ingredient, along with other ingredients not included in Figure 1.2, might be of great importance for describing industrialised timber frame housing. It is neither the intention, nor within the scope of this thesis to provide a complete and definitive description and definition of industrialised timber frame housing. Selected ingredients are instead described and analysed in an industrialised timber frame housing context. Selecting ingredients has been an iterative process where a mix of pre-understanding, research findings, industrial needs, and interests of the researcher have contributed to the gradual emerging choices of ingredients. The motive for selecting the specific ingredients mentioned below, is the increasing awareness during the research process that they are central parts of industrialised timber frame housing. Hence, describing these ingredients and their relations to each other as well as to industrialised timber frame housing can contribute in reaching the aim. The research process is further described in section 2.1.

![Figure 1.2. Industrialised timber frame housing: tentative ingredients.](image)

Ingredients of specific interest are customisation, information management including adoption of IS and IT support, and change. Brief initial explanations of some additional central concepts in the thesis, i.e. “timber frame houses”, “construction...
process”, “supply chain”, “information management”, and “IS”, are provided in section 1.3.1 to further understand this and forthcoming sections. These concepts, along with customisation and change, are further developed in an industrialised timber frame housing context in this and forthcoming sections and appended papers.

1.3.1 Central concepts

Timber frame houses are houses with load-bearing structural lightweight or solid wood frames. Log houses and log cabins are here not included in the term timber frame houses. Construction process is the life-cycle a product such as a house undergoes, as all products produced by discrete assembly industries: concept – design – planning and controlling – manufacturing – assembly (Winch, 2003). Not included in the term construction process are the parts of a product’s life-cycle following assembly (maintenance and demolition). This description provided by Winch (2003) matches the needs of the thesis, where the planning and controlling phases of the construction process along with manufacturing, assembly, and design are the most important, while concept is covered only briefly. A supply chain can be viewed as a network, supported by processes, organisational structures, and technologies, consisting of suppliers, manufacturers, distributors, retailers, and customers, supporting material, information, and financial flows (Akkermans et al., 2003). Information management in an organisation comprises the gathering, storing, analysing, communicating, and using of information, preferably in a timely and intelligent manner (Feldman and March, 1981). IS are IT based software systems used to support, e.g. business management and production related business processes such as materials management and production control. A typical example of IS is enterprise resource planning (ERP) systems used for enterprise business integration.

1.4 Limitations

The empirical data collection was conducted only among industrialised timber frame housing companies in Sweden from 1999 to 2004. The focus of the research has been how industrialised timber frame housing companies, mainly small and medium-sized enterprises (SMEs), are aiming for construction process and supply chain improvements on an organisational level. The research is not conducted and analysed from an SME perspective, but instead refers to the companies as SMEs since the term carries important information regarding the industry and its companies. Influencing external and internal factors, except those mentioned as the focus of this research, of these companies have not been analysed, such as political interventions or the working environment of an individual construction worker. As described in section 1.3 the thesis presents a multi-scientific approach. Appropriate theories related to the examined ingredients of industrialised timber frame housing have thus been selected to properly match each specific research question, not attempting to completely cover each research area. Instead, to reach the overall aim, methods like quality function deployment
(QFD), concurrent engineering (CE), and theory of constraints (TOC) have been used as means to describe industrialised timber frame housing and how industrialised timber frame housing companies are aiming for construction process and supply chain improvements. These methods have also been used as a systematic way of collecting empirical quantitative and qualitative data.

1.5 Disposition and research questions

This compound thesis consists of two main parts, I and II. Part I comprises sections 1-6, preceding Part II, which contains appended papers briefly described in section 1.5.1. The backbone of the thesis is the papers, which contain all empirical findings. Each main phase of the research process, represented by one paper, is consequently based on the preceding main phases. In each paper, the aims and sometimes research questions are articulated. Each paper is one step towards reaching the overall aim to develop an increased understanding of industrialised timber frame housing. Each paper represents a description of industrialised timber frame housing, focusing on the selected ingredients described in section 1.3. Based on the aim of each paper, the research questions to be answered in this thesis can, in a condensed form, be articulated as:

- How can industrialised timber frame housing production benefit from an integration of a customer-oriented design and production? (Paper I)
- Can industrialised timber frame housing needs and ERP match? (Paper II)
- What are the benefits and disadvantages of ERP as applied to industrialised timber frame housing in Sweden? (Paper III)
- How are front-runners in industrialised timber frame housing in Sweden addressing prospects and pitfalls? (Paper IV)
- How are specific characteristics pertaining to a medium-sized industrialised timber frame housing company impacting ERP system implementation? (Paper V)

Each paper can, of course, be read and understood separately and so can Part I. However, to present the findings as a thesis, both Parts I and II are needed. Part I is needed to connect and integrate the papers and position the overall findings scientifically and practically. Most importantly, the sections “Method”, “Results and discussion”, and “Conclusions” describe identified cross paper relations. The main purpose of each section in part I is to link the papers in the following perspectives:

- Demonstrate the need of research regarding industrialised timber frame housing, section “Introduction”
- Illustrate the overall research strategy and describe the chosen research methods, section “Research methods”
• Describe and, regarding some areas, develop the theoretical framework in the papers, section “Theory”
• Summarise the results from the papers, discuss the results of each paper, and discuss the cross paper findings and the research process, section “Results and discussion”
• Based on the appended papers and preceding sections in Part I present the overall conclusions of the thesis, practical implications, and outlines for further research, section “Conclusions”

1.5.1 Appended papers

Paper I Integrated design and production of multi-storey timber frame houses: production effects caused by customer oriented design by Lars Stehn and Max Bergström was published in International Journal of Production Economics (Elsevier) 2002. Max Bergström’s contribution to the paper was planning, performing, and evaluating the second main part of the data collection as well as participating in writing the manuscript for the paper. In this paper, a medium-sized industrialised timber frame housing company was investigated from the viewpoint of customer orientation, production, and design of multi-storey timber frame houses.

Paper II Matching industrialised timber frame housing needs and enterprise resource planning: a change process by Max Bergström and Lars Stehn is accepted for publication in International Journal of Production Economics (Elsevier) during 2004. Max Bergström’s contribution to the paper was planning, performing, and evaluating three of the four single case studies. Both authors wrote the manuscript for the paper. In this paper, the change process of a medium-sized industrialised timber frame housing company is described and analysed.

Paper III Benefits and disadvantages of ERP in industrialised timber frame housing in Sweden by Max Bergström and Lars Stehn was submitted for publication in Construction Management and Economics (Spon Press) in May 2004. After being reviewed, the paper was revised and resubmitted in September 2004. Max Bergström’s contribution to the paper was planning, designing, administrating, and evaluating the survey. Both authors wrote the manuscript for the paper. In this paper, a survey of industrialised timber frame housing companies in Sweden is presented.

Paper IV Customised industrialised timber frame house manufacturing: prospects and pitfalls by Max Bergström and Mats Westerberg was submitted for publication in Construction Innovation (Arnold Journals) in November 2004. Max Bergström’s contribution to the paper was planning, performing, and evaluating the multiple-case study. Both authors wrote the manuscript for the paper. In this paper, the prospects and pitfalls among four industrialised timber frame housing
companies, manufacturing complex products utilising advanced prefabrication, are described and analysed.

Paper V ERP system implementation: a case study of a medium-sized industrialised housing company by Max Bergström was submitted for publication in International Journal of Production & Operations Management (Emerald) in August 2004, and has passed the initial screening and is currently under review. In this paper, ERP system implementation of a medium-sized industrialised timber frame housing company is described and analysed.
2 Research methods

This section describes the research strategy, its implications on the choice of research methods, population of interest, examples of production systems and products, how the research has been conducted, and the role of the researcher.

2.1 Research strategy and choice of research methods

Along with the need for improvements in housing construction, the origin of the thesis is the author’s pre-understanding and interest of industrialised timber frame housing. A licentiate thesis by Bergström (2001) represents the scientific pre-understanding of the author. In Bergström (2001) results from a research and development (R&D) project (VR, 2001), aiming for an industrialised development of a customised multi-storey timber frame house system, are reported along with findings from other research regarding production process developments in industrialised timber frame housing. The research has been conducted in an industrialised timber frame housing research environment. For example, supplier – contractor relations (Fredriksson, 2003), and modularization for buildability (Björnfot, 2004) have been investigated.

The aim and research questions determine the research method. For each paper the specific aim has resulted in choosing an appropriate research method to reach the aim. Each paper is consequently based on the preceding papers. Paper I represents the starting point for the thesis, where research findings from the R&D project (Bergström, 2001; VR, 2001) are reported. The following papers are influenced by the findings in Paper I. Paper II follows up and expands the findings from Paper I. The survey in Paper III was conducted to broaden the knowledge base established in Papers I and II. The findings in Paper III prompted Paper IV, since a follow-up, e.g. in the form of a multiple-case study, of selected surveyed companies would provide valuable, additional knowledge. The case study presented in Paper V is prompted mainly by Papers I and II, but also by the opportunity to uncover supporting or non-supporting findings related to Papers III and IV. The research process is summarised in Table 2.1 and illustrated in Figure 2.1.

Table 2.1. Characteristics for each main phase in the research process.

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</thead>
<tbody>
<tr>
<td>Method for data collection</td>
<td>Case study</td>
<td>Case studies</td>
<td>Survey</td>
<td>Multiple-case study</td>
<td>Case study</td>
</tr>
<tr>
<td>Qualitative or quantitative focus</td>
<td>Both</td>
<td>Qualitative</td>
<td>Both</td>
<td>Qualitative with quantitative elements</td>
<td>Qualitative</td>
</tr>
<tr>
<td>No. of observed companies</td>
<td>1</td>
<td>1</td>
<td>48</td>
<td>4</td>
<td>1</td>
</tr>
</tbody>
</table>
The research strategy has led to different research methods (single/multiple case studies and a survey), different methods for data collection (interviews, observations, archival records and documents, and a questionnaire), and collection of both qualitative and quantitative data. Interviews and parts of the survey are examples of qualitative data, with production costs and financial performance measures being examples of quantitative data. As stated earlier, the aim and research questions determine the research method. Since the overall aim of the thesis is to develop an increased understanding of industrialised timber frame housing and how industrialised timber frame housing companies are aiming for construction process and supply chain improvements, the combination of qualitative and quantitative methods has been the pervading approach. By using a multi-methodological approach different phenomena can be addressed, while the different methods can be used to support each other and provide a solid foundation for creating new knowledge (Beach et al., 2001).

Due to an increased knowledge of the research area and the research process, the researcher’s pre-understanding has evolved during the research process. During the research process, the research questions, section 1.5, have gradually emerged as a result of the research findings along with the changed pre-understanding. Hence, the choices of appropriate research methods have also emerged during the research process. The overall research strategy is thus a consequence of the emerging research questions, the progressively increasing pre-understanding regarding theoretical areas and research processes, and the research findings based on the empirical data collection and empirical data analyses.

### 2.2 Analysis level and population of interest

Figure 2.2 illustrates the relations between the entire construction industry (A) and various subgroups (B-E). Industrialised timber frame housing (D1) is here considered as a part of the entire construction industry, comprised of the housing industry (B1) and the “rest of the construction industry” (B2). This definition is illustrated in Figure 2.2 where the categorisation also includes the individual company level (E). The housing industry is here further categorised into industri-
Industrialised housing (C1) and traditional on-site construction (C2), according to the initial definitions in section 1.3.1. Industrialised housing is here further categorised into three main categories, depending on the material in the structural frame (timber, steel (D2), or concrete (D3)). Of course, alternative categorisations are possible, such as categorising the housing industry according to product type or company size, or categorising industrialised housing according to the degree of prefabrication. The categorisations in Figure 2.2 are not entirely rigid; crossing over between different categories is possible. For example, it is possible that an industrialised housing company or a network of companies manufacture timber and steel frame houses. Here, a company is categorised as a timber house manufacturing company if at least 75% of its production volume is timber frame houses. For the case studies, the analysis level is the individual company, while for the survey the individual company and industry (and subgroups of industry) represent the analysis level.

Figure 2.2. Population of interest (D1) and analysis levels (D1, E).

The total population of interest in this study is all industrialised timber frame housing SMEs and large enterprises (according to the European Communities definition for company size classification, Table 2.2) manufacturing products like garages, one/multi-family dwellings, schools, offices etc., in Sweden. Table 2.2 illustrates and quantifies the different company size categories for informational purposes. Manufacturers of log houses and log cabins are excluded from the population of interest. Micro enterprises are also excluded for two reasons; they are considered too small (often one, two, or three employees) to utilise a sufficiently high degree of industrialisation, and the population of interest increases significantly if micro enterprises are included. Hence, including micro enterprises in the population of interest would only increase the amount of work needed to administer the data collection without contributing any interesting and relevant knowledge. The total population of interest was included in the survey presented in paper III, where more details are found. Section 2.4 provides further details regarding the survey. In papers I, II, IV, and V, selected subgroups from the total population of interest are used for data collection. In the following, the term “industry” refers to the described total population of interest.
Table 2.2. Company size classification with respect to annual turnover.

<table>
<thead>
<tr>
<th>Category</th>
<th>Micro</th>
<th>Small</th>
<th>Medium-sized</th>
<th>Large</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turnover</td>
<td>€2 M</td>
<td>€10 M</td>
<td>€50 M</td>
<td>&gt; €50 M</td>
</tr>
</tbody>
</table>

2.2.1 Production systems and products

Industrialised timber frame housing production includes factory and on-site production. Factory production can comprise manufacturing of building elements, i.e. walls, floors, and inner roofs or volume elements. Volume element manufacturing is the manufacturing of building elements, Figure 2.3a, assembly of building elements to three-dimensional volume elements, Figure 2.3b, volume element completion (plumbing, electrical and ventilation work, surfaces finishing, fixed equipment, etc.), Figures 2.3c–e, and preparation for transport to construction site, Figure 2.3f.

![Figure 2.3. Industrialised timber frame housing production: a) building element manufacturing, b) volume element assembly, c-e) volume element completion, and f) completed volume element.](image)

When only building elements are manufactured in the factory, they are assembled at the construction site, Figure 2.4a. After the volume elements are completed in
the factory they are transported to the site, assembled, Figure 2.4b, and plumbing and electrical work etc. are connected.

![Figure 2.4. Assembly of: a) building elements and b) volume elements.](image1)

As described in section 1.1.1, one-family houses and multi-storey houses comprising such as dwellings, Figure 2.5a, are products manufactured by industrialised timber frame housing companies. Examples of other products are garages/storehouses, Figure 2.5b, and dwellings in two-storey houses, Figure 2.5c.

![Figure 2.5. Products manufactured by industrialised timber frame housing companies: a) four-storey house comprising dwellings, b) bicycle storage, and c) two-storey house comprising dwellings.](image2)

Additions to existing houses using, e.g. volume elements, is one method of increasing popularity and increase the number of dwellings in cities, Figure 2.8.
2.3 Case studies

Applying a case study research method is appropriate when the research problem requires an understanding of complex phenomena, e.g. influencing an entire organisation, and is not controllable by the researcher (Meredith, 1998). One important rationale for conducting a single case study is when the case is unique and provides findings otherwise hard to find. Multiple-case studies are often considered as providing compelling and robust evidence (Yin, 2003). Case studies can be used for theory building by using empirical findings, e.g. within a limited set of companies (Wacker, 1998). Both qualitative and quantitative data collection are appropriate methods for case study research (Beach et al., 2001; Yin 2003). Case studies are used here to understand multifaceted phenomena, briefly described below and in detail in each appended paper, to increase knowledge of industrialised timber frame housing, as articulated in the aim.

Different case study designs, utilising different data collection methods, have been applied. The research in Papers I, II, and V was conducted using single case study research at one company with unique characteristics. The company is a medium-sized industrialised timber frame housing company utilising advanced prefabrication manufacturing of complex products. The company is further described in each of the above mentioned papers. A one-year single case study was performed in Paper I. In Paper II four single case studies were successively performed over three years. In Paper V, a one-year single case study was conducted. Paper IV presents a multiple-case study performed at four companies where data collection was conducted during one day at each company. The case studies thus represent snapshots and longitudinal strategies, see also Table 2.1. A snapshot strategy focuses on the present situation, while the time frame of a longitudinal strategy is more extended. Hence, the longitudinal strategy allows reflection and analyses also during data collection, not only after the data has been collected.
In Paper I, the integration of customer-oriented design and production of multi-storey timber frame houses was studied. Data collection was conducted in two main parts. First, direct observations of a product development and design process applying methods for incorporating and integrating requirements from customers, i.e. tenants, into the design process. Second, direct observations of production of a three-storey house with customised flats (individually designed) and a multi-storey standard system house to investigate possible disturbances and cost effects from alternative design solutions.

In Paper II a change process illustrating the shift towards an ERP approach was described. Four, single case studies, the first study as in Paper I and included in Paper II to explain the whole change process, were successively performed. Data collection was performed in four main parts. First, this part coincides with data collection for Paper I, described above. Second, direct observations and analysis of a formulation of the internal change drivers performed by all of the case company’s employees. Interviews with managers from the whole business process and several floor workers, together with direct observations of the current production process, were also carried out for data collection. Third, interviews with production management and direct observations of production during a project with a high degree of customer choices. Fourth, interviews and participant observations were carried out during a development project regarding a possible ERP system implementation.

In Paper IV a multiple-case study is used to understand the current prospects and pitfalls within four industrialised timber frame housing companies (SMEs). Case companies were identified and selected among the surveyed companies in Paper III due to their advanced prefabrication of complex products. Data collection was conducted through interviews with production management and production staff and direct observations of the companies’ production systems and production processes (in the factories). Archival records are used for data collection regarding the companies’ financial performances, indicated through return on assets (ROA) and turnovers.

ERP system implementation was studied in Paper V. Data collection was conducted through interviews of implementers and top management and direct observations during the implementation.

2.4 Survey

Surveys have been commonly used to research small business and entrepreneurship, and one important methodological issue is response rate (Dennis, 2003). Enlarging the sample (not necessarily affecting the response rate) and attempting to minimise non-responses are two ways of avoiding generalisation from survey findings being questioned. According to Erdogan and Baker (2002) the latter so-
olution is preferred. The survey here is used to investigate the industry structure of the total population and if and how subgroups have different key-characteristics.

One survey has been conducted, presented in Paper III. The population of interest was the total population according to section 2.2. A questionnaire, Appendix A, consisting of fixed (concerning company characteristics) and open-ended (e.g. applied to ERP impacts) questions was mailed to production managers during September 2002. The cost-effectiveness, self-administration, and confidentiality for the respondent are advantages that outweighed any possible disadvantages, such as potentially low response rates and misunderstandings. The fixed questions apply to customisation, main product, production method, company size, and ERP approach. The open-ended questions apply to experiences and attitudes regarding ERP use. The questionnaire was designed to promote a high response rate since establishing the industry structure as correctly as possible was regarded as an important factor to increase reliability and the possibilities for generalisation. Biases due to non-responses might disrupt any possibilities to generalise the survey findings (Erdogan and Baker, 2002). Hence, the questionnaire was short, easy to complete, and preceded by a telephone call informing of the aim of the study. Pre-addressed, postage-paid response envelopes and a signed cover letter were included with the questionnaire. To the respondents that did not return the questionnaire, a follow-up telephone call was made and a second copy of the questionnaire was sent if necessary. Summary results were distributed to the participating companies. Besides the questionnaire the survey included the companies’ financial performance (indicated by ROA), where archival records were used for data collection. The questionnaire provided a snapshot of the examined variables as per September 2002. However, archival records along with the questionnaire design also gave insight regarding the companies’ past.

2.5 Access to empirical data and role of researcher

The case company in Paper I is the same as in Papers II and V. The company was also included in the survey in Paper III and the multiple-case study in Paper IV. This is because (1) the company participated in the R&D project mentioned in section 2.1 and Figure 2.1, (2) the company participated in and partly financed the research presented in Bergström (2001), and (3) the company has a history (change processes prior 1999), the characteristics (product mix, production method, and IS approach), and driving forces for development, making it interesting for empirical data collection. Hence, access to empirical data along with company characteristics and previous and on-going change processes have been a base for conducting unique single case studies. The role of the researcher when doing case studies is to understand the investigated phenomena within the researcher’s perceptual framework, not understanding the phenomena independent of the research context (Meredith, 1998). Hence, it is not possible to conduct and analyse case studies without considering and being aware of the biases due to the subjectivity of the researcher. For example, different researchers would most
probably focus on different areas or collect different empirical data if given the same basic conditions for conducting a case study. Furthermore, different researchers would also probably interpret the exact same case study data differently. This means that it is not the intention within the frame of this thesis to present an objective and “true” model of reality, made independently of the researcher’s pre-understanding and values, based on the case studied phenomena. Rather, the intention is to increase knowledge of the case studied phenomena through interaction with the research context.

The role of the researcher is somewhat different when conducting a survey compared to case study research. When the questionnaire is designed, sent out, and returned the empirical data is “fixed”. However, interpreting the collected data, as well as the questionnaire design, might differ between different researchers.
3 Theory

This section presents the overall theoretical framework of the thesis, representing theories selected to match the aim. The framework covers the following areas: manufacturing concepts and supply chain management, housing construction and its industrialisation, information management and information systems, and change. Finally, the implications of the theoretical framework for industrialised housing are presented.

3.1 Manufacturing and customisation

The eras of manufacturing have changed from craft and mass production to lean production, mass customisation, and agile production (Brown and Bessant, 2003). The manufacturing concepts superseding craft production have all aimed for improved performance regarding responsiveness to changing market conditions. These concepts have commonalities as well as differences and are appropriate for different business environments (Sahin, 2000). The primary goals of the lean production concept are increased product quality and reduced costs (Yusuf and Adeleye, 2002). To attain these goals, lean production stresses the critical importance of improving the two main conversion processes (design and production) and eliminating waste (Crowley, 1998). The customisation approach of lean production is to manufacture large varieties of high volume products rather than manufacturing individually designed products in any quantity as in the agile concept (Yusuf and Adeleye, 2002). The agile concept includes the core elements of lean production, but is extended to include the key features responsiveness to unplanned changes, flexibility, and availability (Aitken et al., 2002). Mass customisation can be regarded as the link between leanness and agility, i.e. underlining the importance of efficient processes and flexibility to respond to planned changes (Sahin, 2000). Common features among the concepts are, for example, continuous improvements, integration of design and production, and simple but flexible production equipment. The mass customisation and agile concepts use IT support to a higher degree than the lean concept, since it enables customisation as well as acts as a driver for organisational change towards agility (Sahin, 2000).

SCM and the supply chain can be viewed and defined in several ways. Generally SCM is associated with the management of the distribution of products from raw material through manufacturing processes to point of sale for the end product. The supply chain is by Lummus and Vokurka (1999) defined as “all the activities involved in delivering a product from raw material through to the customer including sourcing raw materials and parts, manufacturing and assembly, warehousing and inventory tracking, order entry and order management, distribution across all channels, delivery to the customer, and the information systems necessary to monitor all of these activities”. SCM “co-ordinates and integrates all of these activities into a seamless process” (Lummus and Vokurka, 1999). According to Krajewski and Ritzman (1999) SCM has a strategic significance since com-
petitive advantages can be achieved from the management of the supply system. Materials management, which includes purchasing materials and services, inventories, production levels, staffing patterns, schedules, and distribution, has an important role in the SCM and it affects the entire organisation (Krajewski and Ritzman, 1999). A supply chain can also be viewed as a network, supported by processes, organisational structures, and technologies, consisting of suppliers, manufacturers, distributors, retailers, and customers, supporting material, information, and financial flows (Akkermans et al., 2003). Supply chains have two main functions: the physical function of transformation, storage, and transportation, and the market mediation function of matching supply and demand (Akkermans et al., 2003). The perspective of materials management has since the mid-1980s been moved from a tactical low level task to a strategic management concept that supports customer focus and creates competitive advantage (London and Kenley, 2001). Ho et al. (2002) have identified several perspectives of viewing and defining SCM ranging from “a set of decisions or activities of purchasing and supplier management” to “a management philosophy involving management and integration of selected key business processes across the supply chain” (i.e. the process view). Challenges facing organisations are the importance of managing the internal supply chain (e.g. manufacturing, logistics, purchasing) as well as the entire supply chain (Pagell, 2004).

Hence, SCM is a broad concept covering multiple aspects of an organisation’s internal and external activities and processes. Here, the SCM concept refers to the internal supply chain of industrialised timber frame housing companies as well as their external supply chain (e.g. customer and supplier relations). The SCM concept is critical here in understanding industrialised timber frame housing, since aspects of SCM, such as materials and information management and IS use are vital for managing the internal and external supply chain (Pagell, 2004). Indeed, effective integration of the major supply chain components, i.e. customers, manufacturing, and suppliers, is the key to an organisation’s long-term success (Tan et el., 1999). Manufacturing concepts and SCM relating to customisation of industrialised timber frame housing are further developed mainly in Papers II, III, and IV.

3.2 Housing construction and its industrialisation

The brief description of the construction process in section 1.3.1 is here developed, as modified from Winch (2003), Figure 3.1:

- Concept: definition of functionality of the product related to market demands
- Design: engineering of the product
- Planning and controlling: manufacturing process needs to be planned and then controlled against the plan
Manufacturing: components and subassemblies are transformed from raw materials into their final form
Assembly: the components are assembled to create the finished product

![Diagram showing the sequence of steps in the construction process: Concept, Design, Planning, Manufacturing, Assembly.](image)

**Figure 3.1. Outline of typical construction process.**

Housing construction is a project-based form for designing and manufacturing unique products (houses). Although many projects involve similar process stages, each project is regarded as unique since it creates a prototype, as well as at a new site with its unique prerequisites (Wegelius-Lehtonen, 2001). Due to housing construction’s one-off nature, temporary production systems and supply chains are utilised, leading to low productivity development and inadequate approaches to control the construction supply chain (Vrijhoef and Koskela, 2000). Furthermore, transfer of concepts such as lean production from manufacturing to construction is difficult due to the different context of construction in comparison with manufacturing (Koskela and Vrijhoef, 2001).

To overcome some of the difficulties regarding traditional crafts-based on-site housing and improve the housing construction process, industrialisation of housing inspired by the possibilities of applying mass production to housing construction has emerged (Winch, 2003). This early industrialisation of housing was initiated during the first half of the 20th century and influenced the evolution of systems building (Gann, 1996). Standardisation of products (a prerequisite for prefabrication), prefabrication, and new methods to control quality and production were elements in the systems building approach (used mainly in the 1960s in countries like Sweden and Great Britain). This approach was production-focused, non-customer oriented, and did not result in increased overall productivity or reduced costs or construction times compared to traditional housing construction (Gann, 1996). Generally, the industrialisation of housing in the form of systems building is seen as a failure for a variety of reasons (Winch, 2003), including:

- Dysfunctional quarters of cities due to poor urban planning
- Quality problems due to poor design and lack of management control
- Poor maintenance of completed houses

Not all of these problems can be related to industrialisation itself, but direct and associated failures of industrialisation of housing and systems building led to a return to traditional housing during the 1970s (Winch, 2003).
Since then industrialised housing has evolved through customer orientation and construction process developments. Japanese industrialised housing companies have successfully adopted and adapted the lean production concept through balancing customisation and standardisation, while developing efficient production processes (Gann, 1996). Standardisation of processes and products can improve the construction process, while prefabrication is shown to improve safety, productivity, and quality; customisation is efficiently achieved by combining standardisation and prefabrication (Gibb, 2001). A re-engineered construction process through new technology (e.g. prefabrication) combined with changes in products and processes is needed to achieve efficient mass customisation in housing (Roy et al., 2003). Industrialised housing both resembles and differs from the manufacturing industry, meaning that there are limitations, though not to be over-emphasised, in the potential transfer of concepts from manufacturing to housing (Gann, 1996). Real lessons can be drawn from the manufacturing industry (Gibb, 2001), e.g.:

- It is possible to replace mass production with mass customisation through improved technology
- The need for customisation, including the offer of choice, must be recognised
- The supply chain must be acknowledged and managed
- Prefabrication is useful, if subservient to the delivery of the end product

3.3 Information management and information systems

Ideally, the information management of organisations is driven by the desire to improve decisions and eventually increase competitiveness. Managing information is a key activity for competitive organisations and it has been long known that to be successful, organisations have to balance information need with information processing capacity (Galbraith, 1972). Still, information management is complex and leads to irrationalities such as collecting too much information or using collected information improperly (Feldman and March, 1981). To change information processing capability an organisation can either reduce the need for information processing or increase information process capacity, as described in Figure 3.2. The amount of uncertainty in Figure 3.2 is represented by the difference between amount of information needed to be processed and the amount actually processed. The need for information processing, in an organisation, can be reduced by creating slack resources or self-contained units while implementing IS or creating new lateral relations are ways of increasing information processing capacity (Galbraith, 1972). This is supported in Flynn and Flynn (1999), where strategies for coping with complexity as proposed by Galbraith (1972) are identified among manufacturing companies.
The importance of IT and IS to support formal planning and controlling of business processes is increasing (Irani, 2002). For manufacturing companies, IS such as manufacturing resource planning (MRP II) and ERP systems are often the natural choice for improving process performance and organisational competitiveness (Irani, 2002). Material requirements planning (MRP), MRP II, and ERP represent different steps in the development of methods for resource planning and controlling, incorporating an increasing number of business processes (Olhager and Selldin, 2003). MRP, MRP II, and ERP also represent the evolution of software tools for manufacturing companies designed to support and optimise business processes (mainly financial, manufacturing, and distribution) (Krajewski and Ritzman, 1999). Many SMEs in the manufacturing industry lack a history regarding the implementation and use of MRP and MRP II systems (Petroni, 2002; Muscatello et al., 2003), exemplifying that SMEs generally have small financial and organisational resources for development (Ylinenpää, 1997). Materials and information management have important roles in the SCM and the development of resource planning methods has shifted focus from logistics and the internal supply chain to an SCM focus. One industrial trend concerning ERP and SCM is the integration between supply chain capabilities and ERP systems, where the drivers are cross enterprise integration and supply chain effectiveness (Tarn et al., 2002). Further descriptions of MRP, MRP II, and ERP along with identified benefits and disadvantages are found in Papers II, III, and V.

Construction companies are often slow to adopt IS and IT applications and unable to obtain potential benefits of investments in IT, furthermore much of the research regarding IT and construction have been conducted within the large construction companies (Stewart et al., 2002; Voordijk et al. 2003; Barthorpe et al., 2004). SME construction companies can achieve strategic benefits from IT support, though managerial and operational benefits are to date often realised more generally (Love et al., 2004). Applying a comprehensive IS approach, such as an ERP business integration approach, is presently more widely adopted in the manufacturing industry than the construction industry (Barthorpe et al., 2004). ERP has the potential to improve effectiveness regarding the supply chain and financial management of large enterprises within construction (Barthorpe et al., 2004). However, according to Shi and Halpin (2003), ERP systems can hardly...
meet the needs of the construction industry, since they are primarily developed for the manufacturing industry and do not address the nature and business culture of construction. By case studying a large construction company, Voordijk et al. (2003) suggest that ERP can play a strategic role within the construction industry if primary processes are inter-organisationally standardised, business and IT strategies are matched, and the ability to use ERP for information management is high. The construction industry and IS are further developed in Papers II, III, and V.

IS implementation is a critical stage and a major obstacle that can require considerable cost and time. Failed implementation might cause major problems such as order-processing difficulties, operating losses, or reduced operation earnings (Motwani et al., 2002), while a successful implementation can produce re-engineered and improved enterprises (Al-Mashari, 2002). Since IS implementation can be considered as a large-scale change, managing the implementation is a major and crucial task (Umble et al., 2003; Carrillo and Gaimon, 2002). Prior implementation re-engineering of key business processes impacting organisational structures, policies, and employees is required (Schniederjans and Kim, 2003). Hence, to accomplish successful IS use, an IS implementation should utilise a proper change management and be initiated and driven by business needs (Umble et al., 2003). IS and IS implementation, as related to industrialised timber frame housing, are further developed in Papers II, III, IV, and V.

### 3.4 Change

An organisational change is initiated by identifying a need of change (i.e. awareness) as related to external or internal driving factors (Mukherji and Mukherji, 1998). There are, of course, also hindering factors that resist change and can be identified during the matching between needs and objectives of the change, but which are possible to use as a supportive force, e.g. for successful adoption of change (Mabin et al., 2001). No general implementation model for a change exists – what is successful for some companies may not work for others; however, both factors of success (Linton, 2002) and hindrance (Mabin et al., 2001) have been identified. After awareness, matching, adoption, and implementation routinisation (i.e. incorporating the change as part of the organisation’s routines (Linton, 2002)) follow, Figure 3.3.

![Figure 3.3. Change phases, adopted from Linton (2002).](image)

The concept of change comprises three inter-connected categories: content, context (external and internal), and process, according to a framework developed
by Pettigrew (1987), and illustrated and described in Figure 3.4. The “what”, “why”, and “how” of change can be represented by content, context, and process. By formulating the content of, for example, a new strategy, managing its external and internal context and process is needed to complete the desired change, since the three terms are related (Pettigrew, 1987). Applying Pettigrew’s framework (1987) implies that the content of one change can be the context or process during another change. For example, manpower can be the area of transformation during one change, the inner context as part of corporate culture or political context during the next change, and the process as an acting and interacting part among other interested parties during yet another change. Managing organisational strategic change is complex, covering objective/analytical and subjective/political aspects inside and outside the organisation (Whipp et al., 1989).

![Figure 3.4. Three integrated components of change, modified after Pettigrew (1987).](image)

For a manufacturing company, changes regarding manufacturing equipment, information technology, and procedures (or combinations) are three main categories for improved performance (Carrillo and Gaimon, 2002). Re-engineering is a method incorporating procedural changes and improved information management, e.g. through information systems, to improve performance through integration, elimination of non-value added activities, and improved managerial decision-making (Carrillo and Gaimon, 2002). A change is complex, conducted in several phases, and consists of several components, i.e. different changes have different characteristics where phases and components have different levels of importance during different changes. A profit driven company acting in a competitive environment must be able to create a competitive advantage and make a profit to survive. Knowing how to manage change and change implementation is thus needed for sustainable competitiveness. Here, the term change is associated to changes of a strategic (or major) nature; however, its operational consequences are also of interest. Change and industrialised timber frame housing are further developed in Papers I, II, and V.

### 3.5 Implications

Sections 3.1-3.4 present the theoretical framework for the thesis. The framework in section 3 is somewhat similar to the theoretical frameworks provided in appended papers and partly incorporates additional theory. The framework in sec-
Section 3 is intended to increase the understanding of industrial timber frame housing and thus contribute in reaching the aim. The framework in section 3 focuses on customisation, industrialised housing, information management, and change. Industrialised timber frame housing is, of course, the main focus of the thesis, while customisation, information management, and change are ingredients of industrialised timber frame housing that are especially examined, as described in section 1.3.

From a theoretical perspective, customisation (Brown and Bessant, 2003), information management (Pagell, 2004), and change (Whipp et al., 1989) are all vital concepts for manufacturing organisations active in competitive environments. Further, concepts are connected to competitive performance. As indicated below, customisation, information management, and change are also possible to identify and recognise as significant for industrialised timber frame housing.

Changes in relations with customers and suppliers, closer integration between market, design, and production, and improved information processing are identified by Barlow (1999) as ways of reaching a level of flexibility in production processes that allow for mass customisation in housing. The agility concept is potentially more suitable for housing than the lean concept due to the housing industry’s need and experience of manufacturing unique objects (Barlow 1999). However, applying and combining lean and agile principles have the potential to improve the construction supply chain for customised housing (Naim and Barlow, 2003). A shift towards mass customisation and agility for the housing industry will, as in the manufacturing industry, require major changes, including an increased capability for information management. An increased focus towards an SCM perspective will demand a changed project focus, where the starting point focuses on efficient internal processes. Managing change in complex production systems, such as construction, requires harmonisation between changes at different levels (design, operation, and improvement); changes only at the level of the design generally yield only modest benefits (Koskela, 2003).

The development in the manufacturing industry, can be illustrated by shifts like: crafts production to agility (Brown and Bessant, 2003), MRP to ERP (Krajewski and Ritzman, 1999), and from merging distribution and production into SCM (London and Kenley, 2001), as shown in Figure 3.5. These changes can be seen as illustrative and interesting models each providing real lessons to learn from rather than be literally copied and adopted for housing.
In the systems building approach, adopting the mass production concept as that being used within the manufacturing industry was an important driving force. Hence, one important lesson from the systems building approach is to consider the nature and culture of housing construction when learning from the manufacturing industry. This lesson can hopefully be useful for today’s industrialised timber frame housing when changes towards increased customer orientation and increased complexity regarding, e.g. products, product mixes, and information flows, are ways towards mass customisation and agility.

The concept of industrialised timber frame housing, as related to customisation, change, and information management and IS, is further analysed in appended papers and sections 4 and 5. Supported by this theoretical framework and mainly highlighted in section 5, some theoretical aspects of these relations demonstrate what has been learnt regarding industrialised timber frame housing from a theoretical perspective.
4 Results and discussion

This section summarises the results from Papers I–V, as seen in the research and theoretical contexts described in sections 2 and 3. Based on the results, the findings from each paper, cross paper findings, their implications, and the research process are discussed.

4.1 Results and discussion, Paper I

Paper I describes the integration of a customer-oriented design and production and its benefits in a medium-sized industrialised timber frame housing company. The findings show that much can be gained by combining QFD and a CE approach, i.e. from a holistic viewpoint, combining all actors, disciplines, and competencies into a team responsible for developing customised design solutions adapted to the production system. The design conflicts (mainly between the structural system, technical installation requirements, and production facilities) were identified by the design team before production. Changes in design solutions have been iterated within the design team and adjusted to the production system before being accepted and finalised, meaning that effects like disturbances and cost should be relatively small. This was confirmed by the case study regarding both building and volume element production, e.g. due to pre-consideration and co-ordination demands from actors like subcontractors and design consultants. Also apparent was the knowledge feedback gained by incorporating demands and restrictions from customers and other actors throughout the entire construction process. Hence, the integrated design and production approach proved to be successful. This reflected the strength of using a CE concept in the involved companies. With a rapidly growing market, an industrialised timber frame housing company faces possible bottlenecks concerning the plant layout, industrial production conception, management control, etc. Indications from the study also suggest that logistics, material flow, co-operation with sub-contractors, and planning and production preparation may significantly influence level of disturbances in the production system.

In Paper I the need for an increased customer orientation acts as a driver for changes and developments of products and product development process for the SME. Incorporating customer demands, through QFD, and applying a CE approach initiated the change process towards an increased industrialisation of the housing concept. The industrialised timber frame housing company could, as the findings show, benefit from an increased industrialisation by integrating customer demands, design, and production from the conceptual phase throughout the entire construction process, Figure 4.1. Hence, matching customer requirements with an industrialised building system (i.e. design and production) was possible through product and process development. Finally, and interestingly, it was suggested that adopting a philosophy incorporating materials and production resources was one passable way towards further changes of the industrialised timber frame housing.
concept, thereby facilitating customer-oriented design and production through, e.g. an improved information management.

![Diagram of product and process development process.](image)

**Figure 4.1. Product and process development process.**

### 4.2 Results and discussion, Paper II

Paper II describes the comprehensive change process of a medium-sized industrialised timber frame housing company and illustrates the shift towards an ERP approach. The findings demonstrate that ERP and the needs of an industrialised timber frame housing company can match as facilitated by some identified prerequisites.

- First, there must be external and internal driving forces for the necessary change process to start. For example, it was found that a high degree of customer choices significantly reduced the pace of the volume completion process. Hence, customisation is not only the panacea; customisation (external driving force) must be balanced with an efficient production system (internal driving force).

- Second, the change process must aim for a production system and business processes that are bi-functional: meeting external and internal needs and facilitating ERP system implementation.

- Third, there must be an awareness that the ERP system can contribute in meeting external and internal needs; simply implementing a software system will most likely not increase efficiency.

- Fourth, the day-to-day work must not be hindered during an ERP implementation and ERP use. For an SME this can be facilitated through careful pre-implementation allowing a stepwise and flexible implementation, i.e. ERP implementation is secondary to day-to-day work as well as the initial change process implementation.

In Paper II, the described change process for the SME is conducted because of a recognised need to improve customisation management, leading to an identified need for improved information management. It was demonstrated that an improved information management capability was needed to support an increased customer
orientation. However, blind customer focus was shown to lead to a poor utilisation of resources. Instead, customer focus must be balanced with efficient business processes. A high degree of customer choices increases production complexity due to increased information flow and differentiated material flow. Hence, both external (customisation) and internal factors (need of efficient internal processes) acted as change drivers towards an ERP approach, including increased information processing capacity. Implementing ERP was performed in several steps. Changes in production system and existing business processes aimed to improve the industrialised timber frame housing concept as well as facilitate a forthcoming ERP system implementation. This is concurrent with literature pointing out that one way towards increased information processing capacity is IS implementation (Galbraith, 1972). Hence, after re-engineering of business processes, implementing a suitable IS could potentially provide additional information management capabilities.

4.3 Results and discussion, Paper III

Paper III surveys the vast majority of industrialised timber frame housing companies in Sweden, investigating MRP and ERP use along with some company characteristics, and financial performance as indicated by ROA, Figure 4.2.

Figure 4.2. Characteristics and financial performance investigated in survey.

The findings demonstrate that some industrialised timber frame housing companies in Sweden do use MRP and ERP systems, though the majority do not. The survey also demonstrates ERP as having a low degree of strategic importance, while operational and managerial benefits can be found. The differences between companies regarding customisation approaches, main products, and production methods indicate that until now a high degree of complexity in the production process does not favour IT support. Instead, it is companies with less complex business processes that tend to implement ERP systems. Hence, companies utilising different degrees of process complexity adapt their information processing capabilities differently: by reducing the information needed or increasing the information process capacity as proposed by Galbraith (1972). This study confirms the existence of prerequisites for a successful match between ERP and industrialised timber frame housing needs, though difficulties in matching ERP and construction industry needs also exist, as identified in Shi and Halpin (2003). The
survey results show a general lack of real drivers for ERP implementation and low awareness of the potential benefits and strategic importance, indicating that ERP is not yet regarded as a way of supporting and improving core business strategies. Since strategic ERP use requires high maturity in IT (Voordijk et al., 2003), the results indicate that IT maturity must increase to utilise the full potential of ERP, while possible ERP system implementations must allow a gradual increase of IT maturity.

In Paper III, the survey investigating the benefits and disadvantages from IS approaches regarding production related business processes demonstrates no clear tendency for benefits or disadvantages to emanate from IS use. Customisation is mentioned as an obstacle to IS implementation, but is not mentioned as a disadvantage among companies utilising IS. Companies without a system point out that their business processes are properly managed without a system and that manual business processes are preferred. However, substantial operational and managerial benefits among IS users are demonstrated. IS for production processes are not generally seen as a means for supporting business strategies, such as customisation approaches. ERP is a driver of comprehensive change and business process improvements (Akkermans et al., 2003). However, this was not confirmed among the surveyed companies. Some salient features regarding industrialised timber frame housing and the industry structure are indicated in Paper III. A snapshot of the industry provided by the survey shows that manufacturing complex products with the use of advanced prefabrication is accompanied by a larger company size. This might indicate utilising advantages arising from prefabrication (e.g. improved productivity, and quality) (Gibb, 2001), when manufacturing products with high degree of complexity (represented by customisation degree and product type) and applying a high degree of prefabrication (volume elements) being facilitated by, and maybe requiring, a certain company size.

4.4 Results and discussion, Paper IV

Paper IV examines the prospects and pitfalls from four SME industrialised timber frame housing companies that manufacture complex products utilising advanced prefabrication, thus representing industry front-runners. Generally, today’s industrialised housing has shifted from the mass production like approach of systems building towards a more customer-oriented approach. This study confirms this trend since the case companies all have increased their focus on customisation during the last years. Customisation is clearly one of the most critical issues for the case companies, demonstrating the need for efficiency as well as flexibility. Customisation is facilitated by a building system that is adapted to industrialised production, demonstrating the importance of integrating design and production. Integration strengthened by e.g. design of technical installations in-house and improved internal and external communication, leading to e.g. better design process and building elements. To facilitate volume element throughput, the entire building system must be designed and adapted according to the industrialised
production. Hence, a further development towards assembly-ready components already adapted to the industrialised production is needed. On-going IS implementations and organisational changes demonstrate the need and awareness of improved and re-engineered business processes. The SME case companies have limited financial and organisational resources regarding developments and major changes. Hence, although the need of major change is recognised, e.g. improved production capacity, changes often have to be conducted incrementally through continuous improvements. In order to increase capacity major investments are needed and this will increase costs for a long time, regardless if capacity can be utilised or not. For an SME a decision to increase capacity may be the most important, and difficult, decision they make.

In Paper IV, customisation and information management are recognised as obstacles, though with the potential to improve SME companies. The ability to balance a high degree of customisation and a short construction time means market competitiveness. However, a short production series of customised products with large variations demonstrates as being difficult to efficiently manage, making the customisation approach advantageous to a potential market but disadvantageous to production. It was shown that the need of change is often recognised, but not always met due to limited financial resources and time. However, major and minor changes are performed with change drivers like customer orientation and need for improved information management. The importance of integrating design and production to facilitate volume element throughput is also demonstrated. This is exemplified by the trend of designing technical installations in-house, the insufficient communication between design and production, and the on-going developments of building elements. Insufficient communication and difficulties in handling customisation are mentioned as major construction process limitations. On-going and completed implementations of IS among the case studied companies demonstrate how they match information need and information management capacity.

An industrialised housing concept does have the potential to be successful as shown in Japan (Gann, 1996) and Sweden, demonstrating the potential of process orientation and construction process efficiency. This indicates the existence of a learning potential for manufacturers of more complex multi-family houses, especially regarding short production series, in relation to one-family house manufacturers with a long experience of manufacturing customised houses to private persons while maintaining high efficiency.

4.5 Results and discussion, Paper V

Paper V describes an IS implementation of a medium-sized industrialised timber frame housing company. The currently ceased IS implementation demonstrates the difficulties in operationalising an ERP approach through ERP system use for an SME housing company. An ERP implementation is a major and crucial
change for most companies, not the least of which for an SME in the construction industry (Muscatello et al., 2003; Barthorpe et al., 2004). Regardless of any similarities with the manufacturing industry, the characteristics and culture of the traditional construction industry are predominant in the case company. One illustrating and important factor is the lack of history regarding the implementation and use of MRP and MRP II systems. System replacement is one major reason for ERP implementation in the manufacturing industry (Olhager and Selldin, 2003). Thus, the manufacturing industry has gradually increased its knowledge, experience, and awareness of the advantages of using these approaches and systems over an extended period of time. Many SMEs in the manufacturing industry lack any history regarding the implementation and use of MRP and MRP II systems (Petroni, 2002; Muscatello et al., 2003). From the reversed point of view, this implies that most ERP suppliers are unfamiliar with these customer categories and their specific cultures and needs. The case study findings also show the importance of conducting the overall ERP implementation sequence in the “right” order. Selecting the ERP system is preferably conducted after re-engineering (Muscatello et al., 2003). The case company’s pre-implementation included a comprehensive evaluation of strategic and operational needs, ERP system evaluation, and system selection. Hence, the system selection was based on the production system prior to re-engineering and therefore excluded the prerequisites and needs of the new production system.

Implementing an IS is one way of increasing information processing capacity (Galbraith, 1972). IS implementation was difficult to manage here and eventually ceased. The break even point between existing information processing capacity and information processing capacity after IS implementation was never reached or experienced as possible to reach. For a housing construction SME, managing a change such as an IS implementation is clearly a great challenge for the numerous reasons mentioned above. Implementation has to also be subordinated the daily operations, and when finding a suitable go-live project factors like degree of customisation, project length, and internal knowledge level of and confidence in the system have to be balanced.

4.6 Concluding discussion

In this thesis industrialised timber frame housing is examined, described, and analysed. Each paper is summarised and discussed in sections 4.1–4.5. For each paper, one main focus along with one to three sub-focuses can be identified, presented in Table 4.1. Each main focus and sub-focus equates to one of the ingredients, section 1.3, selected to describe industrialised timber frame housing. Hence, in retrospect, Table 4.1 can be considered as a summary of the research process. Instead of the main focus alone, each main focus together with the sub-focuses contribute to an increased understanding of industrialised timber frame housing. All papers demonstrate salient features regarding industrialised timber frame housing and are presented with different main focuses and different sub-
focuses, as summarised in Table 4.1. These features are discussed below to identify commonalities and differences among the findings and describe important ingredients (and their relations) of industrialised timber frame housing.

Table 4.1. Main focus and sub-focuses for each appended paper.

<table>
<thead>
<tr>
<th>Paper</th>
<th>Main focus</th>
<th>Sub-focus 1</th>
<th>Sub-focus 2</th>
<th>Sub-focus 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Customisation</td>
<td>Change</td>
<td>SME</td>
<td></td>
</tr>
<tr>
<td>II</td>
<td>Change</td>
<td>Customisation</td>
<td>Information management</td>
<td>SME</td>
</tr>
<tr>
<td>III</td>
<td>IS</td>
<td>Industry structure</td>
<td>Customisation</td>
<td></td>
</tr>
<tr>
<td>IV</td>
<td>Customisation</td>
<td>Information management</td>
<td>Change</td>
<td>SME</td>
</tr>
<tr>
<td>V</td>
<td>IS</td>
<td>SME</td>
<td>Change</td>
<td></td>
</tr>
</tbody>
</table>

Customisation is one ingredient of industrialised timber frame housing investigated in several of the appended papers, representing the main focus or sub-focus. Finding a reasonable level of customisation that can be matched with a sufficiently efficient production system is clearly one major subject with implications from the strategic to the operational level. This indicates the importance of balancing project and process orientation, efficient internal communication and information management, and knowledge of the industrialised building system among all actors in the construction process. Customisation is one ingredient that impacts other ingredients, as shown in sections 4.1, 4.2, and 4.4. One important finding regarding customisation and industrialised timber frame housing is thus the importance of managing change towards an increased customer orientation, while allowing the production system to match the increased customisation.

As demonstrated by sections 4.1, 4.2, and 4.4, awareness and implementation of change have the potential to develop the entire industrialised construction process from the conceptual phase to production. Change can thus be regarded as another important ingredient for an increased and improved industrialisation of housing. Changes regarding products and processes are needed to develop industrialised timber frame housing beyond “only” prefabrication and standardisation. Shifting from stick building on the construction site to stick building in a factory can provide certain benefits. Prefabrication is shown to improve safety, productivity, and quality (Gibb, 2001). However, industrialised timber frame housing is not only prefabrication, as tentatively indicated by Figure 1.2. Standardisation of products, prefabrication, and methods to control quality and production were ingredients in the systems building approach (Gann, 1996). But the mass production like systems building approach could not address specific customer needs, demonstrating that these ingredients are insufficient for an industrialised timber frame housing concept aiming towards mass customisation. As in the manufacturing industry, the development towards mass customisation (and agility) is also necessary in housing (Barlow, 1999). The entire building system must be designed and adapted according to the industrialised production, while utilising de-
sign and production processes aiming for a production system without disturbances. This demonstrates the importance of components, subassemblies, and processes adapted to industrialised production and their continuous development. Changes through customer orientation and concepts such as CE are ways to achieve this development.

Sections 4.1, 4.2, and 4.4 illustrate the importance of adapting information management according to changing needs due to customisation. An increased customer orientation changes the prerequisites regarding information management. Although sufficient and efficient information management is needed, how to adapt information management capacity differ. Adopting IS is one way to increase information processing capacity, demonstrating benefits as well as disadvantages. Generally, complex IS tend to be adopted by companies utilising less complex business processes, while companies utilising complex business processes tend to retain non-IT supported business processes. The history and tradition of housing construction is one complicating factor regarding implementation and use of IS in parts of the construction process other than the design phase.

The industry is dominated by SMEs (96%), as described in Paper III. The individual company has been the analysis level in the case studies and the examined companies have been selected in each case study. The case companies have not been selected because they are SMEs; rather, they have been selected due to their other company characteristics and the possibility of conducting case studies of on-going phenomena in a real life context not clearly differentiated from the phenomena, as formulated by Yin (2003). Hence, the SME sub-focus has emerged as a consequence of the industry structure contrary to customisation, change, and information management, i.e. selected ingredients to describe industrialised timber frame housing. The SME sub-focus is important because the term SME carries vital information regarding the companies and the conditions and circumstances under which the companies act. For example, SMEs have generally small financial and organisational resources for development (Ylinenpää, 1997). Although the need for major change is recognised, e.g. improved production capacity, changes are often conducted incrementally through continuous improvements, for the SMEs. Hence, when examining areas like change processes, information management, and IS adoption the SME aspect must be somewhat recognized, though the research is not conducted as SME research and research findings are not analysed from an SME perspective.

The ability to manage an increased customer orientation, impacting both design and production, has acted as an external driving force for change. Awareness and implementation of changes in products and processes have identified the need for an increased information management capacity and an increased integration of design and production. Identified different IS approaches are related to the companies’ characteristics regarding, e.g. customisation and company size. The overall
results show that customisation, change, and information management are important ingredients in industrialised timber frame housing, Figure 4.3. Customisation can act as a driver for change and improved information management. Changes in business processes are needed to facilitate customisation and information management. Information management has a key role in the entire construction process to facilitate customisation while the need for efficient information management can act as a driver for change.

4.7 A methodological discussion

Three single case studies, one multiple-case study, and one survey have been conducted. As described in section 2.1 the case studies and the survey are related to each other in the search for new knowledge. The reason for highlighting customisation, change, and information management in industrialised timber frame housing is because of an increasing awareness during the research process due to the continuous interaction between the research findings and pre-understanding of the researcher, that these ingredients are important for describing and understanding industrialised timber frame housing. Of course, other research designs and research focuses could have been applied. For example, the findings in Paper I might have prompted research aiming for improved design solutions, improved production facilities, or improved external relations with suppliers. Possible alternative research designs could, for example, include longitudinal case studies of a number of case companies investigating how their characteristics affect financial performance, or through surveys and questionnaires, thereby obtaining a series of snapshots illustrating the changes and developments of industry structure, company characteristics, and success factors. Instead, how industrialised timber frame housing companies manage customisation, change, and information was investigated through case studies and the survey.

The role of the researcher has been somewhat different during different research methods. Varying distances to the current unit of analysis has led to varying degrees of subjectivity and objectivity. Of course, the survey represented the high-
est degree of objectivity and the lowest degree of subjectivity. It can thus be stated that the overall description of industrialised timber frame housing provided in this thesis is not an objective model to be examined independently from the various contexts where empirical data have been collected. It is the research findings along with the descriptions of the examined phenomena and their contexts that have contributed towards reaching the aim of an increased understanding of industrialised timber frame housing.
5 Conclusions

This section summarises the overall conclusions of the thesis based on Part I and II and discusses if the aim has been reached. Practical implications are discussed and suggestions for further research are presented.

5.1 Scientific contribution

Has the aim been achieved and have the research questions been answered?

The research questions are answered in the appended papers and section 4 and are thus not treated specifically in this section.

The overall scientific aim was to develop an increased understanding of industrialised timber frame housing and how industrialised timber frame housing companies are aiming for construction process and supply chain improvements. To achieve this aim, the research approach aimed to cover several aspects of industrialised timber frame housing rather than focus on one separate and isolated aspect. In the thesis, some ingredients (mainly customisation, change, and information management) of industrialised timber frame housing have thus been highlighted and illustrated. These ingredients are not sufficient to completely describe industrialised timber frame housing, as indicated by the tentative multiple ingredients proposed in Figure 1.2. However, customer orientation, change (from awareness to implementation and in different categories), and efficient information management have been illustrated as a means for industrialised housing companies aiming to improve the construction process. The ingredients are important when analysed individually, but their integrated connections and interactions can also contribute to an increased knowledge.

Internal (improved information processing and closer integration between market, design, and production) and external (relations with customers and suppliers) changes are identified by Barlow (1999) as ways to achieve mass customisation in housing. Mass customisation and agility are potentially more suitable for housing than the lean concept due to the housing industry’s need and experience of manufacturing unique objects (Barlow, 1999). The lean and agile concepts are appropriate for different business environments implying that a lean concept is more useful for manufacture of standardised products. However, applying and combining lean and agile principles have the potential to improve the construction supply chain for customised housing (Naim and Barlow, 2003). Customer orientation is here demonstrated to be considered both as opportunities, Paper I and IV, and obstacles, Paper II and IV, for industrialised timber frame housing. The research findings demonstrate that industrialised timber frame housing companies have different approaches for managing the increased customer orientation, e.g.:
• Re-engineering of business processes, Paper I, II, and IV
• Aim for increased integration of design – production and improved communication in the construction process, Paper I and IV
• Implement IS with different degrees of complexity, Paper II, IV, and V
• Holding the standpoint that IS such as MRP or ERP not will facilitate customisation, Paper III and IV

Considering the potential of mass customisation and agility in housing the differences in IS approaches are interesting. In the manufacturing industry, mass customisation and agile concepts use IT support to a higher degree than the lean concept, since it enables customisation as well as acts as a driver for organisational change towards agility (Sahin, 2000).

Organisations can manage task uncertainty by means of rules, goals, and hierarchies. As related to internal and external changes, rules, goals, and hierarchies are eventually inadequate, since new situations demand new strategies for information processing (Macintosh, 1994). To change information processing capability an organisation can either reduce the need for information processing or increase information process capacity, as described in Figure 3.2. Implementing IS is one way of increasing information processing capacity (Galbraith, 1972).

In Paper III different IS approaches (MRP and ERP) were investigated. By relating IS approach to level of complexity in the factory some interesting trends can be identified, Figures 5.1a–d. The labels “Low”, “High”, “Simple”, and “Adv.” in Figures 5.1a–d are related to the levels of complexity in Table 1 in Paper III (“A1–E4”) according to Table 5.1. Label “Low”, Table 5.1, represents a low level of complexity regarding the dimensions customisation approach, main product, production method, and company size, while label “High”, Table 5.1, represents a high level of complexity. Complexity is here referring to the factory production where, for example, garages (B1) represent a low level of complexity in the dimension main product, while multi-storey houses (B4) represent a high level of complexity. Label “Simple”, Table 5.1, represents an IS approach without MRP or ERP usage, while label “Adv.”, Table 5.1, represents an IS approach of MRP or ERP usage.

<table>
<thead>
<tr>
<th>Table 5.1. Labels in Figures 5.1a–d and their relations to labels “A1–E4” in Table 1, Paper III.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
</tr>
<tr>
<td>High</td>
</tr>
<tr>
<td>Simple</td>
</tr>
<tr>
<td>Adv.</td>
</tr>
</tbody>
</table>

42
In the boxes in Figures 5.1a–d, percentage distributions of the IS approaches “Simple” and “Adv.” as related to the levels of complexity “Low” and “High” (regarding customisation, main product etc.) are shown. For example, the upper box to the left in Figure 5.1a illustrates that 36% of companies applying customisation approach “Low” (manufacturers of customised standard products) apply IS approach “Adv.” (MRP or ERP usage). The percentage distributions originate from Table 2 in Paper III, although they are adapted according to the labels used in this section.

<table>
<thead>
<tr>
<th>IS approach</th>
<th>Adv.</th>
<th>36%</th>
<th>25%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simple</td>
<td>64%</td>
<td>75%</td>
<td></td>
</tr>
<tr>
<td>Customisation approach</td>
<td>Low</td>
<td>High</td>
<td></td>
</tr>
<tr>
<td>a)</td>
<td>b)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IS approach</td>
<td>Adv.</td>
<td>30%</td>
<td>37%</td>
</tr>
<tr>
<td>Simple</td>
<td>Low</td>
<td>70%</td>
<td>High</td>
</tr>
<tr>
<td>Main product</td>
<td>63%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>c)</td>
<td>d)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IS approach</td>
<td>Adv.</td>
<td>34%</td>
<td>25%</td>
</tr>
<tr>
<td>Simple</td>
<td>Low</td>
<td>66%</td>
<td>High</td>
</tr>
<tr>
<td>Production method</td>
<td>75%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>c)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IS approach</td>
<td>Adv.</td>
<td>36%</td>
<td>25%</td>
</tr>
<tr>
<td>Simple</td>
<td>Low</td>
<td>64%</td>
<td>High</td>
</tr>
<tr>
<td>Company size</td>
<td>75%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>d)</td>
<td></td>
<td></td>
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</tbody>
</table>

Figure 5.1. IS approaches related to: a) Customisation approach, b) Main product, c) Production method, and d) Company size.

Generally, usage of IS such as MRP and ERP is low in the industry. Companies scoring low (with the dimension main product as the exception) on the dimensions, customisation, production method, and size, tend to implement IS more than companies scoring high. From the reversed point of view, companies scoring high, reflecting a complex factory production, demonstrate a tendency of less IS implementations. This might indicate that IS adoption is relatively easy for low scoring companies and that they have realised IS as a means for improved information management, decisions, and competitiveness. This part of the strategies proposed by Galbraith (1972) can thus be used as an indicator of the companies’ willingness and ability of change. However, the strategy requires two step, each with several potential obstacles: first, implementation of IS, second, the capability of proper system use. Companies scoring high might choose to cope with uncertainty utilising other strategies. For example, aim for reduced need for information processing or, create new lateral relations to increase information processing capacity. However, these strategies for changing information processing capability have not been investigated within this research. Figures 5.1a–d represent snapshots of actual relations regarding the population of interest (i.e. entire
industry), as per September 2002, however the percentage distributions have not been statistically analysed.

The findings that companies scoring both low and high generally not tend to implement IS such as MRP or ERP, Figures 5.1a–d, can be seen as supportive to previous research regarding ERP and construction. According to Shi and Halpin (2003), ERP systems can hardly meet the needs of the construction industry since they are primarily developed for the manufacturing industry and do not address the nature and business culture of construction (mainly related to the project focus). Alternative viewpoints suggest that ERP can improve effectiveness of large enterprises within construction (Voordijk et al., 2003; Barthorpe et al., 2004). This relation between complexity (reflected by the large company size) and ERP does not correspond with the relations in Figure 5.1a–d where the larger complexity not seems to favour IS usage.

IS implementations can be highly complex and difficult, comprising several phases such as re-engineering of key business processes impacting organisational structures, policies, and employees (Schniederjans and Kim, 2003). The day-to-day work is highly prioritised among the case studied and surveyed companies, leaving small room for complex development projects, which also require financial resources. Identifying the need of change (awareness) for increased information processing capacity, matching need and objectives, adoption of change, along with implementation and routinisation of parts of the change might be realised and conducted, Paper II. Still, finalising a complex IS implementation is difficult leading to difficulties to completely accomplish the total change process for an SME housing company with highly complex factory production, as described in Paper V. Hence, the hardest part for fulfilling the overall change for improved information management might be IS implementation, Paper V, demonstrating the complexity of both IS implementation and change.

As described in section 4.6, customisation, change, and information management are affected by and affect each other. This relation can explain the overall change process needed for developments and improvements of industrialised timber frame housing beyond prefabrication and standardisation. Based on the research findings, Figure 5.2 can be used as an illustration of the dynamics between the ingredients in an overall industrialised timber frame housing context. In Figure 5.2 different examples of the “what” (content), the “why” (context), and the “how” (process) of change as applied to industrialised timber frame housing are shown based on the framework provided by Pettigrew (1987).
Figure 5.2. Examples of dynamic relations between customisation, change, and information management, framework adopted from Pettigrew (1987).

Systems building is one kind of industrialised housing where ingredients like prefabrication, standardisation, and methods for production and quality control were central (Gann, 1996). However, this mass production like approach failed for the various reasons described in sections 3.2, 3.5, and 4.6. The new industrialised housing approach must include more, as indicated by the failure of systems building, the tentative suggestion in Figure 1.2, and the research findings presented in this thesis. This is also supported by the recognised need for increased customer orientation and improved processes (design, production, and information), to be accomplished through change and innovation and thereby achieve mass customisation in housing (Barlow, 1999; Roy, 2003).

It is demonstrated here that a developed industrialisation has been possible to achieve by integrating customer demands, design, and production from the conceptual phase throughout the entire construction process. Customer orientation is an important aspect in the new industrialised housing; however, blind customer focus was shown to lead to poor utilisation of resources, Paper II and IV. Instead, customer focus must be balanced with efficient business processes. One passable way is finding the balance between standardisation and customisation through balancing process and project orientation. It is also demonstrated that the entire building system must be designed and adapted according to the industrialised production system. Hence, components, subassemblies, and design and production processes adapted to the industrialised production are required. To develop the industrialised housing construction process (originating from traditional on-site housing construction), changes through customer orientation and concepts for improved communication and information processing are here demonstrated as contributing ingredients.

The increasing complexity in a factory arising from increased degree of prefabrication might sound like a paradox. Why increase complexity through increased prefabrication, should not prefabrication increase efficiency, as proposed by Gibb (2001)? However, all of the dimensions customisation approach, main product, production method, and company size have different levels of complexity where the reason for increased complexity is the possibilities for increased overall effi-
ciency (“do things right”) or effectiveness (“do the right things”), eventually leading to increased competitiveness and profitability. For example, a more complex internal supply chain can lead to a more efficient entire supply chain, or more complex products might develop new, more profitable, markets. Hence, in a competitive environment, a volume element manufacturer’s relatively high complexity in the factory and low complexity at the construction site is competing with e.g. a traditional housing company having no complexity in the factory but a relatively high complexity at the construction site.

Some insights regarding industrialised timber frame housing have been gained, though more insights can be attained since the industrialised timber frame housing concept is not entirely described. Describing and analysing more ingredients in Figure 1.2, and other ingredients, are interesting research areas. The investigated ingredients and their relations have also the potential for further research ranging from theory building to more practical-oriented research and development, section 5.3.

5.2 Practical implications

The practical implications can be summarised in one sentence. Customise, develop products, product mixes, and production methods, and adopt IS, but do it moderately. Different companies with different backgrounds imply that different approaches must be utilised to adopt or increase industrialisation in housing. There is a trade-off between potential improvements possibly emerging from attractive change possibilities versus conflicts between new and old working methods. For example, real internal change drivers, including awareness, attitudes, and insights of real possibilities of increased competitiveness and profitability arising from industrialisation, will be needed for a traditional housing company (or a traditional material supplier) to increase the degree of industrialisation. Housing construction is tradition-bound. Hence, external potential change drivers such as governmental reports (or this thesis) pointing out the needs in housing and possible solutions will not be sufficient. Of a more general interest, considering the obstacles and opportunities in the entire housing industry, is the communication between academia and industry. Is this communication and interaction sufficient (i.e. leading to operationalisation of research findings)? If not, how should it be improved towards a real win-win situation?

5.3 Further research

Much research and development related to the housing industry remain. Based on this thesis' findings and limitations, some motives for further research and possible research areas are listed below. The suggestions range from need of theory building and testing to needs more directly linked to industry needs.

Theory building regarding e.g. information management, change, and SCM in an industrialised timber frame housing context can yield valuable knowledge for
further understanding and improving of industrialised construction processes. Similarly, empirical findings related to industrialised timber frame housing need to be further tested. For example, how developed are the companies’ external supply chains regarding management and integration of key business processes? Such theory testing leading to deductive conclusions can be valuable for further cross industry learning between construction and manufacturing industry.

New actors with various backgrounds are applying volume element production after having identified a potential on, e.g. the market for multi-storey houses. Can this additional competition promote a further development of industrialised housing? A follow-up of the multiple-case study in Paper IV to examine changes regarding the prospects and pitfalls among these companies, along with other frontrunners with different characteristics, is one way of increasing knowledge and understanding of industrialised housing.

Many lessons regarding industrialised timber frame housing and its development could be learned from describing and analysing each change (and following changes), and their quantitative and qualitative impacts in the change process described in Paper II.

Despite the existence of multiple obstacles, implementation and use of appropriate IS also has a clear role as a change and development driver in housing construction. How should an industrialised housing company utilise IS to match the needs in the entire construction process, covering aspects like 3D-CAD, ERP, and customer and supplier relations?

The working methods in the volume completion process are very similar for industrialised timber frame housing companies and the corresponding processes performed by traditional on-site housing companies. This implies a practical development potential for increased industrialisation both regarding both processes and equipment.

Another area with the potential for improvement is the material supplier–housing company relation. How can the development of components adapted to an industrialised timber frame housing production be improved? Again, industrialised timber frame housing companies are often SMEs, while material suppliers are often large companies with customers having differentiated needs.

Industrialised timber frame housing in Sweden is dominated by SMEs, with generally small financial and organisational resources for development. What are the reasons for this industry structure and the market success of these companies? Can large construction companies be more active regarding industrialised housing and timber frame housing? Should they be more active? An examination of large
construction companies and their experiences and attitudes regarding these areas could provide further insights of industrialisation of construction.

To continue to deepen and broaden the knowledge, and perform statistical quantitative analyses, of industry structure and company characteristics, the survey presented in Paper III can be followed-up from a number of perspectives:

• A developed overall analysis (including qualitative and quantitative (multivariate analysis) methods) of the industry: What are the real success factors leading to operational and managerial efficiency and flexibility, and eventually a competitive advantage and profitability? This analysis can also include a broadened and deepened financial performance analysis, by including more industry performance measures.

• Examine changes regarding the industry structure to identify new trends regarding, e.g. product mixes, production methods, and company sizes as well as attitudes and impacts regarding implementation and use of IS.

• Broaden and deepen the descriptions of interesting backgrounds of companies regarding major changes and their impacts and their implications for future potential changes.
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Paper I

Integrated design and production of multi-storey timber frame houses: production effects caused by customer-oriented design

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This paper has been edited to fit the format of the thesis, but the content remains the same.
Abstract

This paper presents the results from an ongoing R&D project aiming for an industrialised development of a multi-storey timber frame house system. The development was conducted systematically using methods from concurrent engineering (CE) focusing on the customer satisfaction and production-design problems/possibilities. A Swedish SME building company was investigated from the viewpoint of customer orientation, production and design of multi-storey timber frame houses. The company uses industrial fabrication of volumes. The aim was to analyse how the production can benefit from an integration of a customer-oriented design and production. First a model based on the QFD method is proposed on how requirements from customers, i.e., tenants, can be taken into account in the design process and how CE can be adapted to a SME design process. Secondly, a preliminary model is proposed considering disturbances and relative cost effects on the production due to changes in the design solutions. The presented model aims to predict the total cost for a customer affected design on the used building system to forecast the costs for the main contractor and building owner for a similar integrated design in the future. All observations are based on case studies of the design process and the industrialised production of a three-storey timber frame house with three different floor designs.

Keywords: Customer oriented design, Integrated design/production, Flexible production, Timber frame houses

1 Introduction

This paper reports results from an R&D project aiming for an industrialised development of a multi-storey timber frame house system with high buildability. In this context the meaning is to develop a system that can compete with existing systems, be easily manufactured, delivered and erected for a competitive prize. Swedish, as well as international, experiences indicate savings in the building costs by the use of timber frames. Together with increasing demands for environmentally sustainable development this implies promising market opportunities for timber frame houses. To the future client, a timber frame system is only interesting if it is competitive in quality and economy. However, a questionnaire survey performed by Stone (1999) shows that 50% of the tenants in some recently built Swedish multi-storey timber frame houses selected the flats just because of the wood. This indicates that people experience and expects high living values in timber frame houses. A similar indication of positive attitudes to wood and timber frame houses in Germany and Japan is reported in Hagstedt (1998). Macfarlane (1999) points out that timber frame construction is competitive if the construction process is efficiently and properly managed. An interesting and seemingly good example of this is the timber frame system presented by Sigrist and Renggli (1999). From a limited numbers of basic designs, the customers are...
offered possibilities of individual solutions. This is possible since i) the company has established a so-called Integrated Product Team (IPT), ii) the designs have been standardised to a high degree and iii) adapted and optimised for the industrial production.

In the US, 80-90% of the block of flats is built using timber frame construction (Eriksson, 1995). The dominant market share of lightweight timber frames is attributed to simple foundations, quick production and low costs. After the changed Swedish building code about 1000 flats in multi-storey timber houses have been built (Stone, 1999). This is nevertheless less than 5% of the total Swedish production of multi-storey houses. Swedish contractors and clients may not yet have enough experience to accurately estimate the costs of construction and maintenance of timber frame houses. However, in a comparative study Stone (1999) showed that the (calculated) building cost was between 6-15% lower for a timber frame multi-storey house compared to similar houses constructed by prefabricated concrete or steel. Customer satisfaction is beginning to be more important on the Swedish building market. There are more players on the scene and the politically controlled building activities have been replaced by more private initiatives. This has led to that the producers are more interested in finding out exactly what the customers want and are willing to pay for. Thus, it is essential to know the customer’s needs to be able to establish the correct Functional Requirements (FRs). By using the method of Quality Function Deployment (QFD) it is possible to incorporate the demands of the customer and convert this into a set of FRs. The QFD methodology has been used in e.g. the mechanical and automobile industries and relatively recent in building projects (Haapasalo, 1999). The concept of Concurrent Engineering (CE) is a well-documented and widely used methodology to integrate customer demands, design and production in a holistic sense (Backhouse and Brookes, 1996). The salient feature that characterises CE is the integrated product teams (IPTs) responsibility for all phases in the development process. CE is based on iterative matching of the product design requirements to the production capabilities. Besides being a tool to increase product quality, the QFD method will also benefit co-operation within an IPT. However, for Small and Medium sized Enterprises (SMEs) very little information is reported about the usability of CE.

Hence, holistic methodologies must be used to develop an effective building system that satisfies tenants, owners and producers. In this project the development was conducted using and adapting systematised ideas from CE. The starting point for the development of the building system was an investigation of how specified customer demands can be determined and met by integrating design and production. A preliminary model is purposed considering disturbances and cost effects on the production process. The presented model aims to predict the total cost for a customer affected design on the used building system to forecast the
costs for the main contractor and building owner for a similar integrated design in the future.

2 Customer demands and customer oriented design

At an earlier stage in this project Stehn and Jonsson (1999) could define core competencies of the main contractor (MC). Based on a strategic competence case study Stehn and Jonsson reasoned that the MC should employ a strategy of market segmentation to enter the market and to increase the company's profits. As a consequence the following R&D question was formulated. What are the requirements on the products and on what activity should the MC concentrate to follow this strategy?

Again appear case studies to be a good choice of approach. Two case studies were conducted for a QFD formulation and a markets survey of customer requirements on the product. An IPT was established from the industrial partners involved in the project including a building owner (BO), a design consultant/architect (DC), the MC, two technical installation sub-contractors (SC) and a wood supplier (WS). The industrial partners are, with the exception of the large sawmill company, all Swedish SMEs in the building trade.

The development project in this study was designed according to Hellard (1995) involving the stakeholders that could benefit from partnering. Partnering is a management philosophy concerning a group involved in the design and implementation of customer requirements. When developed, the MC will own the concepts for the product. The SC and DC operate through royalty based agreement with the MC to provide the incentive to participate. The system is adapted/designed to meet the needs and production of the BO and WS, thus creating the incentive for future business agreements between the BO, WS and the MC.

2.1 QFD formulation of requirements on the product

In the QFD study the demands on a timber frame house and the linked production/machining capabilities of the MC were investigated from the viewpoint of requirements on the product. Only the first stage of the QFD methodology was used in this study. This means the construction of the matrix called House of Quality (HOQ). It displays the customer's wants and needs in the rows of the matrix and the IPTs technical response to meeting those demands in the columns. To obtain “real” customer demands two estate agents employed by the BO complemented the IPT. The strengthened IPT identified the customer demands through a mind-mapping method. The wants and needs were categorised/labelled to the five major demand groups in Figure 1. The demands were then rated based on a 1-4 scale where 4 means most important. The rating from the estate agents was given a relative importance of 5 compared to the other members of the team. Based on these rankings, the demand with the highest rat-
Possible FRs to meet the customer demands were determined in a similar way. The suggestions were iterated through, and accepted by, the IPT before the final FRs was decided. The IPT then determined the degree of interaction between each customer demand and FR. The interaction was given numerical values for 9 (strong), 3 (moderate) and 1 (weak) relationship. The overall QFD-rating was obtained by multiplying each customer weighting and the interaction weighting and then by summing up all these values.

![Figure 1. House of Quality (HOQ) transformation of customer demands to FRs.](image)

Conclusions for the development strategy that can be drawn from Figure 1 are:

- The most important customer demands to focus on are: Investment (9 - the price to be paid is of prime importance for the future tenant), inner design (8 – the importance of architectural design and attractive flat layout), operation and maintenance (6 – the implications of an integration of well-planned design including maintenance aspects) and variable design (5 - indicates that it should be possible to change the flat layout).

- The most important FRs that, in an overall/general sense, best fulfils the customer demands are: an appropriate materials choice (213 QFD points) and integrated design-production (235 QFD points) development strategy.

- To be able to meet the most important customer demand (investment) Figure 1 shows strong interactions (9) with the FRs of short construction time and complete building systems. However, both have low QFD-rating. Recognizing both FRs as important, the industrialised building system already used by the MC...
was judged a perfect base for the continued development as considered in section 3.3.

2.2 Market survey of requirements on the product

In a just completed building project the MC and BO have jointly developed, marketed and constructed a two-storey timber frame town house settlement (52 units). With the aid of local estate agents and the market segmentation model put forth in Stehn and Jonsson (1999), the BO focused on a segment of the market by offering their “expandable home” concept. Specific or typical features are offered to the customers by options (extras) in a predefined principle design targeted to a specific customer group - Young families with limited economy. Only minor changes of the principle design are allowed to keep a high production-cost efficiency.

Questionnaires (with a 77% answer statistics) and ten interviews were used in the survey. All results and corresponding analyses are presented in Bergling (1999). The house purchasers were asked to choose the three most important factors in the purchase selection and give numerical values for 3 (the most important), 2 (second most important) and 1. The result of the market survey is presented in Table 1. The relative customer rating was obtained summing up all values for each factor and dividing them with the total sum.

Table 1. Results from the market survey study on requirements on the product.

<table>
<thead>
<tr>
<th>Factor</th>
<th>Customer rating (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location of the house</td>
<td>24</td>
</tr>
<tr>
<td>Economy</td>
<td>24</td>
</tr>
<tr>
<td>Flat layout</td>
<td>22</td>
</tr>
<tr>
<td>Influence of flat layout (flexible design)</td>
<td>13</td>
</tr>
<tr>
<td>Area landscaping and lot size</td>
<td>10</td>
</tr>
<tr>
<td>The options program</td>
<td>7</td>
</tr>
<tr>
<td>Marketing of the settlement</td>
<td>0</td>
</tr>
<tr>
<td>Service program and reception from the BO</td>
<td>0</td>
</tr>
</tbody>
</table>

Excluding location, economy, flat layout and influence of flat layout are the important aspects to focus the development strategy on. The general strategy followed by the BO, in this case, to achieve customer orientation was a predefined house/flat design and an individualisation through the options program. The low importance (7% ranking) for the options program is not a satisfying result for the MC and BO. Only 17% thought that the extent of the options program (cabinets, equipment, flooring, finishing etc.) was sound but more than 60% thought that in was not acceptable.

The conclusion that can be drawn is that a more integrated (inner) design–production philosophy is needed to offer customers the extras that they want and
that the MC can offer and still make good profit. Also apparent is the need of clear and structured information where flexibility is coupled to price (price/performance relations).

2.3 Customer oriented design strategy

Apart from the location and area landscaping, factors that are not attributed to the house design, the relative customer rating in Table 1 points in the same direction as the QFD-study in Figure 1. The house should provide an acceptable life cycle economy with attractive and flexible flats. It must be remembered that customer ”representatives” performed the QFD study and that the questionnaire and interviews did not specifically focus on the QFD customer demands which makes these studies not exactly comparable.

Good economy and attractive flats are very general, and maybe obvious, conclusions. The same types of findings are observed elsewhere, e.g. (Macfarlane, 1999). But what the studies also reveals is that a promising way to actualise this is by integrating design- and production closely. The results from the QFD study shows that by focusing on an appropriate materials choice and integrated design-production the important customer demands of economy (operation and maintenance) found both from Figure 1 (QFD) and Table 1 (market survey) and flat layout (inner architectural design and flexibility) can be matched and optimised to the production capacity. The proposed development strategy is thus:

An integrated design-production CE approach will be managed and adapted in the continued development of the timber frame houses. Customer orientation, focused to specific niche groups, will be included by utilising input from the studied described above. To accomplish the strategy available methods form CE will be used.

3 Integrated design and production

As a starting point, the strategy described above was used for the development of a three-storey timber frame house that was erected in January 2000. To demonstrate the concept and the limitations of the strategy the demand attributed to three niche groups were incorporated into one house, see Figure 3. The customer niche groups are:

1 Young people moving from home (students),
2 Young families with limited economy (families with children) and
3 Young families without children.

The BO and MC jointly identified these groups by using the market segmentation model in Stehn and Jonsson (1999). The choice of these specific groups originates from known general and specific (Table 1) market demands in Sweden for small, flexible apartments. The purpose was to demonstrate: i) the possibilities
of flexible design when using an industrialised production (customer viewpoint) and ii) the limitations imposed by the preferred standardised structural system (R&D viewpoint). As a result, the house has been given three different floor designs, described in section 3.3. The potential of this approach was investigated in the case study in section 3.4.

3.1 The CE methodology

Several FRs, from the QFD study, was developed and tested by the IPT. All these design solutions are not elaborated on in this paper, instead the design process to accomplish the FR on visible installations is presented as an example. Electrical installations are commonly fastened to the timber stud frame within the wall element, so-called hidden installations. In this project the QFD characterised FR of visible installations was used. In this context visible installation means electrical installations assembled on the wall and covered with a multi-purpose wood trimming. The wood trimming was jointly designed by the IPT to incorporate several requirements. By this solution customer demands on variable flexible design can be met and one step in the element production was eliminated, i.e., the preparations and assembling of the electrical installations.

The CE methodology and decision flow within the IPT, see Figure 2, when designing the wood trimming will serve as an example on how the CE concept was used in this project. The first step, C1 in Figure 2, is the concept development phase and includes the phases presented in sections 2.1 – 2.3. The following (coupled) processes necessary to achieve high buildability are, for all different design solutions in the project, principally linked together according to Figure 2. The design process was divided into two linked parts performed partly parallel: fulfilling buildability (conceptual design) and optimising the structure (detailing and production process development).

![Figure 2. Scheme of the CE development leading to the final design of the wood trimming.](image)

D1 A sub-group of the IPT was created comprising the DC, SC and WS. A preliminary design was produced based on: i) production requirements of the WS, ii) DC esthetical values harmonising with flat design and iii) SC space requirements for electrical and data installations.
Suggested design solutions were iterated through IPT meetings, with representatives from all companies (MC, BO, DC, SC and WS), held each month. Improvements and changes based on conceptual considerations are brought back to the sub-groups. A primarily concern was to optimise the requirements ii and iii.

Refinement of the proposed design by optimising different space requirements (e.g. environmentally acceptable cable material put restrictions on minimum cable bending radius that in turn affects the thickness and height of the trimming etc.).

A design sub-group comprising the MC, SC and WS was formed for a parallel validation of production capabilities and restrictions for the involved companies in the production phase of the wood trimming. Prototypes of the wood trimming were produced incorporating the effects of: i) the machining capabilities for the WS, ii) production changes for the MC (wall elements production and volume element mounting, see 3.2) and iii) the SC fixing of electrical cables and estimation of changes in installation work in the MCs element production work.

The WS produced a prototype. The SC and MC fixed on the electrical installations system in a test volume.

Systems validation of both the product design and it’s manufacturing process. The result is a specified design appraising all IPT and perceived customer’s requirements.

3.2 The industrialised production

The MC started 1924 as a family owned (still is) local construction company and has expanded to an enterprise that produces and erects around 700 volumes per year. The company uses an industrialised house volume production in a factory with about 4000 m² of production area. The SME employs around 60 people (staff and carpenters/workers). During the last 5 years more than 600 flats (one flat often comprises several volumes) in multi-storey timber frame houses have been produced and sold.

The outer walls are produced in a line that is partly automated. The process to produce an outer wall element consists of five steps. First, the structural frame is assembled and insulated. Then the plastic foil and double layers of gypsum wallboard are applied. The third step consists of preparation for the electrical installations after the element has been turned around. Then the horizontal timber studs are nailed to the frame and a second layer of insulation and the outer gypsum wallboard are applied. The fifth and final step is to cover the element with a fa-
cade. All types of inner walls are produced at two working stations in a similar way. The wooden floor elements are produced by assembling the structural frame, the installation for heating, water and sewage and completed by applying the particle and gypsum floorboards.

When the elements required for one volume are ready they are gathered on a truck bed and hauled to the station for assembling the elements to a volume. After the volume is fabricated finishing work follows. This is done both by the MCs own workers and by subcontractors. Typically, subcontractors do inside and outside painting, surfaces finishing and technical installations and fixation of heating and water equipment. Assembling of inner doors and equipment such as wardrobes and cabinets are done by the MC. Volume finishing works is the production bottleneck that causes disturbances in the total production flow. It is also here where the highest potential can be found to increase the production flow. Both single and multi-storey buildings are erected and site completed by the MCs own workers. The time from order to a complete and ready-to-move-in house is approximately 12 weeks.

3.3 Design for flexibility

In order to create a system where the flexibility is consistent with the production an integrated design-production CE approach were administrated by the IPT and performed by Luleå University of Technology. The necessary knowledge about the constructional system as such was gained using this methodology. To accurately perform the production case study, knowledge about the design and design process must be as detailed as possible. The utilisation of different flat layouts in this projects aim to show the possibilities for the client/tenant to move/add/take away both load bearing and non-load bearing inner walls. This flexibility gives the BO the opportunity to choose among a number of different layouts in cooperation an architect and the MC.

The ground floor, called the open flat layout, consists of three flats, see Figure 3a. The layout gives a worst-case structural design scenario to solve. Some of the rooms are twice as wide as one volume. A volume has, in this case, a floor span of 3.6 m implying a span in the order of 7.2 m. The free span when using a wooden floor structure is limited to approximately 4.5 m due to tough requirements on static and dynamic deflections and impact sound insulation. When volume production is used limitations in transportation will also put constraint on the total width of the volume. The open flat layout also implies a careful bracing design to carry the high horizontal wind loads caused by the large openings. The first floor, called the normal flat layout, also consists of three flats, see Figure 3b. The second floor, called the student flat layout, consists of student flats, two or three per kitchen. The three different floor designs are attributed to the selected niche groups, see beginning of section 3, in the respect that the open floor layout is primarily aimed for the third group (families without children). The normal flat
layout corresponds to the second group (families with children) and the student layout for the first group.

![Figure 3. Three different flat layouts: a) open, b) normal and c) student.](image)

Design requirements are taken from the QFD formulation in Figure 1. As noted in the conclusions in section 2.1 the interaction between the important customer demand *good economy* and the FRs *short construction time* and *complete building system* implies design constraints for the IPT to use the highest degree of standardisation in the structural solutions. These solutions should also cause as little disturbances in the production as possible and the new or altered design solutions should preferably be of wood (*materials choice*).

Two walls carry the floor in a standard volume. The walls are perpendicular to the timber joists in the floor element. To allow the open flat layout the free span must be increased and one of the two load-bearing walls must be taken away. The solution was to replace a wall by a beam to carry the load and reduce static and dynamic deflections. In an earlier four-storey building project the MC used an UPE-steel beam to carry the load instead of one of the load-bearing inner walls. The steel beam had to be manufactured by a separate steel supplier and the timber joists had to be especially prepared before they where joined to the steel
beam. The MC considered this as a complicated and expensive design solution. Following a similar procedure of that depicted in Figure 2; a glulam beam 115x270 mm$^2$ was designed. Figure 4a shows a cross section where the glulam beam is supported by a glue-nailed timber stud column. Figure 4b shows a cross section for an open layout. Last, Figure 4c shows the joint between the volumes when inner walls are placed on the glulam, as in Figures 3b and 3c. To make an open layout possible glulam beams were integrated in the necessary floor elements at three different locations. Where the open layout was used the joint between the volumes was covered with a trimming of board. This has to be done on site after the erection.

![Glulam beams](image)

**Figure 4.** Detail solutions of floor-wall connections caused by customer demands on flexibility.

### 3.4 Production case study

To investigate if the flexible structural system caused any disturbances on the production a comparative study was performed. Comparisons were made between the flexible system and the standard system. The standard system is defined as timber frame houses where one volume comprises a complete student flat. The standard and flexible volumes were produced in November 1999 to January 2000. The customer oriented design was identified to affect the floor elements, the load bearing inner walls and to some degree the ceiling. An important restriction for the overall house design was to refine the technical installations in the floor elements. This means that for each flat the water and sewage installations have been concentrated to only one “wet” volume. Thus, the rest of the volumes only have heating installations in the floor elements. Due to these facts and, partly, because the project is still running (all data is not yet available) the production study was concentrated on a comparison between the standard and the flexible system for elements belonging to the “dry” volumes 1 – 3 in Figure 3.

Table 2 sums up the results from the production study. The numbers for the standard system are based on the study of six floor elements and seven load-bearing inner walls. For the flexible system five floor elements and six load-bearing inner walls, two per floor, were studied. The figures presented are calculated in the common way, i.e., cost per m$^2$ useful area. In this case a “real” living
area has been used, which means a larger area for the open flat layout. The table shows the relation between the standard and the flexible system as the amount of man hours and material cost considering the production process for whole element. In this context, man hours are defined as the total number of man hours required to produce an element with the number of man hours required for installation work excluded. The material cost includes all material cost, except installations, needed to produce an element. After the time measurements and determination of costs the standard system was normalised to a relative factor 1. For the floor elements and the load bearing inner walls the changes in the design solutions only affects the first step in the manufacturing process, i.e. the structural assembling, as described in section 3.2. Only the flexible system has visible installations. Thus, for a more correct comparison the measured man hours and material cost for preparation for the electrical installations are subtracted from the total amount of man hours and material cost for the standard system. Otherwise the comparison would be inadequate since the visible installations require one less step in the flexible element production process.

Table 2. Results from the production study.

<table>
<thead>
<tr>
<th></th>
<th>Standard system</th>
<th>Flexible system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Floor elements, man hours</td>
<td>1</td>
<td>All floors 1.46</td>
</tr>
<tr>
<td>Floor elements, material cost</td>
<td>1</td>
<td>Ground floor 1.23</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Floor 1-2 1.26</td>
</tr>
<tr>
<td>Inner wall elements, man hours</td>
<td>1</td>
<td>Ground floor 0.76</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Floor 1 1.52</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Floor 2 1.00</td>
</tr>
<tr>
<td>Inner wall elements, material cost</td>
<td>1</td>
<td>Ground floor 0.60</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Floor 1 1.13</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Floor 2 0.91</td>
</tr>
</tbody>
</table>

For the flexible system the variations between the different floors depend on the structural solutions. For example, the load-bearing inner wall on floor 1 has integrated columns in three places that lead to disturbances. The implications are a relative increase in man hours to 1.52 and in material costs to 1.13 compared to the standard system. On the second floor no columns are needed, thus the inner walls are practically the same for the standard and the flexible system. In the standard system all inner walls are of the same type. In the flexible system on the other hand the design of the inner walls varies depending on the flat layout, see Figure 3. The studied inner walls on the ground floor have only three columns and for that reason the relative man hours (0.76) and the material cost (0.60) are low. The inner walls on the first floor are walls with integrated columns and hence the man hours and the material cost are a bit higher.
The man hours required to produce the floor elements are much larger for the flexible system than for the standard, 1.46 against 1. In this case the floor element in the flexible system must incorporate the glulam beam in Figure 4. This glulam beam was fastened in a different way than the header used in the standard system.

The absolute importance of a specific element on the total cost cannot be extracted directly from Table 2 since the numbers in Table 2 are relative. For instance, slightly less than 5 to more than 8 man hours, for elements in a dry volume, extra are required to produce a floor element than to produce a wall element. This clearly implies that the figures 1.46 and 1.23 (the ground floor elements) have the largest influence on the total effects (disturbances and material cost) on the completed volume or house.

4 Discussion and conclusions

Interesting synergies can be found, and much can be gained, by a continued combination of theoretical, and practical, fields of production research and engineering design research. The methodologies are, from a holistic viewpoint, based on the same ideas, i.e., combining all involved stakeholders, disciplines and competencies into a team and making the team responsible for an effective design with the aim of enhancing the value. The example of the design process leading to the wood trimming and glulam beam has clearly pointed out the benefits of a CE approach to the SMEs in this study. The design conflicts (production difficulty, interference with technical installations requirements etc.) were identified by the IPT before production. This reflected the strength of using a CE concept to the involved companies. Without taking consideration of SC and DC demands the volume finishing works would have been more expensive. Also apparent for the IPT was the feedback gained compared to the ordinary “solve-the-problem-as-it–manifests” philosophy. The knowledge gained from incorporating customer demands and demands and restrictions from other parties involved in the business will be developed further.

The results from the production study excludes installations, i.e. heating, water and sewage installations in the floor element. The reason for this is that the necessary information have not been collected and analysed due to the project is still running. For the studied floor elements without water and sewage installations, as the case is in a living room or a bedroom, the ratios presented are relatively close to “true” values. Only the cost and time connected to the heating installation are excluded. For an element that also contains installations for water and sewage the ratios presented are misleading in disadvantage for the flexible system. If the ratios would include figures for these installations a cost and a step in the element production process is added. Therefore the differences between the standard system and the flexible system are assumed to decrease the more complete the figures become.
The MC has for a number of years developed and refined skills in the volume building technique. The standard system developed by the MC has been the platform that the flexible system has been developed from. In this project the changes in the design solutions have been iterated within the IPT and adjusted to the production system before accepted and finalised. This implies that the effects like disturbances and cost should be relatively small. This was confirmed by the ratios presented in Table 2 that shows that the effects considering disturbances in the production and cost for the elements have been relatively limited. In this case the integrated design and production approach proved to be successful.

The four-storey building project mentioned in section 3.3, shows that design solutions that differ too much from the standard system adjusted to the production causes too big disturbances to be economically justified. The fourth storey had been given a shape of a mansard roof. This meant that the outer walls in the forth storey were not flat but inclined. To assemble this kind of element it had to be taken out from the production line and put together on the floor. This led to disturbances both for the element production and the volume assembling.

With a rapidly growing market the MC faces possible bottlenecks concerning the plant layout, industrial production conception, management control etc. Preliminary indications from the study suggests that issues like logistic, material flow, cooperation/partnering between the MC and SCs and planning and production preparation may have significant influence on disturbances in the production system. This is a strong indication that further work and analysis are needed to complete the proposed preliminary model. An interesting avenue is to include and adapt a Materials and Production Resources philosophy so that disturbance from logistics, material flow etc can be considered. Continued work will also be done to deepen the knowledge on how customer oriented design solutions affects the production. The aim is to be able to predict the time, capacity and cost needed to produce different variations of multi-storey timber frame houses.

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6 References


Paper II

Matching industrialised timber frame housing needs and enterprise resource planning: a change process

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This paper has been edited to fit the format of the thesis, but the content remains the same.
Abstract

The potential for improvements in industrialised housing through the adoption of concepts like enterprise resource planning (ERP) from the manufacturing industry, as applied to small and medium-sized enterprises, is evaluated in this paper. Four single, consecutive case studies were performed at a Swedish medium-sized industrialised housing company. The findings suggest that ERP can meet industrialised housing needs as well as promote an organisation to be re-engineered through comprehensive change and act as a driver for a more efficient internal and external supply chain.

Keywords: Industrialised housing, Change process, Enterprise resource planning, Supply chain management, Timber frame houses

1 Introduction

The majority of one-family detached houses in Sweden have timber frames and are nowadays manufactured in permanent factories (approximately 74% between 1990 – 2002). By comparison, about 69% (down from 90% 20 years ago) of all housing starts in the US are stick built on site. From a market point of view, this indicates that an industrialised and process-oriented production approach could have potential for the whole housing industry. This is supported by an extensive governmental evaluation of the Swedish construction industry [1], indicating that it is possible to reduce production costs in housing construction through industrialisation, customer orientation, and a more efficient construction process. Logistics and supply chain management (SCM) are demonstrated [2,3] as disciplines with the potential to increase efficiency in the construction process. In the large enterprise manufacturing industry, the supply chain concept has been one model for improvements in efficiency. Holistic production philosophies such as lean production, and comprehensive planning methods such as enterprise resource planning (ERP), which are supported by information technology (IT) based software systems, are used to manage parts of or the entire supply chain [4,5,6]. The potential for improvements in the housing industry as well as the use of concepts such as SCM, lean production, and IT supported ERP, as applied to small and medium-sized enterprises (SMEs), motivate the research presented in this paper. The possibility of cross industry learning is discussed and analysed in two perspectives: from the manufacturing to the housing industry and from large enterprises to SMEs. The conclusions and outlines for future research are, together with an extensive literature review, based on the analysis of four consecutive case studies.
2 Production philosophies, methods and software systems

This section includes philosophies, methods, and software systems, i.e. the central concepts used by the manufacturing and the construction industries, to increase the effectiveness and efficiency in manufacturing and construction processes. A description of industrialised timber frame housing in Sweden is also included.

Section two is also the theoretical framework for the analysis in section three. Based on similarities and differences of the concepts and the two industrial systems, the potential for cross industry learning is presented. The literature review, though broad, does not claim to be a complete foundation to entirely describe and analyse each concept. Instead, literature in the fields of construction management, economics, and supply chain was reviewed to properly match the purpose and research questions.

2.1 Production in the manufacturing industry

SCM can be viewed as the management and integration of key business processes across the supply chain, i.e. a process-based perspective [7]. From a logistics and transportation perspective, SCM is seen as the management of materials, products, and information flow. It can also be considered as the simultaneous integration of customer requirements, internal processes, and supplier performance [8]. Effective integration of the major supply chain components, i.e. customers, manufacturing, and suppliers, is the key to an organisation’s long-term success [8].

The concept of lean production, developed during the 1950s at the Japanese car manufacturer Toyota, resulted in economic benefits, a production system yielding higher product quality, greater possibilities of variation, and less use of resources as compared with previous production concepts [9]. The lean production concept can be described as a holistic management philosophy, with product quality as the primary goal, which underlines the critical importance of employees, customers, improvements of the two main conversion processes, design and production, and elimination of all other activities, to achieve customisation of high volume products [4,10].

The theory of constraints (TOC) is a systems philosophy aimed at ongoing improvement of an enterprise that includes theoretical methodologies and tools focused on the organisation-wide aim [11]. Originally developed for production, TOC is now also applied to areas like finance and measures, projects, supply chains, marketing, and strategy [12]. The implementation and use of TOC can improve the overall performance of a manufacturing organisation [11]. Meta-analysis [11] shows improvements like reductions in lead and cycle times, inventory, financial improvements, and better customer satisfaction and team functioning due to TOC application.
Three elements defining ERP are identified in [13], viz. a technical, a functional, or a business perspective. From the technical and functional perspectives, material requirements planning (MRP), manufacturing resource planning (MRP II), and ERP represent the development of methods and software tools for the planning and controlling of resources for manufacturing companies. To support a manufacturing company’s business processes (mainly financial, manufacturing, and distribution), MRP, MRP II, and ERP are widespread [14-19]. In the following, only the term ERP will be used. In the business perspective, ERP can be viewed as a business approach integrating strategic and operational functions, e.g. procurement, shop floor control, and financial accounting, through the entire organisation [13]. ERP is also regarded as a driving technology in the re-engineering of business processes [13,17,20]. A review of 17 papers [5,6,13,15-28] describing ERP and its benefits, covering part of the literature, from 2001 to 2003, is labelled and presented in Table 1 (one paper can comprise multiple categories). According to Table 1, the main focus of ERP research has been case studying the implementation phase of large enterprises in the manufacturing industry. Together with the great number of conceptual papers, e.g. analysing ERP using a holistic viewpoint, this demonstrates the need for empirical findings regarding SMEs. The European Communities’ SME definition is, in this paper, consistently used for company size classification.

Table 1. ERP research focus summarised from [5,6,13,15-28].

<table>
<thead>
<tr>
<th>Category</th>
<th>Number of papers with each main focus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aim</td>
<td>Implementation: 10, Impact: 7, Other: 5</td>
</tr>
<tr>
<td>Industry</td>
<td>Manufacturing: 10, Other industry: 3, No specific: 5</td>
</tr>
<tr>
<td>Company size</td>
<td>Large: 9, SME: 1, No specific: 7</td>
</tr>
<tr>
<td>Data collection</td>
<td>Case study: 8, Survey: 4, Conceptual: 6</td>
</tr>
</tbody>
</table>

Table 2 summarises the potential benefits found in the literature review [5,6,13,15,16,18,19,21,23,24,28] that organisations can achieve by implementing ERP systems. Labels 1-3 refer to different organisational levels, label 4 to the overall organisation, and label 5 to IT infrastructure. Each label in Table 2 contains a different number of ERP benefits. The benefits are not statistically ranked; however, the higher position in Table 2, the more often this specific benefit is mentioned in the literature. Adopting an ERP approach might not only yield benefits. An ERP implementation is shown to be a major obstacle and ERP use can cause considerable financial and organisational problems; however, both ERP implementation success and hindering factors are identified [26,28].

The described philosophies, i.e. SCM, lean production, and TOC, clearly have common features. All are based on a holistic perspective and a customer and supplier oriented approach; they are often supported by comprehensive IT based systems, like ERP, for planning, controlling, and business process integration; and they have common objectives like increased throughput and quality, low total
costs, and short lead times. As well, their objectives are to be achieved through efficient (business) processes that are continuously improved. A salient observation and important conclusion is that all concepts prove that a re-engineered and a more effective organisation is possible if the philosophies are realised through the use of proper planning methods, with or without the implementation of software systems.

Table 2. ERP benefits reported in [5,6,13,15,16,18,19,21,23,24,28], labelled according to [6].

<table>
<thead>
<tr>
<th>1) Operational</th>
<th>2) Managerial</th>
<th>3) Strategic</th>
<th>4) Organisational</th>
<th>5) IT infrastructure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Improved business operations, process integration, and process standardisation</td>
<td>Better information availability/quality</td>
<td>Facilitates philosophy and ERP integration</td>
<td>Improved overall financial performance: revenue, cost reduction, labour savings, and profitability</td>
<td>Supports global IT systems</td>
</tr>
<tr>
<td>Better inventory management</td>
<td>Improved planning and controlling</td>
<td>Supports core business strategy, growth, and goal achievement</td>
<td></td>
<td>More flexible organisation</td>
</tr>
<tr>
<td>Facilitates customer service and customisation</td>
<td>Eliminates limitations</td>
<td>Supports new partnerships opportunities and supplier management</td>
<td>Facilitates change programs</td>
<td></td>
</tr>
<tr>
<td>Better efficiency</td>
<td></td>
<td>Increased transparency of marketplace and global negotiation power</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2.2 Production in the construction industry

During the 60s and 70s, the production-focused and non-customer oriented systems building approach was developed and used in countries like Sweden and Great Britain. Forms of contract like build-operate/own-transfer and a responsibility to fulfil performance requirements are current trends in Swedish housing construction. This could indicate that a more process-oriented approach is being developed in markets other than one-family houses, but the project focus is still strong [29]. The project culture is predominant in the construction industry while the company culture is stronger in the manufacturing industry [30], indicating that knowledge transfer between the industries requires a redesign of philosophies and methods. With the introduction of the 1994 Swedish building code, the already initiated direction towards performance requirements and market orientation was reinforced.

In construction, the primary focus regarding the logistics concept is to improve co-ordination and communication between project participants during the design and construction phases, particularly in the materials flow control process [2].
The impact of adopting an SCM philosophy in housing indicates that this approach can develop new markets and increase revenues [29], as well as deliver total value for the customer, if the supply chain is designed combining principles from lean and agile production [3]. The agile concept focuses more on customisation and effectiveness than the lean concept, which focuses on technical efficiency of processes [3].

One of the most important features of lean production is the success in managing the balance between standardisation and flexibility [4]. The concept of industrialised housing using standard components, a flexible assembly, and a wide range of customer choices has shown to be popular among Japanese house buyers, indicated by an increased market share [9]. From a more general process perspective, the lean production philosophy can also naturally be applied to the construction industry, i.e. lean construction [31]. Even though construction projects are often considered unique, the lean construction approach can improve flows in the construction process if the general principles of flow design, control, and improvement are appropriately applied [31].

The manufacturing industry appears to have been successful in developing and adopting philosophies and methods to render the supply chain and production more efficient. However, successful production concepts from the manufacturing industry require adaptation to properly match the construction industry’s needs and demands, i.e. the importance of finding a balance between project and process focus [4,30]. The impact of customer orientation, the on-going development of niche markets, and a greater range of customer choices mean that a construction company’s production system has to be both flexible (agile) and efficient (lean) to balance production process variations and cost efficiency.

2.3 Industrialised timber frame housing in Sweden

A recent survey of industrialised timber frame housing in Sweden (SMEs, micro enterprises excluded, and large enterprises) is presented in Table 3, [32]. In Table 3 the companies are categorised in to five dimensions (A–E) and differentiated in two or three levels (1–3). Level 1 represents the lowest degree of complexity. The product can, regarding layout and customer choices, be standardised (A1) or (totally) customised (A3). Another option is customisation through modification of standardised products (A2). There are two main types of production methods: production of building elements (C1), e.g. floors and walls, and production of volume elements (C2). A volume element is composed of building elements, though it is much more complex than a building element, which also applies to the corresponding production processes. A production process where the volume elements are completed (technical installations, surfaces finishing, fixed equipment etc.) in the factory rather than on the construction site means that more of the flow processes – material and information – are performed in the factory, leading to a higher degree of complexity in the factory.
Thus, a typical industrialised timber frame housing company sells customised detached houses, manufactures building elements, is small, and does not use any ERP system. As a comparison, 75% of Swedish manufacturing companies use ERP systems, while an additional 14% are implementing ERP or planning to implement [19].

Table 3. Description of industrialised timber frame housing in Sweden [32].

<table>
<thead>
<tr>
<th>Category</th>
<th>Classification levels, 1-3, and their distribution</th>
<th>1 (%)</th>
<th>2 (%)</th>
<th>3 (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A) Customisation approach</td>
<td>1) Standard products, 2) Customised standard products, 3) Customised products</td>
<td>2</td>
<td>33</td>
<td>65</td>
</tr>
<tr>
<td>B) Main product</td>
<td>1) Garages and cottages, 2) One-family houses, 3) Multi-family dwellings, schools, and offices</td>
<td>12</td>
<td>70</td>
<td>18</td>
</tr>
<tr>
<td>C) Production method</td>
<td>1) Building elements, 2) Volume elements</td>
<td>65</td>
<td>35</td>
<td>-</td>
</tr>
<tr>
<td>D) Company size</td>
<td>1) Small, 2) Medium-sized, 3) Large</td>
<td>60</td>
<td>33</td>
<td>7</td>
</tr>
<tr>
<td>E) ERP use</td>
<td>1) No system, 2) No system – will implement, 3) System user</td>
<td>46</td>
<td>19</td>
<td>35</td>
</tr>
</tbody>
</table>

3 Implications for industrialised housing

Industrialised housing both resembles, and differs from (mentioned in section 2.2), the manufacturing industry [9]. Similarities can be found in production systems like the production of customised products, the importance of materials management with respect to performance, and the possibility for process-orientation and supply chain integration. This indicates the importance of the proper use and adaptation of production philosophies that can result in productivity gains, as in the manufacturing industry. Awareness of supply chain efficiency in the housing industry has increased, as indicated by the forms of contract and the success from industrialised production. This stresses the growing importance of materials management supported by ERP methods as well as, possibly, IT systems; properly managed, they can be the foundation of a more efficient industrialised housing. The efficiency development has been better for the construction of detached houses than for multi-family dwellings [1], possibly due to the higher degree of process-orientation and use of an SCM philosophy in detached housing construction for the companies examined in [32].

Since the implementation of an ERP system can be considered as a large-scale change, managing the implementation is a major and crucial task [28,33]. The required re-engineering of key business processes typically impacts organisational structures, policies, and employees, hence, an ERP implementation should be business driven utilising a proper change management [28]. An organisational change process is initiated by a need of change as related to the external or the internal environment [34]. There exists no general implementation model; what is successful for some companies may not work for others; however, both factors of success [35] and hindrance [36] have been identified.
The needs, prerequisites, and implementation of process change for business and production improvements in the housing industry are addressed in this paper. Hence, the purpose of this work can be formulated as three research questions:

- Can industrialised timber frame housing needs and ERP methods and systems match?
- Can SMEs in the construction industry benefit from theories and findings regarding large companies and supply chain efficiency?
- How could the change process, due to ERP implementation, within a medium-sized industrialised timber frame housing company be managed?

This paper describes results from four case studies performed during three consecutive years at one medium-sized industrialised timber frame house builder.

4 Case study research method

The research was conducted using a single case study research design. Four single case studies were successively performed at one company, i.e. the case company described in section 4.1, from 1999 to 2002. The data collection (interviews and participant observations) was performed continuously and successively during, and between, each case study. A commonality among the case studies was that the interviewees were selected on the basis of their special knowledge and their ability to provide information that might be useful in understanding motivation, behaviour, and perspectives. Case study research is appropriate when the research problem requires understanding of complex phenomena not controllable by the researcher, for case study research, one goal, here expressed as the purpose and the research questions, is to expand and generalise theories, i.e. analytic generalisation [37]. The third research question represent the inductive approach while the two first represent more of a deductive approach. No other company, among the 43 investigated in [32] (representing the great majority of industrialised timber frame housing), has the case company’s characteristics considering customisation approach, main product, production method, size, and ERP attitude. This enhances uniqueness, an important feature for single case studies [37].

Each case study yields important results. However, it is the overall result – the combined case study findings – that makes significant contributions, which are found when the case studies are analysed together, not separately. Not only are the case study results important, but also the changes by the case company as per the case study findings, since there is strong interaction between each case study and the results and changes. Although these changes are important it is out of the scope of this paper to in detail describe each change and its corresponding impact. Figure 1 shows the research process and the relations between the case studies (box 1-4), case study results (R1-R4), external (ED1-ED4) and internal (ID1-ID5) driving forces, and changes (C1-C2) taken by the case company as per
the case study results. Figure 1 shows that case studies 1 and 2 provided results that, acting as internal driving forces, prompted case study 3. Similarly, the combined findings in case studies 1, 2, and 3 prompted case study 4 as well as several changes by the case company. The results and changes from each case study are progressively based on the preceding case studies.

![Figure 1. Single case study research design and research process.](image)

Case study 1 – “flexible design and production disturbances” – was performed during late 1999 and early 2000 [38]. To show the possibilities of customisation through flexible design when using the industrialised timber frame system, production studies were performed at the case company. The design and production of a three-storey timber frame house with three different floor designs were analysed. A comparative production study was made between the flexible system and a standard system to investigate if the flexible structural system caused any production disturbances. A Quality Function Deployment (QFD) formulation of customer requirements was performed to determine perceived customer demands on the flexible design. In the QFD study eight key informants from different organisations were selected: a building owner, a design consultant/architect, the main contractor (i.e. the case company), two technical installation subcontractors, a timber component supplier, and two estate agents.

Case study 2 – “employee QFD study” – was performed during late 1999 and early 2000. The case study includes observations and analysis of a QFD formulation of the internal change drivers performed by all (60) of the case company’s employees. The QFD method was used as a systematic tool for identifying improvements to the production system and production processes. Interviews with managers of the whole business process (one production manager, one planning and controlling manager, one purchasing manager, and one designer) and several floor workers, together with observations of the current production process, were also carried out for data collection.

Case study 3 – “production analysis using TOC” – was performed during the first six months of 2000. The case study included production studies at the case company, to evaluate the production system using TOC as a theoretical frame-
work. Data collection included interviews with key informants, mainly production management, and observations of production during a project with a high degree of customer choices.

Case study 4 – “ERP pre-implementation” – was performed between mid-2001 and mid-2002. The case study was conducted during a development project within the case company, who wanted to possibly integrate SCM and ERP methods. Participants in the project were again managers of the whole business process, whom to the vast majority are the same individuals in all case studies. The QFD method is used as a systematic tool to identify the critical functional and manufacturing resource requirements of implementing ERP methods. Data collection using interviews and participant observations were carried out during the entire development project and key activities were analysed regarding a possible IT-based ERP implementation. After the project, interviews were performed to evaluate the development project and its consequences.

4.1 Description of case company

The case company started in 1924 as a family-owned (still is) local construction company and has expanded to a medium-sized enterprise with a turnover of over €13 M. The company produces and erects customised multi-storey timber frame buildings using an industrialised volume element production (elements are completed in the factory). Building element production and assembling of inner doors and fixed equipment, as well as on site erection, are done by the company’s own workers. Typically, subcontractors paint the interior and exterior, finish the surfaces, do technical installations, and fixation of heating and water equipment, in the volume completion process. In 1994, the company performed two large-scale changes regarding the main product and production method. The company shifted from a building element production for houses up to two storeys to a volume element production of multi-storey houses. In Figure 2 the key-characteristics (categorised according to Table 3) for the case company before and after the large-scale changes and the typical company according to Table 3 are shown. The characteristics in Figure 2 are demonstrated to influence and partly explain the change process needed for ERP adoption [32]. Figure 2 does not differentiate between multi-family dwellings up to two storeys and the more complex multi-storey houses, although there is a big difference regarding technical as well as economical issues. The transformation took two years of development and preparation.
5 Results

Case study 1: flexible design – production disturbances. Preferably, the flexible building elements should be based on the standard elements as per the QFD formulation. At most, a 50% increase in man-hours costs and around a 10% increase in material costs for a flexible element were identified. On average the effects of production disturbances and cost for all building element types in the flexible design system were relatively limited. However, issues like internal logistics and material flow, co-operation with subcontractors, and planning and production preparation disturbed the production system more than design variations due to customisation [38]. The result of this case study, not surprising though consistent, shows that the manufacturer should, and must, use the highest degree possible of standardisation in the structural solutions for the individual building elements, to efficiently manage customisation.

Case study 2: employee QFD study. The results from the case study are summarised in Figure 3, where a higher percentage indicates a greater importance according to the employees. The results suggest that issues like manufacturing and requirements planning and internal logistics are very important for the operational performance of the company and have great potential for operational and managerial improvements. Other important issues were found to be the work environment, internal communication, co-ordination between factory – construction site, and management of customer choices.
Case study 3: production analysis using TOC. When using TOC-tools to improve production, the bottleneck in production was found to be volume completion. This production process is complex and time consuming and is dependent on an appropriate plant layout. Volume completion is the process with the highest degree of material and labour intensity, including the number of subcontractors involved. It was found that a high degree of customer choices significantly reduced the pace of the volume completion process. Interestingly, it was confirmed that an increase in building element production capacity would have no impact on the overall volume element throughput. The results of the case study suggest that the most important barriers to a customised effective business and production, as well as from a TOC viewpoint, are typical elements in internal operations and financial/business perspectives. Potential areas for improvement were found to be: materials management and logistics including the factory plant layout, the connection between design, production planning, and purchasing, and the co-ordination and co-operation with the large number of involved subcontractors.

Case study 4: ERP pre-implementation. As a consequence of the findings in case studies 1 to 3, the question “What are the opportunities and obstacles for the manufacturer to shift the attention from material only to an ERP approach?” was formulated. A two-part development project was initiated and performed to answer this question. The first part involved formulating the company’s needs and identification of possible changes to meet the requirements. The second part considered the change implementation, an analysis considering the possibility of implementing an ERP system, and development of ERP implementation strategy. Results from the first part showed that the company’s needs were in the short-range primarily related to logistics and materials management issues in the factory, while in the long-range related to the construction site logistics and the integration of factory and construction site. Typical examples of improvement areas were inventory management, production planning/controlling and follow-up, management of customer choices, purchasing processes, and project economy. These findings suggested that there is good potential to implement a software support like ERP to handle, improve, and re-engineer the situation. Hence, the pre-implementation was continued. The findings also suggested that, primar-
ily, it is preferred to improve the current business processes as a first step towards a re-engineered enterprise.

The findings from the first part of the development project initiated changes of the current business processes, e.g. inventory and materials management and purchasing. The pre-implementation continued with identification of suitable ERP systems/vendors and a formulation of detailed performance requirements that were sent to 12 ERP vendors. After an evaluation of systems, vendors, and price, three systems were selected for deep-analysis. When pre-implementation ended with the aid from an independent consultant, it was concluded that an ERP implementation could provide substantial benefits, and one system was selected based on system and vendor performance. The selected system was chosen primarily due to a proper match between performance requirements and system performance, including strong manufacturing and resource planning performance, a proper balance of system maturity and development potential, and a positive customer feedback, partly in industrialised housing. The implementation strategy was designed for a stepwise and flexible ERP implementation. For the short-range needs, three main implementation phases were identified early on. However, each phase could easily be divided, if necessary, to further reduce the speed of change and to be able to properly perform the day-to-day work. At this stage, the long-range needs were not considered as necessary to specify in detail, although it was necessary to clarify that they were possible to accomplish.

It can be noted that after the pre-implementation, the ERP implementation was initiated. Prior to the ERP implementation a number of changes, as are shown in the discussion, taken by the company due to the case study findings were made.

6 Discussion

The external driving force in all case studies has been customisation. The internal driving forces have been the case study findings, which continuously have increased the awareness of the need for improved and efficient internal processes like materials management. The total and combined findings in case studies 1 to 3 resulted in case study 4, where a broad approach was used to thoroughly investigate appropriate changes to attain efficient internal processes, to successfully manage the customisation. The change process, caused by the external and internal driving forces, was initiated during case study 1 and was still ongoing after the completion of case study 4, see Figure 1. Some of the findings from case studies 1 to 4, i.e. the case company’s needs for efficient business processes and an improved ability of managing customer choices, are summarised in Table 4. A comparison between Table 4 and Table 2 (ERP benefits) clearly shows that the needs of an industrialised housing company and ERP can match. Table 4 also shows that current needs are focused on operational and managerial issues. The case study findings indicate that there also are needs of a strategic character, i.e. co-operation with subcontractors.
Table 4. Case company needs, labelled according to Table 2.

<table>
<thead>
<tr>
<th>1) Operational</th>
<th>2) Managerial</th>
<th>3) Strategic</th>
<th>4) Organisational</th>
<th>5) IT infrastructure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Improve internal logistics, material flow, and operations</td>
<td>Improve production planning, preparation, controlling, and follow-up</td>
<td>Co-operation with subcontractors</td>
<td>Need of change</td>
<td></td>
</tr>
<tr>
<td>Improve materials and inventory management</td>
<td>Improve internal co-ordination, cooperation, and communication</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Improve customer choice flexibility</td>
<td>Improve external co-ordination and communication</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Changes made by the case company to meet the needs were carried out in two steps. The first step included evaluation of the current production system and business processes, identification of necessary changes, and change implementation. These changes have been implemented across the enterprise and concern the production system, business processes, and organisation. Changes regarding inventory and materials management, production processes, factory layout (re-designed and expanded), and organisation as well as internal (purchase – inventory – production) and external (subcontractors) co-ordination were made. These changes have resulted in a re-engineered production system with new working methods and equipment. This change process was a result of the case study findings and the forthcoming ERP implementation, facilitated by re-engineered business processes.

The second step considers the implementation of an ERP system. Changes prior to the ERP system implementation were made to both improve the company, aiming for an ERP approach, and facilitate the forthcoming ERP system implementation. The needs in Table 4 could partly be fulfilled by the first changes of the production philosophy; however, an implementation of an ERP system could clearly be beneficial in advancing further. The implementation of an ERP system, without the first changes, would most likely not have increased efficiency since the change would have been too big for a medium-sized construction company. To attain a balance between the increasing complexity due to customisation and internal efficiency, implementing a large-scale change must not disturb the day-to-day work. Instead, stepwise implementation and consolidation is recommended.

The case study findings show that full integration of ERP and SCM is a long process. However, to improve the overall performance it could be a long-range objective in industrialised housing. The case study findings also show that there are some important goals to achieve first, i.e. functional internal processes, proper organisation, and the need of external as well as internal driving forces to carry
through the necessary change process. Based on the results and discussion, a possible strategy for improvements to the construction process for an industrialised housing SME can thus be articulated in four steps: 1) Improvement of internal supply chain/logistics including ERP system preparation, 2) implementation and use of ERP system, 3) improve entire supply chain, including customer, supplier, and subcontractor relations, and 4) integrate ERP and SCM.

7 Conclusions

The use of ERP systems in the manufacturing industry is widespread [17-19]. The benefits that can be gained from ERP use are illustrated [6,15,18], along with ERP disadvantages [26,28]. It is also shown that the implementation phase can be a major obstacle [26,28], but that it can also produce re-engineered and improved enterprises [13,17,24]. After implementation, proper use of ERP systems can further increase the competitiveness of an organisation [6,20,23]. In industrialised timber frame housing in Sweden, ERP use is not widespread [32]. The reasons vary, but generally IT systems are not considered compatible with the needs of the industry [32]. This paper, however, shows that ERP and the needs of an industrialised housing company can match and identifies the prerequisites for this match. First, there must be external and internal driving forces for the necessary change process to start. In this case, the main theme has been balancing customisation and an efficient production system. Second, the change process must aim for a production system and business processes that are functional in two aspects: meeting the external and internal needs and facilitating ERP system implementation. Third, within an organisation, there must be an awareness that the ERP system can contribute in meeting external and internal needs; simply implementing a software system will most likely not increase efficiency. Fourth, the day-to-day work must not be hindered during an ERP implementation and ERP use. For an SME this can be facilitated through careful pre-implementation that allows a stepwise and flexible implementation, i.e. that the ERP implementation is secondary to day-to-day work as well as the initial change process implementation.

The industrial trend is to integrate supply chain capabilities and ERP systems, where the drivers for the on-going development of IT systems are cross enterprise integration and supply chain efficiency [5]. For industrialised housing there is still a long way to go, but the full utilisation of ERP benefits and the possibility to achieve supply chain efficiency can be a long-range goal to successfully integrate customers, manufacturing, and suppliers. Productivity gains in the manufacturing industry can partly be due to technological innovations, but significant contributions come from the organisation and management of production [4]. For industrialised housing to attain its goal, the business processes must be properly re-engineered and the production processes must be functional, i.e. apply an appropriate production philosophy before the implementation of an ERP system and find the balance between project and process orientation.
In Figure 2, some salient features regarding industrialised housing are indicated. The pattern that derives from the external driving force (customisation), and the internal driving forces (the need of efficient internal processes, visualised by main product and production method) can explain the need for industrialisation plus the need for IT based support. The case company has continuously moved towards the edge in the spider diagram. To handle customisation and a complex product, the case company shifted to volume element production, which has great potential advantages regarding efficiency, quality, work environment, etc. However, as shown in the case studies, a high degree of customer choices increases the complexity due to increased information and material flow. Simply shifting from stick building on the construction site to stick building in a factory can provide certain benefits, but to utilise the full industrial potential the business process must be industrialised, initially enterprise wide, in the entire supply chain. Hence, an advanced customisation approach, a complex product, along with a production method lead to needing appropriate and efficient business processes (real industrialised processes) and IT based support (ERP system). It should be noted that there is no contradiction in being efficient and producing, for example, one-family houses, but the drivers for industrialisation, starting with customisation, are stronger when producing complex products using complex production methods.

More research is needed to increase ERP knowledge in industrialised housing. ERP implementation follow-ups, within industrialised housing, would provide useful insights regarding the utilisation of ERP benefits. More empirical findings and theory building regarding SME and ERP in the manufacturing industry are needed for a deepened analysis. More research about customisation and production efficiency in industrialised housing, covering broad aspects in the entire supply chain, is a major task that can contribute to more generalised construction process improvements in the whole housing industry.

8 Acknowledgements

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Paper III

Benefits and disadvantages of ERP in industrialised timber frame housing in Sweden

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This paper has been edited to fit the format of the thesis, but the content remains the same.
Abstract

Industrialised timber frame housing is successful in the Swedish market for one-family housing. In the manufacturing industry, methods and software systems such as enterprise resource planning (ERP) are widespread demonstrating significant benefits. This paper presents a survey of the vast majority of industrialised timber frame housing companies in Sweden, demonstrating low ERP use with a low degree of strategic importance while operational and managerial benefits can be found. The results also show the ERP approach as having potential for industrialised housing while its use is favoured by an increased maturity in IT.

Keywords: Enterprise resource planning, industrialised housing, small and medium-sized enterprises

1 Introduction

Logistics and supply chain management (SCM) are demonstrated as disciplines with the potential to increase efficiency in the housing construction process (Naim and Barlow, 2003; Roy et al., 2003). Methodologies provided by SCM, e.g. for control, can resolve many construction supply chain problems (Vrijhoef and Koskela, 2000). In the manufacturing industry, the supply chain concept has been one model for improvements in efficiency. Supported by IT-based software systems, holistic production philosophies such as lean production and comprehensive planning methods such as enterprise resource planning (ERP) are used to manage parts of or the entire supply chain (Crowley, 1998; Tarn et al., 2002). The implementation of an ERP system is shown to promote operational, managerial, and strategic benefits (Kennerley and Neely, 2001; Al-Mashari et al., 2003). The aim of this paper is to examine ERP benefits and disadvantages as applied to industrialised housing. Based on a survey conducted among the vast majority of industrialised timber frame housing companies in Sweden prerequisites and potential of ERP use and industrialisation in housing construction are analysed.

2 Manufacturing industry

The manufacturing industry has achieved productivity gains throughout the entire supply chain via the SCM concept and the use of production philosophies like lean and agile production (London and Kenley, 2001). The agile concept focuses more on customisation and effectiveness than the lean concept, which focuses on the technical efficiency of processes (Naim and Barlow, 2003). Technical innovations and their applications have contributed to productivity gains, but the significant contributions are linked to organisation and management of production where comprehensive resource planning methods have a major role (Crowley, 1998).
2.1 Enterprise resource planning

Three elements defining ERP are identified in Akkermans et al. (2003), viz. a technical, a functional, or a business perspective. From the technical and functional perspectives, material requirements planning (MRP), manufacturing resource planning (MRP II), and ERP represent the development of methods and software tools for the planning and controlling of resources for manufacturing companies. MRP systems could initially be used for calculating material requirements and handling orders, but were expanded to handle capacity planning and scheduling (Umble et al., 2003). In the 1980s, MRP II systems incorporating business-managing functions were developed and evolved in the 1990s to include all resource planning for the entire enterprise, i.e. ERP systems (Umble et al., 2003). In the business perspective, ERP can be viewed as a business approach integrating strategic and operational functions through the entire organisation (Akkermans et al., 2003).

The use of ERP systems is shown to provide benefits like core business strategy support and increased profitability (Al-Mashari et al., 2003), along with improved information availability/quality and improved business operations and integration (Olhager and Selldin, 2003). Short-range benefits are often associated to operational and managerial areas while strategic and financial impacts are related to long-term use (Kennerley and Neely, 2001). ERP implementation is shown to be a major obstacle; however, both success and hindering factors are identified (Umble et al., 2003). Identified benefits from ERP use come not only from using methods and software systems, ERP is a driver of comprehensive change, business process improvements, and process orientation (Akkermans et al., 2003).

2.2 Construction industry and enterprise resource planning

By case studying a large construction company Voordijk et al. (2003) suggest that ERP can play a strategic role within the construction industry if primary processes are inter-organisationally standardised, business and IT strategies are matched, and the ability to use ERP for information management is high. Based on case study research in a medium-sized industrialised housing company, it is shown that industrialised housing needs and ERP can match (Bergström and Stehn, 2004). Important prerequisites are:

- A change process initiated by external and internal driving forces aimed at re-engineered business processes that functionally meet the needs and facilitate ERP system implementation.
- It must be evident that the ERP approach can contribute in meeting both external and internal needs; simply implementing a software system will most likely not increase efficiency.
However, according to Shi and Halpin (2003), ERP systems can hardly meet the needs of the construction industry since they are primarily developed for the manufacturing industry and do not address the nature and business culture of construction.

3 Industrialised housing

Industrialised housing, i.e. housing construction conducted in a factory (prefabrication) utilising industrial processes and machinery, in Japan has successfully adopted and adapted the lean production concept by balancing customisation and standardisation while developing efficient production processes (Gann, 1996). The combination of standardisation, prefabrication, and customisation can promote improvements in the construction process (Gibb, 2001). The importance of materials management in industrialised housing is shown by Stehn and Bergström (2002). A re-engineered construction process through new technology (e.g. prefabrication) combined with changes in products and processes are needed to achieve efficient mass customisation in housing (Roy et al., 2003). Industrialised housing both resembles and differs from the manufacturing industry, implying limitations in the potential transfer of concepts from manufacturing to housing (Gann, 1996). However, real lessons can be drawn from the manufacturing industry (Gibb, 2001), e.g.:

- It is possible to replace mass production with mass customisation through improved technology
- The customer’s needs, e.g. offer of choice, must be identified and addressed
- The supply chain must be acknowledged and managed
- Prefabrication is useful, if subservient to the delivery of the end product

3.1 Industrialised timber frame housing in Sweden

Most one-family detached houses in Sweden are prefabricated by industrialised timber frame housing companies (approximately 74% from 1990 to 2002). Build-operate/own-transfer forms of contract including responsibilities to fulfil performance requirements are predominating. The companies own and perform design and production processes (factory and on-site) and possesses factory buildings including industrial machinery. Annual export value of Swedish industrialised timber frame housing is approximately €140 M (from 1999 to 2002), while total annual production value is approximately €720 M. Major export markets are Denmark, Finland, Norway, Japan, and Germany. The production of multi-storey timber frame houses is small compared to the total production of timber houses and multi-storey houses in Sweden.

3.2 Implications for housing

The literature review shows that SCM along with industrialisation can develop the housing construction process and that information management (e.g. plan-
ning methods) and IT systems (e.g. ERP systems) have key-roles for management and control of manufacturing companies’ supply chains. Successful organisations have balanced information need and information management capacity (Galbraith, 1972). The literature review also shows that manufacturing industry concepts require adaptation to match the construction industry’s needs. The ongoing customer orientation means that construction companies must be both flexible (agile) and efficient (lean) to balance production process variations and cost efficiency. Consequently, industrialisation, process-orientation, a customer-focused production approach, and information management are of interest for the housing industry. Hence, industrialised timber frame housing in Sweden is an interesting research platform for increased knowledge regarding industrialisation of housing and information management and its IT support.

4 Method

The population of interest is all small and medium-sized enterprises (SMEs), micro excluded, and large enterprises (according to the European Communities definition of company sizes, Table 1) prefabricating timber frame houses in Sweden. A questionnaire with fixed (company characteristics) and open-ended (e.g. ERP impacts) questions was sent during September 2002 to production managers. Quantitative data applies to customisation, main product, production method, company size, ERP approach, and financial performance (indicated by return on assets (ROA)). Financial performance indicates competitive companies’ efficiency and can be shown in several ways using several variables not included in ROA. Here ROA indicates financial performance on an overall level, for subgroups of the total population of companies within the same industry. Qualitative data applies to experiences and attitudes regarding ERP.

5 Results

The questionnaire was sent to 74 companies representing the vast majority of the industry. Of 62 responses, 13 came from companies outside the population of interest. From the time the questionnaire was sent out to when the responses were collected, one company went out of business. Hence, the “usable” response rate is 80% (48/60).

5.1 Quantitative results

In Table 1, the companies are categorised into five dimensions: A) customisation approach, B) main product, C) production method, D) company size, and E) ERP approach. Each dimension comprises of two to four levels. The customisation approach relates to the house (or flat) design. The customer can design the house within certain limits (A1) or (almost) without limitations (A2). Building systems for detached houses (B2) and multi-storey houses (B4) are often similar; however, performance requirements and durability are technically and economically more difficult to achieve for the more complex multi-storey houses. There are two main types of production methods: production of building elements
(C1a, C1b), e.g. floors and walls, and production of volume elements (C2a, C2b), i.e. three-dimensional structures composed of building elements hence, much more complex than building elements. Building elements can be completed with technical installations (plumbing and electrical work etc.) at the construction site (C1a) or in the factory (C1b). Volume elements can also be completed (technical installations, surfaces, fixed equipment, etc.) at the construction site (C2a) or in the factory (C2b). When the elements are completed in the factory rather than at the construction site, more of the flow processes – material and information – are performed in the factory. Hence, the highest degree of complexity in the factory is achieved when producing customised multi-storey houses using volume element (completed in the factory) production. The company size categories are small (D1), medium (D2), and large (D3). The ERP approach comprise four categories (E1-E4), where MRP II use is included in ERP use. “N” represents the number of companies at each level.

**Table 1. Categorisation of the 48 examined companies.**

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Level</th>
<th>Description</th>
<th>(%)</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Customisation</td>
<td>A</td>
<td>1 Customised standard products</td>
<td>31</td>
<td>15</td>
</tr>
<tr>
<td>approach</td>
<td>2</td>
<td>Customised products</td>
<td>69</td>
<td>33</td>
</tr>
<tr>
<td>Main product</td>
<td>B</td>
<td>1 Garages, cottages, and sheds</td>
<td>17</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>One-family detached houses</td>
<td>67</td>
<td>32</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Multi-family dwellings, schools, hotels, and offices ≤2 storeys</td>
<td>12</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>Multi-family dwellings, schools, hotels, and offices &gt;2 storeys</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Production method</td>
<td>C</td>
<td>1a Building element manufacturer type 1a</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>1b</td>
<td>Building element manufacturer type 1b</td>
<td>63</td>
<td>31</td>
</tr>
<tr>
<td></td>
<td>2a</td>
<td>Volume element manufacturer type 2a</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>2b</td>
<td>Volume element manufacturer type 2b</td>
<td>31</td>
<td>15</td>
</tr>
<tr>
<td>Company size</td>
<td>D</td>
<td>1 Small, annual turnover &lt; € 10 M</td>
<td>58</td>
<td>28</td>
</tr>
<tr>
<td>ERP approach</td>
<td>E</td>
<td>1 Uses no system, will not implement</td>
<td>50</td>
<td>24</td>
</tr>
<tr>
<td>ERP approach</td>
<td></td>
<td>2 Uses no system, will implement</td>
<td>19</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3 MRP system user</td>
<td>19</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4 ERP system user</td>
<td>12</td>
<td>6</td>
</tr>
</tbody>
</table>
Each row in Table 2 shows the percentage distribution of every level (e.g. A1) in each dimension (customisation approach, main product etc.). In Table 2 and the following, C1 includes C1a and C1b, while C2 includes C2a and C2b.

Table 2. Industry structure, labels according to Table 1.

<table>
<thead>
<tr>
<th>Customisation approach (%)</th>
<th>Main product (%)</th>
<th>Production method (%)</th>
<th>Company size (%)</th>
<th>ERP approach (%)</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>13 73 13 0</td>
<td>73 27</td>
<td>53 40 7</td>
<td>33 20 27 20</td>
<td>15</td>
</tr>
<tr>
<td>A2</td>
<td>18 64 12 6</td>
<td>64 36</td>
<td>61 36 3</td>
<td>58 18 15 9</td>
<td>33</td>
</tr>
<tr>
<td>B1</td>
<td>11 75</td>
<td>75 25</td>
<td>100 0 0</td>
<td>50 13 12 25</td>
<td>8</td>
</tr>
<tr>
<td>B2</td>
<td>34 66</td>
<td>72 28</td>
<td>50 44 6</td>
<td>53 19 16 12</td>
<td>32</td>
</tr>
<tr>
<td>B3</td>
<td>33 67</td>
<td>50 50</td>
<td>67 33 0</td>
<td>33 17 50 0</td>
<td>6</td>
</tr>
<tr>
<td>B4</td>
<td>0 100</td>
<td>0 100</td>
<td>0 100 0</td>
<td>50 50 0 0</td>
<td>2</td>
</tr>
<tr>
<td>C1</td>
<td>34 66</td>
<td>19 72 9 0</td>
<td>66 31 3</td>
<td>44 22 15 19</td>
<td>32</td>
</tr>
<tr>
<td>C2</td>
<td>25 75</td>
<td>12 56 19 13</td>
<td>44 50 6</td>
<td>63 12 25 0</td>
<td>16</td>
</tr>
<tr>
<td>D1</td>
<td>29 71</td>
<td>29 57 14 0</td>
<td>75 25</td>
<td>53 11 25 11</td>
<td>28</td>
</tr>
<tr>
<td>D2</td>
<td>33 67</td>
<td>0 78 11 11</td>
<td>56 44</td>
<td>50 33 6 11</td>
<td>18</td>
</tr>
<tr>
<td>D3</td>
<td>50 50</td>
<td>0 10 0 0</td>
<td>50 50</td>
<td>0 0 50 50</td>
<td>2</td>
</tr>
<tr>
<td>E1</td>
<td>21 79</td>
<td>17 71 8 4</td>
<td>58 42</td>
<td>63 37 0</td>
<td>24</td>
</tr>
<tr>
<td>E2</td>
<td>33 67</td>
<td>11 67 11 11</td>
<td>78 22</td>
<td>33 67 0</td>
<td>9</td>
</tr>
<tr>
<td>E3</td>
<td>44 56</td>
<td>11 56 33 0</td>
<td>56 44</td>
<td>78 11 11</td>
<td>9</td>
</tr>
<tr>
<td>E4</td>
<td>50 50</td>
<td>33 67 0 0</td>
<td>100 0</td>
<td>50 33 17</td>
<td>6</td>
</tr>
</tbody>
</table>
In Figure 1, the subgroups classified according to Table 1 are compared as per ROA to the total population shown as median and upper and lower quartile (thin black lines).

![Graph showing ROA trends for different subgroups and industries](image)

Figure 1. ROA, 1999-2002, for subgroups and industry: a) production method, b) company size, and c) ERP approach.

### 5.2 Qualitative results

In this section, the term ERP includes MRP and MRP II. Answers to the open-ended questions are summarised in Table 3. Categories I-III apply to ERP system users, categories IV-VI to non-ERP users, i.e. I: Main reasons for implementing ERP systems, II: Experienced main benefits, III: Experienced main disadvantages, IV: Main implementation obstacles, V: Presumed main potential benefits, and VI: Presumed main potential disadvantages. The answers are labelled in seven labels. Labels 1-3 refer to different organisational levels, label 4 to the overall organisation, and label 5 to IT infrastructure. Labels 6 and 7 refer to answers not matching labels 1-5.
Table 3. ERP experiences and attitudes, labels adapted from Al-Mashari et al. (2003).

<table>
<thead>
<tr>
<th></th>
<th>1) Operational (%)</th>
<th>2) Managerial (%)</th>
<th>3) Strategic (%)</th>
<th>4) Organizational (%)</th>
<th>5) IT infrastructure (%)</th>
<th>6) No experienced disadvantage (%)</th>
<th>7) No answer (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>33</td>
<td>67</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>II</td>
<td>27</td>
<td>73</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>III</td>
<td>0</td>
<td>20</td>
<td>0</td>
<td>7</td>
<td>53</td>
<td>20</td>
<td>0</td>
</tr>
<tr>
<td>IV</td>
<td>61</td>
<td>21</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>18</td>
<td>18</td>
</tr>
<tr>
<td>V</td>
<td>30</td>
<td>24</td>
<td>0</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>43</td>
</tr>
<tr>
<td>VI</td>
<td>36</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>9</td>
<td>0</td>
<td>46</td>
</tr>
</tbody>
</table>

Companies using ERP systems generally state that the potential of improved materials management was the driving force behind the implementation. Other driving forces are the potential for improved purchasing processes and the possibility of a better business process overview. These companies also state that better information flow, planning, control, and insight, and improved materials management are the greatest benefits, while system maintenance and update are the greatest disadvantages. Notably, no ERP users mention customisation as the most negative impact or company size as an obstacle to implementation. In general, companies without any systems stress the difficulties, costs, time, and the small company size as implementation obstacles. Companies without a system also point out that business processes are properly managed without a system and that customisation yields a production process too complicated for a system to handle.

6 Discussion

The results imply that a high level in one dimension of main product, production method, and company size is related to a high level in the other dimensions. The ERP approach dimension is not related in a similar way. This is illustrated in Figures 2a-c, which are based on Table 2, showing comparisons between average companies in subgroups. Figure 2 illustrates the industry structure in 2002, but ROA for 1999 to 2002 are calculated as mean values to get a more robust value. During this period, the companies mainly belonged to the same level within each dimension. The ERP approach is the dimension with the highest degree of shifts between different levels, indicated by e.g. stated number of years of ERP use.

Figure 2a illustrates that volume element producing companies manufacture a higher degree of complex products (circle 1), comprise a higher degree of larger/medium-sized companies (circle 2), and have a lower total degree of MRP and ERP use than building element producing companies. Figure 2b exemplifies that medium-sized companies manufacture complex products (circle 3) and use volume element production (circle 4) to a higher degree than smaller companies, while their ERP approaches are similar. Figure 2c exemplifies that ERP users do not manufacture complex products (circle 5) or use volume element production (circle 6) to a high degree, while MRP users do the opposite and manufacture
complex products and use volume element production to a relatively high degree.

Figure 2. Comparisons regarding: a) production method, b) company size, and c) ERP approach. Number of companies is shown in the parentheses.

A high complexity (level 2-4) regarding customisation approach, main product, and production method, shows low ERP use, Table 2. Regarding customisation, the lowest degree of ERP use and the highest degree of none-users is found at the highest degree of customisation, Table 2. Only companies manufacturing less complex products using building element production use ERP systems, Table 2. What are the reasons for these relations? The maturity in dimensions A-D, Table 1, and information management approaches have parts of the answer. Companies that for a longer time period not have changed characteristics have refined and improved their customisation approach, product, and production method to a degree where further improvements are hard to achieve. These companies might have realised that a business process improvement, like applying an ERP approach, is the next step in the organisation-wide development process. Companies manufacturing more complex products using volume element production have generally not reached this point yet. For an SME, major changes regarding product mixes or production methods or both require time and financial endurance for implementation and adaptation until further major changes like adopting an ERP approach can be initiated. To change information processing capability an organisation can either reduce the information needed or increase information process capacity (Galbraith, 1972). Here, only companies with less complex business processes tend to increase information process capacity, i.e. implement ERP systems. Companies with complex business processes tend to reduce the infor-
mation needed, i.e. keep the manual business processes. Hence, the current need of change is different for companies with different overall characteristics and different histories within each dimension. However, one long-range potential for developments realised and utilised regardless of the company characteristic profile, is the ERP approach dimension as illustrated in Figures 2a-b.

Differences in financial performance, Figures 1 and 2, are generally small. However, differences exist between building and volume element manufacturers, Figures 1a and 2a, and between different ERP approaches, Figures 1c and 2c. These differences are mainly due to one very successful company with high ROA values compared to the whole industry. This company is large and manufactures customised standard one-family houses using MRP supported volume element production and has clearly utilised the potential of industrialisation to a high degree, without totally adopting an ERP approach. The other companies are rather homogenous regarding financial performance, perhaps indicating that the ERP approach dimension is not considered crucial since, until now, ERP success stories do not exist as in the manufacturing industry. This is also supported by the findings summarised in Table 3: impacts and attitudes, regarding ERP use, are mainly related to operational and managerial issues, not strategic.

The survey results show that realising and utilising ERP benefits in industrialised timber frame housing is a long process. However, this process has been initiated in some of the examined companies and several operational and managerial benefits can be found. The majority of the companies focus on areas other than ERP and are so far satisfied with their current business processes. Industrialised housing is often considered as equivalent to prefabrication of the frame. When broadening the term, standardisation of products and processes is mentioned, indicating the importance of how the prefabrication is conducted. Adopting an ERP approach is not a necessary element in industrialised housing. However, to utilise the potential benefits from industrialisation, efficient and flexible business processes are needed, i.e. prefabrication and standardisation is not enough. Applying an ERP approach, e.g. via MRP system use, is one way to achieve a more efficient and flexible industrialised housing.

7 Conclusions

The results of this study show that some industrialised timber frame housing companies in Sweden do use MRP and ERP systems, but the majority do not. The differences between companies regarding customisation approaches, main products, and production methods have indicated, until now, a high degree of complexity in the production process not favouring IT supported business processes. Instead it is companies with less complex business processes that tend to implement ERP systems. Hence, companies utilising different degrees of process complexity adapts the information processing capability differently: by reducing the information needed or increasing the information process capacity (Galbraith,
This study confirms the existence of prerequisites for a successful match between ERP and industrialised housing needs, as identified in Bergström and Stehn (2004), although difficulties in matching ERP and construction industry needs also exist, as identified in Shi and Halpin (2003). The survey results show a general lack of real drivers for ERP implementation and low awareness of the potential benefits and strategic importance, indicating that ERP is not yet regarded as a way of supporting and improving core business strategies. Since strategic ERP use requires high maturity in IT (Voordijk et al., 2003) the results indicate that IT maturity must increase to utilise the full potential of ERP while possible ERP system implementations must allow a gradual increase of IT maturity.

ERP is a driver of comprehensive change and business process improvements (Akkermans et al., 2003). This is verified and shown in industrialised housing where preparing for a forthcoming ERP implementation was shown to promote important changes in the production system and production processes (Bergström and Stehn, 2004). Hence, it is not the implementation of a software system that will yield the major benefits. Rather, it is the change processes aiming for organisation-wide improvements and the ERP approach adoption that will contribute to increased competitiveness. Whether an agile or lean approach is preferred, adequate resource planning methods have a major supporting role. The similarities between the manufacturing industry and industrialised housing (Gann, 1996), the identified prerequisites for matching industrialised housing needs and ERP (Bergström and Stehn, 2004), and the survey results all indicate that the ERP approach can provide benefits in industrialised housing if matching industry needs and ERP abilities are more generally identified and realised.

8 Acknowledgements

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9 References


Paper IV

Customised industrialised timber frame house manufacturing: prospects and pitfalls

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This paper has been edited to fit the format of the thesis, but the content remains the same.
**Abstract**

Industrialised timber frame housing has increased in popularity on the market over the last years probably largely due to increased customer focus. However, blind customer focus leads to poor utilisation of resources. By combining customer orientation with prefabrication using standardisation of products and processes, an effective construction process seems possible to achieve. Based on case study research of front-runners in industrialised timber frame housing, three principal problem areas were identified. These are 1) inadequate communication between actors in the construction process, 2) to strike an appropriate balance between customer focus and internal efficiency, and 3) capacity limitations. To improve the construction process there need to be an increased integration between the actors. Better IT support is one way to facilitate integration, communication, and customisation, while improving internal efficiency, e.g. by balancing project and process orientation. However, IT only is not the panacea; re-engineered business processes along with components and working methods adapted to the industrialised production are also needed for an improved construction process.

*Keywords*: Industrialised housing, construction process, customisation, prefabrication, timber frame houses

**1 Introduction**

Industrialised timber frame housing (house manufacturing utilising prefabrication along with industrial processes and machinery) is successful in the Swedish market for one-family housing. Prefabrication along with standardisation of products and processes are shown to contribute in construction process improvements (Gibb, 2001; Roy et al., 2003). With the introduction of the 1994 building code, the already initiated direction towards market orientation was reinforced in Swedish housing construction. Internationally, similar trends of increased importance of customer orientation in housing are reported in Barlow (1999) and Ozaki (2003). In the manufacturing industry, production philosophies like lean and agile production are used to render the production of customised products more efficient and flexible (Brown and Bessant, 2003). Combining lean and agile principles has the potential to also improve the construction supply chain for customised housing (Naim and Barlow, 2003). Construction companies, regardless of size, can achieve strategic benefits from information technology (IT) support although managerial and operational benefits are to date often realised more generally (Love et al., 2004). Swedish industrialised timber frame housing companies, manufacturing complex products, such as multi-family dwellings, utilising a high degree of prefabrication have potential for developments regarding business processes and IT support (Bergström and Stehn, 2004). The aim of this pa-
per is to examine current prospects and pitfalls, and their impacts, among front-runners in industrialised timber frame housing in Sweden.

2 Manufacturing and customisation

The eras of manufacturing have changed from craft and mass production to lean production, mass customisation, and agile production (Brown and Bessant, 2003). The manufacturing concepts superseding craft production have all aimed for improved performance regarding responsiveness to changing market conditions. The concepts have commonalities (e.g. continuous improvements and integration of design and production) as well as differences (e.g. customisation approaches) and are appropriate for different business environments (Sahin, 2000). The primary goals of lean production are increased product quality and reduced costs, achieved through process improvements and waste elimination while manufacturing large varieties of high volume products rather than individually designed products in any quantity as in the agile concept (Yusuf and Adeleye, 2002). The agile concept extends the lean concept to also include the key features responsiveness to unplanned changes, flexibility, and availability (Brown and Bessant, 2003). Mass customisation can be regarded as the link between leanness and agility, underlining the importance of efficient processes and flexibility to respond to planned changes (Sahin, 2000). The mass customisation and agile concepts use IT support to a higher degree than the lean concept, since it enables customisation as well as acts as a driver for organisational change towards agility (Sahin, 2000).

3 Information management and information systems

Managing information is a key activity for competitive organisations and it has long been known that in order to be successful organisations have to balance information need and information processing capacity (Galbraith, 1972). The importance of IT and information systems (IS) to support formal planning and controlling of business processes is increasing. For manufacturing companies, IS, such as manufacturing resource planning (MRP II) and enterprise resource planning (ERP), are often the natural choice for improving process performance and organisational competitiveness (Irani, 2002). ERP, extended from material requirements planning (MRP) and MRP II, integrates strategic and operational functions for manufacturing companies and can act as a driver of comprehensive change and process orientation (Akkermans et al., 2003).

4 Industrialised housing

Industrialised housing has in Japan successfully adopted and adapted the lean production concept through balancing customisation and standardisation while developing efficient production processes (Gann, 1996). Standardisation of processes and products can improve the construction process while prefabrication is shown to improve safety, productivity, and quality; efficient customisation can be achieved by combining standardisation and prefabrication (Gibb, 2001; Stehn and Bergström 2002). A re-engineered construction process through new technology
(e.g. prefabrication) combined with changes in products and external and internal processes, along with closer integration between market, design, and production and improved information processing is needed to achieve efficient mass customisation in housing (Barlow, 1999; Roy et al., 2003). Industrialised housing both resembles and differs from the manufacturing industry, implicating both possibilities and limitations in the potential transfer of concepts from manufacturing to housing (Gann, 1996). Hence, real lessons can be drawn from the manufacturing industry (Gibb, 2001), e.g.:

- The need for customisation must be recognised; replacing mass production with mass customisation is possible through improved technology
- Prefabrication is useful, if subservient to the delivery of the end product

4.1 Industrialised timber frame housing in Sweden

Most one-family detached houses in Sweden have timber frames and are prefabricated by industrialised housing companies (approximately 74% from 1990 to 2002). Production of multi-storey timber frame houses is small compared to the total production of timber houses and multi-storey houses in Sweden. Of predominance are the build-operate/own-transfer forms of contract including the responsibilities to fulfil performance requirements. The companies own and perform design and production processes (factory and on-site) as well as possess factory buildings including industrial machinery.

A survey of the vast majority of industrialised timber frame housing companies (micro enterprises excluded) in Sweden, (Bergström and Stehn, 2004), is summarised in Table 1. The companies are categorised into five dimensions, A–E, which each comprise two to four levels where each level indicates increased complexity. For example, performance requirements and durability are technically and economically more difficult to achieve for multi-storey houses (B4) than for detached houses (B2). There are two main types of production methods: production of building elements (C1), e.g. floors and walls, and production of volume elements (C2). A volume element is a three-dimensional structure composed of building elements, and is thus much more complex than a building element. Building and volume elements can be completed at the construction site or in the factory. When the elements are completed in the factory rather than at the construction site, more of the flow processes – material and information – are performed in the factory. The industry is clearly dominated by SMEs, according to the European Communities definition of company sizes, as shown in Table 1. “N” represents the number of companies at each level. Table 1 also shows case company characteristics (columns labelled 1–4), which are further described in section “Method”.

3
Table 1. Industrialised timber frame housing in Sweden, (Bergström and Stehn, 2004), and case company characteristics.

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Level</th>
<th>Description</th>
<th>(%)</th>
<th>N 1 2 3 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>A Customisation approach</td>
<td>1</td>
<td>Customised standard products</td>
<td>31</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Customised products</td>
<td>69</td>
<td>x x x x</td>
</tr>
<tr>
<td>B Main product</td>
<td>1</td>
<td>Garages, cottages, and sheds</td>
<td>17</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>One-family detached houses</td>
<td>67</td>
<td>32</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Multi-family dwellings, schools, hotels, etc. ≤2 storeys</td>
<td>12</td>
<td>6 x x</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>Multi-family dwellings, schools, hotels, etc. &gt;2 storeys</td>
<td>4</td>
<td>2 x x</td>
</tr>
<tr>
<td>C Production method</td>
<td>1</td>
<td>Building element manufacturer</td>
<td>67</td>
<td>32</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Volume element manufacturer</td>
<td>33</td>
<td>16 x x x x</td>
</tr>
<tr>
<td>D Company size</td>
<td>1</td>
<td>Small (annual turnover ≤ €10 M)</td>
<td>58</td>
<td>28 x</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Medium-sized (annual turnover ≤ €50 M)</td>
<td>38</td>
<td>18 x x</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Large (annual turnover &gt; €50 M)</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>E ERP approach</td>
<td>1</td>
<td>Uses no system, will not implement</td>
<td>50</td>
<td>24 x x</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Uses no system, will implement</td>
<td>19</td>
<td>9 x</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>MRP system user</td>
<td>19</td>
<td>9 x</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>ERP system user</td>
<td>12</td>
<td>6</td>
</tr>
</tbody>
</table>

4.2 Implications and research questions

The Swedish market for one-family housing demonstrates the potential of an industrialised timber frame housing concept. The survey presented in section “Industrialised timber frame housing in Sweden” gained interesting knowledge, however further insights regarding industrialised housing are needed. The ongoing customer orientation, the need for efficient information management, and the potential for an increased industrialisation regarding products and processes are all areas where further insights can be reached. Hence, the aim of this paper is formulated as three research questions addressed to companies manufacturing complex products utilising advanced prefabrication:

Q-1: What are the limitations of current construction processes?
Q-2: How are the companies approaching information management and IS?
Q-3: How are the companies working to avoid limitations and improve the construction process?

5 Method

Given the aim and research questions, a multiple case study of a selection of the surveyed companies seemed as an appropriate way to obtain increased knowledge of industrialised housing. A case study research design is appropriate when the research problem requires understanding of contemporary phenomena through qualitative and quantitative data collection (Meredith, 1998). Multiple–case studies are appropriate in the search for compelling and robust evidence for relatively new phenomena (Yin, 2003). Here, the multiple–case study is used for under-
standing prospects and pitfalls within front-runners among industrialised timber frame housing companies and through cross-case conclusions increase knowledge of industrialised housing.

Based on the aim, each case company should score high on each of the four dimensions A-D (see Table 1), reflecting a highly complex production. This means that every case company should be rather large and have a well-developed production method of complex main products with high level of customisation. This will make the total need of information processing related to the industrialised production large. Companies with both simple and more advanced ERP approaches were selected, enabling to investigate how the level of ERP support influenced the production process. The selection process thus resulted in four companies matching the selection criteria covering three of four levels in the ERP dimension, as shown in Table 1.

Each company was examined during one day in September 2003 through interviews with production management (at different organisational levels) and production staff and direct observations of the companies’ production systems and production processes (in the factories). The interviews covered areas addressed in the research questions.

6 Results and discussion

The first part of this section describes some common features among the case companies. After the first part, the main results (summarised in Table 2) and short descriptions of the companies and their financial and market performance are presented company wise. Financial and market performance are indicated by return on assets (ROA) and turnover development, Figures 1a and b, as supplement to the company descriptions to increase the understanding of the companies’ prospects and pitfalls.

The companies’ construction processes span from conceptual design to delivery of customised turnkey houses. The companies design the structural frame and an increasing share of the technical installations while consultants design layouts and rest of technical installations. Volume elements are assembled by own staff and completed by own staff and subcontractors. The size of the volume elements is limited mainly by transport regulations but also by the factory layout. The companies have aimed for reducing processing of raw materials during building element production, with different degree of development (larger companies more advanced) and different approaches regarding external (i.e. by the suppliers) or internal pre-processing. The building element production utilises industrial machinery to a higher degree than the volume completion process, which is mainly

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1 Company 4 in Table 1 is positioned in the upper quartile of company size category “small” (2001 and 2002) and was thus considered to match the selection criteria.
conducted with similar methods and tools as traditional on-site construction, yet in indoor conditions. The companies have only professional (private and public) customers although the end-customer may be private persons. Customised products and short construction times are prerequisites for market competitiveness; standard products do not address specific customer requirements. Hence, there is a variation between each project but also within a project a lesser or larger variation between each volume element. The companies experience that projects with a great degree of internal variation are more time-consuming than projects comprising similar volume elements. They also experience project learning meaning that the production time decreases as a project proceeds.

![Figure 1](image1.png)

**Figure 1.** a) Financial performance in terms of ROA, 1999-2003, for case companies and industry (median and upper and lower quartile) and b) Market performance in terms of turnover developments, 1999-2003, for case companies and industry.

Turning to the individual cases, Company 1 started as a volume element manufacturer of rather low-complex products. During the last 20 years, the company has manufactured schools, hotels, offices, and dwellings up to two storeys with an increased focus on customisation during the last years. The company uses no ERP system and does not intend to implement either. This is due to that the customisation in each project is unique making management of such a system too time-consuming. Ten years ago, an MRP system implementation was considered but never initiated.

The company initially showed high financial performance, but has steadily dropped over the time period in focus. In 2003 the company operated in the red. Market performance shows a similar trend. The setback in firm performance is due to decreased sale of standardised products and an inability to successfully adapt to a customer oriented approach.

Company 1 notes that their primary construction process limitation has to do with poor communication. This causes difficulties to generate correct and timely product descriptions. Combined with pressure from customers and sales department for short construction times, along with late changes of customer require-
ments, it can cause changes in the design and descriptions (sometimes even during production). The result is disturbances during design or production potentially causing quality problems. The second limitation – that design consultants lack knowledge regarding industrialised construction systems – causes incorrect design of technical installations. According to Company 1, closer co-operation between all designers, including use of 3D-CAD systems, and allowing the design to take longer time aiming for correct first design and shorter overall construction times would be a possible solution.

The first construction process improvement area – implementation of small-scale IT-solutions – is aimed to reap, managerial and operational benefits, like reducing the workload on operational managers and facilitate information availability and quality regarding materials management. Implementation of a more sophisticated (ERP) system is currently not even a long-range goal, since a too large change is required considering the company’s poor IS maturity. Moreover, finding a suitable ERP system supporting, not controlling, the company’s business processes, is a difficult task even with a greater IS maturity. The prospects for the second improvement area – business process re-engineering – is regarded as a prerequisite for increased production efficiency (i.e. increased throughput and decreased production costs), with or without an increased IT support.

Company 2 shifted some 10 years ago from building element production for detached and multi-family houses up to two storeys with a clear production orientation to a more customer-oriented volume element production of multi-storey houses (mainly four storey multi-family dwellings). The company is about to implement an ERP system to improve the construction process to be able to efficiently manage an increased product mix.

The company had initially a poor financial performance that over the time period increased to become adequate. The market performance has been up and down in the five-year-period, however the last two years indicate that the company has found a concept that the customers appreciate. Thus, the company seems to have accomplished the shift from production orientation to customer orientation. The company also has prospects for further increases in both financial and market performance.

The first limitation put forward by company 2 – a too small construction site organisation – constraints overall throughput, since production capacity in the factory is not fully utilised. However, as the third limitation – that capacity in building element production line is close to maximum – suggests, the company faces multiple capacity limitations simultaneously. This means that the company faces heavy investments if they want to be able to increase production more than moderately. If the second limitation – poorly motivated production staff – can be remedied, more capacity can be realised without any heavy investments.
The aim for the major construction process improvement area in Company 2 - to manage customisation – is of course to gain an improved ability to efficiently manage projects with a high degree of internal variation. One aim is to be able to visualise all necessary information (alternative technical solutions and inner and outer design and their effect on the cost) to the customer early in the construction process. The company has developed standardised processes to manage customer choices where the possibility of making choices is synchronised with the design and production phases. Sometimes demands for late changes can be met, how far-reaching and comprehensive depends on the customer’s previous history (i.e. importance) and the consequences regarding costs and construction times.

Company 3 started as a volume element manufacturer of less complex products and shifted some 20 years ago towards a production with an increasingly higher degree of customisation, where products include schools, hotels, offices, and multi-family dwellings up to three storeys. During the last five years the company has exclusively manufactured more complex customised products. The company appreciates an increased and developed IT support in the design phase, but not regarding production related processes.

The company lifted its financial performance from a low level in the beginning of the five-year period to show a rather good financial performance the last three years. As can be evidenced, the beginning of the higher level of financial performance coincides with a steep improvement in market performance three years ago. The last two years have been stable looking at the turnover. The performance record thus indicates that the company has successfully shifted towards an increased customer orientation, but that the company after this shift not has been able to further increase its performance.

The first limitation mentioned by Company 3 – that the company has no good approach to handle differential customer demands – results in a high workload regarding both design and production. The customer is often highly involved in the design process, which may affect both design and production processes due to many late decisions and changes. However, the high degree of customisation is also a major advantage. The ability to provide a high degree of customisation and short construction times means that the company can be competitive. The problem is thus to manage customisation so it can be done without leading to too much increase in costs. The second limitation – that the production facilities are too small – imposes restrictions in how much production (and thus turnover) can increase. The solution to the problem requires an increased factory area, which is a large investment. The company applies a “continuous improvement strategy” and sees currently no specific major improvement area.
Company 4 started as a volume element manufacturer of less complex products. During the last 20 years the company has focused on a production of customised schools, hotels, and offices up to two storeys. The company uses an MRP system to support the construction process regarding purchase, production preparation and planning, inventory, and administration and has experienced managerial and operational advantages. The company has not experienced that the customisation or company size has hindered the implementation but the initial attitude among the personnel did. However, the initial negative attitude may have affected the implementation in a positive direction due to the bottom-up like implementation strategy.

The company had a very good financial performance in the beginning of the last five-year-period that since has dropped to a low level at the end of the period\textsuperscript{2}. The market performance increased in the beginning of the period but the two last years has meant decreases. It thus seems the company, after a good start, is failing both to attract customers and to produce for these in a profitable way.

The first and second limitation in Company 4 – inability to manage customisation efficiently and poor communication between design and production – by themselves and in combination, cause disturbances in the production phase. The third limitation – capacity close to maximum – affects volume completion negatively and limits volume element throughput. An increase requires increased factory space, which is a large investment.

The aim of the major construction process improvement area in Company 4 – to better adapt the design for industrialised volume production – is to facilitate overall factory throughput by finding better design solutions for the industrialised production.

\textsuperscript{2} R.O.A as per 2003 is calculated using a higher profit than reported due to that significant events not directly linked to operational activities had caused additional costs of € 0.45 M during this financial year.
Table 2. Prospects and pitfalls summarised for the case companies.

<table>
<thead>
<tr>
<th>Company 1</th>
<th>Company 2</th>
<th>Company 3</th>
<th>Company 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year</td>
<td>-99</td>
<td>-99</td>
<td>-99</td>
</tr>
<tr>
<td></td>
<td>-00</td>
<td>-00</td>
<td>-00</td>
</tr>
<tr>
<td></td>
<td>-01</td>
<td>-01</td>
<td>-01</td>
</tr>
<tr>
<td></td>
<td>-02</td>
<td>-02</td>
<td>-02</td>
</tr>
<tr>
<td></td>
<td>-03</td>
<td>-03</td>
<td>-03</td>
</tr>
<tr>
<td>No. of employees</td>
<td>157</td>
<td>179</td>
<td>194</td>
</tr>
<tr>
<td></td>
<td>223</td>
<td>162</td>
<td>64</td>
</tr>
<tr>
<td></td>
<td>67</td>
<td>54</td>
<td>51</td>
</tr>
<tr>
<td>Current major construction process limitations</td>
<td>1) Insufficient communication between: A) customer and sales and B) customer/sales and design</td>
<td>2) Construction site organisation too small</td>
<td>1) Customisation combined with the customer involvement in the design phase</td>
</tr>
<tr>
<td></td>
<td>2) Lack of knowledge regarding industrialised construction system among design consultants</td>
<td>3) Building element production line capacity</td>
<td>2) Limitations set by the current factory layout (mainly too small, which affects volume completion)</td>
</tr>
<tr>
<td>Current major construction process improvement areas</td>
<td>1) Initial (and on-going) implementation of small-scale IT support in production related processes, i.e. purchase and inventory, to improve information availability and quality</td>
<td>1) Management of customisation, i.e. increased ability to efficiently manage a high degree of variety between and within projects</td>
<td>1) Continuous (small) improvements regarding production efficiency</td>
</tr>
<tr>
<td></td>
<td>2) Re-engineering of current business processes</td>
<td>3) Limitations set by the current factory layout (mainly too small, which affects volume completion) due to increased production volumes</td>
<td>1) Design phase, i.e. adaptation of the building elements (regarding structural frame and technical installations) to the industrialised volume element production</td>
</tr>
<tr>
<td>Most important experienced benefit from the industrialised production</td>
<td>Short construction times</td>
<td>Already demonstrated competitiveness compared to traditional on-site multi-storey housing construction</td>
<td>Short construction times, the moisture-protected production, and flexibility for the customer</td>
</tr>
</tbody>
</table>
7 Concluding discussion

The customisation approach is clearly a market advantage but a production disadvantage. The ability of balancing a high degree of customisation and short construction time means market competitiveness. The shift towards an increased customer orientation has not been frictionless for front-runners in the industry as indicated by the accounts given above. The companies are currently in different phases in the on-going shift. Company 1 had a very good position as a standard product manufacturer but had to shift to a more customised approach based on market needs. This has clearly caused many problems that still are not solved. The prospects for the company are uncertain if they cannot break the bad trends for both financial and market performance. Company 2 is in another situation. After several years where financial performance has been dismal, they now seem to have found a working recipe for profitable customisation.

The importance of integrating design and production is indicated by the trend of designing technical installations in-house, lack of knowledge among design consultants, insufficient communication between actors in the construction process, and the aim for reduced processing of raw materials during building element production. Taken together, this clearly shows that companies in this industry need to focus on how to better link design and production to each other. Without a good system for this, customisation becomes difficult to achieve in a way that both pleases customers and provides an efficient production.

The on-going IS implementations and organisational changes demonstrate the need and awareness of improved and re-engineered business processes along with increased information processing capacity and information availability. It is however clear from the cases that firms can have very different IS strategies, ranging from having virtually no IS support to an integrated ERP system. Even though the normal response to a more complex task is better information processing (i.e. a more sophisticated system), it can sometimes be better to keep the information system simple. The Kanban system used by Toyota, as a part of their lean production concept, is a clear indication that this is true.

Three of the cases have increased their turnover rather much during the five-year period and all these companies mention capacity as an important limiting factor. When capacity is close to maximum, a company often faces a difficult decision. In order to increase capacity major investments are needed and this will increase costs for a long time, regardless if capacity can be utilised or not. For an SME, with limited resources, a decision to increase capacity may be the most important decision they make. It may open up for a bright future where major growth is possible. It may also lead to failure, if the investments do not lead to more sales. However, when the production system is in need of an overhaul, it may be beneficial to start from scratch instead of just make patches in the current pro-
duction system. Thus, in the situation facing the examined cases, to facilitate volume element throughput, it may be better to design and adapt the entire building system according to an industrialised production system utilising appropriate production facilities.

8 Conclusions

This paper has examined current prospects and pitfalls among four front-runners in industrialised timber frame housing and analysed some important ingredients in the industrialised housing concept. Today’s industrialised housing has shifted from mass production towards increased customer orientation. Customisation is clearly one of the companies’ most critical issues requiring both efficiency and flexibility. The customisation is facilitated by a building system adapted to the industrialised production demonstrating the importance of integrating design and production and efficient information processing.

Implementing IS is one strategy for increasing the information process capacity (Galbraith, 1972). The companies are more experienced IS users regarding design than production although the on-going IS implementations imply an identified need to increase information process capacity through IS implementation also in production. ERP is a driver of comprehensive change, business process improvements, and process orientation, (Akkermans et al., 2003). However, applying a comprehensive IS business approach, such as implementing an ERP system, is not prioritised. Rather, the front-runners tend to implement less complex IS incrementally. The examined companies are all SMEs with limited financial and organisational resources regarding developments and major changes. Hence, although the need of major change is recognised, e.g. improved production capacity, changes often have to be conducted incrementally through continuous improvements.

An industrialised housing concept has the potential to be successful as shown in Japan, (Gann, 1996), and Sweden (one-family houses), demonstrating the potential of process orientation and construction process efficiency. The shift towards mass customisation and agility in housing require finding the balance between project and process focus. The agility concept is potentially more suitable than the lean concept for housing due to the housing industry’s need and experience of manufacturing unique objects (Barlow 1999). Agility requires flexible organisations managing virtual ad hoc knowledge based collaboration for joint design and manufacture of customised products balanced with internal efficiency (lean-ness) (Yusuf and Adeleye, 2002). Indeed, applying and combining lean and agile principles have the potential to improve the construction supply chain for customised housing (Naim and Barlow, 2003). The findings regarding e.g. customisation, integration of design and production, and IS implementations among the examined SMEs indicate that these companies are moving towards agility rather through incremental evolution than occasional major changes.
8.1 Concluding remarks and suggestions for further research

Prefabrication is one ingredient in the industrialised housing concept, which can be performed in several ways, i.e. utilising industrial processes and machinery to a varying degree and including varying degrees of the product. Standardisation of products and processes are other ingredients in the industrialised housing concept demonstrating the importance of how the prefabrication is conducted. Finding a reasonable level of customer focus by balancing process orientation and project focus (within and between projects) is also critical due to the on-going customer orientation. IT support may or may not be considered as a necessary ingredient in industrialised housing. However, IT support has long been used in the design phase and benefits can be identified also in the production phase. Hence, the industrialised housing concept should be considered as an approach influencing the entire construction process, through adapted design solutions, prefabrication utilising suitable production facilities, and integrated and efficient business processes supported, where appropriate, by IS. To achieve industrialisation, internal business processes (e.g. production processes), the connection between design and production, and external business processes (e.g. supplier relations) must facilitate overall throughput and customisation.

The findings implicate potential for further research. Components adapted to the industrialised building system along with efficient (lean) and flexible (agile) industrial processes and machinery are prerequisites for effective customisation. Hence, a further development towards assembly-ready components, e.g. by suppliers, is one step towards new working methods better adapted to the industrialised production. The differences in degree of industrialisation between building element production and volume completion process imply a potential for further developments in the volume element completion process. IT support is another area with the potential for development. For example IS usage in production and linking IS for design and production to achieve real enterprise wide IT solutions aiming for improved communication in the entire construction process. Matching IS complexity with the overall business process complexity is also worth investigating with both theoretical and practical implications.

9 References


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Paper V

ERP system implementation: a case study of a medium-sized industrialised housing company

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This paper has been edited to fit the format of the thesis, but the content remains the same.
Abstract

This paper analyses the enterprise resource planning (ERP) system implementation of a medium-sized industrialised housing company. The aim is to address ERP system implementation characteristics pertaining to a medium-sized, industrialised housing company. The research was conducted using a single case study research design aiming to understand the complex ERP system implementation and expand theories regarding ERP and large manufacturing companies. The findings suggest that a lack of history regarding IT systems for production processes and the timing of the system selection in the overall ERP adoption both have significant importance for the implementation outcome. The single case study research design nature might limit the robustness of the findings. Hence, future research can focus on ERP system implementation follow-ups among industrialised housing companies with other key-characteristics and histories. More empirical findings and theory building regarding small and medium-sized enterprises (SMEs) and ERP are also needed. To overcome implementation difficulties the ERP supplier must fully understand the needs of the customer and the nature and culture of the customer’s industry. With no previous history of IT systems for production processes, an ERP system implementation is a big step even if it is carefully conducted allowing gradual increase of IT maturity. Most ERP research is conducted within the large manufacturing industry while ERP research regarding construction or SMEs is limited. ERP use has the potential to improve construction companies and SMEs demonstrating the need of an increased knowledge within these areas.

Keywords: Enterprise resource planning, industrialised housing, small and medium-sized enterprises, information technology, timber frame houses

1 Introduction

Industrialised timber frame housing utilising factory prefabrication is successful in the Swedish market for one-family housing. Prefabrication combined with changes in processes can promote the increasingly important customisation in housing (Roy et al., 2003). Enterprise resource planning (ERP), a business integration approach including methods and IT tools for the planning and controlling of enterprise resources, is to date more widely adopted in the manufacturing industry than the construction industry (Barthorpe et al., 2004). ERP has the potential to play a strategic role within the construction industry if IT maturity is high (Voordijk et al., 2003). Implementation of an ERP system is a critical stage and successful implementations can produce re-engineered and improved enterprises (Al-Mashari, 2002). ERP system implementation is included in a possible strategy for construction process improvements of an industrialised housing company (Bergström and Stehn, 2004a). The aim of this paper is to address ERP system implementation characteristics pertaining to a medium-sized, industrialised
housing company. Based on case study research, the prerequisites for ERP system implementation are analysed and discussed.

2 Theory

Industrialised housing is here defined as the prefabrication of at least the frame in a permanent factory. There are two main types of production methods: production of building elements, e.g. floors and walls, and production of volume elements. A volume element is a three-dimensional structure composed of building elements, though it is much more complex than a building element. Both building and volume elements can be completed at the construction site or in the factory. Industrialised housing both resembles and differs from the manufacturing industry, meaning that there are limitations, though not to be over-emphasised, in the potential transfer of concepts from manufacturing to housing (Gann, 1996). Real lessons can be drawn from the manufacturing industry, such as the possibility of replacing mass production with mass customisation through improved technology and the importance of acknowledging and managing the supply chain (Gibb, 2001). Solutions from the manufacturing industry, properly re-engineered according to construction industry conditions, have the potential to increase construction process efficiency and flexibility provided the existence of driving forces originating from market requirements (Crowley, 1998). Most one-family detached houses in Sweden have timber frames and are prefabricated by small and medium-sized industrialised housing enterprises (SMEs) (according to the European Communities definition for company size classification, see also Table II), approximately 74% from 1990 to 2002. With the introduction of the 1994 building code, multi-storey timber frame houses were again allowed to be built. However, the production of multi-storey timber frame houses is small compared to the total production of timber and multi-storey houses in Sweden.

Three elements defining ERP are identified in Akkermans et al. (2003), viz. a technical, a functional, or a business perspective. From the technical and functional perspectives, material requirements planning (MRP), manufacturing resource planning (MRP II), and ERP represent methods and IT tools for the planning and controlling of resources for manufacturing companies. MRP systems could initially be used for calculating material requirements and handling orders, but were then expanded to handle capacity planning and scheduling (Umble et al., 2003). In the 1980s, MRP II systems incorporating business-managing functions were developed and evolved in the 1990s to include all resource planning for the entire enterprise, i.e. ERP systems (Umble et al., 2003). Manufacturing organisations using computer-aided design (CAD) and ERP systems can either re-enter needed information into the ERP system or integrate CAD and ERP systems, thus automate information input from CAD to ERP (Soliman et al., 2001). In the business perspective, ERP can be viewed as a business approach integrating strategic and operational functions through the entire organisation (Akkermans et al., 2003).
The use of ERP systems is shown to provide strategic, operational, and information-related benefits like increased competitiveness and profitability as well as improved information availability/quality and improved business operations and integration (Muscatello et al., 2003). Short-range benefits are often associated with operational and managerial areas, while strategic and financial impacts are related to long-term use (Kennerley and Neely, 2001; Poston and Grabski, 2001). The identified benefits from using ERP also come from ERP being a driver of comprehensive change, business process improvements, and process orientation (Akkermans et al., 2003). However, an ERP system might also disrupt a company’s culture, lead to productivity dips, and result in a return on investment loss (Umble et al., 2003).

Implementation is a critical stage that can require considerable cost and time, and is shown to be a major obstacle; Table I identifies both success and hindering factors (Umble et al., 2003). Failed implementation might cause major problems such as order-processing difficulties, operating losses, or reduction in operation earnings (Motwani et al., 2002), while a successful implementation can produce re-engineered and improved enterprises (Al-Mashari, 2002). Most existing MRP and ERP research are conducted within the large manufacturing industry though MRP and ERP use have the potential to improve SMEs with the appropriate implementation (Petroni 2002; Muscatello et al., 2003).

Table I. ERP implementation success and hindering factors adopted from Umble et al. (2003).

<table>
<thead>
<tr>
<th>Success factors</th>
<th>Hindering factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clear understanding of strategic goals</td>
<td>Strategic goals are not clearly defined</td>
</tr>
<tr>
<td>Commitment by top management</td>
<td>Top management is not committed to the system</td>
</tr>
<tr>
<td>Excellent project management</td>
<td>Implementation project management is poor</td>
</tr>
<tr>
<td>Organisational change management</td>
<td>The organisation is not committed to change</td>
</tr>
<tr>
<td>A great implementation team</td>
<td>A great implementation team is not selected</td>
</tr>
<tr>
<td>Data accuracy</td>
<td>Data accuracy is not ensured</td>
</tr>
<tr>
<td>Extensive education and training</td>
<td>Inadequate education and training</td>
</tr>
<tr>
<td>Focused performance measures</td>
<td>Performance measures are not adapted to the organisational change</td>
</tr>
<tr>
<td></td>
<td>Technical difficulties</td>
</tr>
</tbody>
</table>

Based on case study research of a large construction company, it is suggested that ERP can play a strategic role within the construction industry if primary processes are standardised, business and IT strategies are properly matched, and the ability to use ERP for information management is high (Voordijk et al., 2003). An ERP approach has the potential to improve effectiveness regarding mainly supply chain and financial management of large enterprises within construction (Barthorpe et al., 2004). However, according to Shi and Halpin (2003), ERP systems can hardly meet the needs of the construction industry, since they are primarily developed for the manufacturing industry and do not address the nature
and business culture of construction. Case study research in a medium-sized industrialised housing company illustrates that industrialised housing needs and ERP can be matched (Bergström and Stehn, 2004a). Important prerequisites are:

- A change process initiated by external and internal driving forces aimed at re-engineered business processes that functionally meet the needs of and facilitate ERP system implementation.
- It must be evident that the ERP approach can contribute in meeting both external and internal needs; simply implementing an IT system will most likely not increase efficiency.

A survey of the vast majority of industrialised timber frame housing enterprises in Sweden (micro excluded), (Bergström and Stehn, 2004b), is summarised in Table II, showing the distribution of five key-characteristics (A–E). The key-characteristics A-D are demonstrated to influence and partly explain the change process needed for ERP adoption (Bergström and Stehn, 2004a). Regarding ERP use, it is shown in Bergström and Stehn (2004b) that, until now, a high degree of complexity in the production process does not favour IT supported business processes. “N” represents the number of companies at each level. In the Swedish manufacturing industry, 75% of the companies use ERP systems, while an additional 14% are implementing or planning to implement ERP (Olhager and Selldin, 2003).

Table II. Industrialised timber frame housing in Sweden (Bergström and Stehn, 2004b).

<table>
<thead>
<tr>
<th>Key-characteristic</th>
<th>Level</th>
<th>Description</th>
<th>(%)</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1</td>
<td>Customised standard products</td>
<td>31</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Customised products</td>
<td>69</td>
<td>33</td>
</tr>
<tr>
<td>B</td>
<td>1</td>
<td>Garages, cottages, and sheds</td>
<td>17</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>One-family detached houses</td>
<td>67</td>
<td>32</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Multi-family dwellings, schools, and offices ≤2 storeys</td>
<td>12</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>Multi-family dwellings, schools, and offices &gt;2 storeys</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>C</td>
<td>1</td>
<td>Building element manufacturer</td>
<td>67</td>
<td>32</td>
</tr>
<tr>
<td>Production method</td>
<td>2</td>
<td>Volume element manufacturer</td>
<td>33</td>
<td>16</td>
</tr>
<tr>
<td>D</td>
<td>1</td>
<td>Small (annual turnover &lt; € 10 M)</td>
<td>58</td>
<td>28</td>
</tr>
<tr>
<td>Company size</td>
<td>2</td>
<td>Medium-sized (annual turnover &lt; € 50 M)</td>
<td>38</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Large (annual turnover ≥ € 50 M)</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>E</td>
<td>1</td>
<td>Uses no system, will not implement</td>
<td>50</td>
<td>24</td>
</tr>
<tr>
<td>ERP approach</td>
<td>2</td>
<td>Uses no system, will implement</td>
<td>19</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>MRP system user</td>
<td>19</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>ERP system user</td>
<td>12</td>
<td>6</td>
</tr>
</tbody>
</table>

The case company’s ERP implementation strategy comprises four phases: 1) Pre-implementation (from mid-2001 to mid-2002), 2) process change (during 2002
and 2003), 3) ERP system implementation (from mid-2003 to mid-2004), and 4) ERP system use (initially scheduled for mid-2004). A key feature of the case company’s pre-implementation is the identified need of change, i.e. re-engineering of business processes and the production system, the aim for an ERP approach, and facilitating the forthcoming ERP system implementation (Bergström and Stehn, 2004a). An additional pre-implementation key feature is the objective for a stepwise and flexible ERP system implementation to properly perform the day-to-day work. ERP implementation is intended to link the case company’s strategic goal (i.e. to improve their ability to efficiently manage an increased product mix with a higher degree of variety within and between projects) with the managerial and operational goals of more efficient internal processes. The focus of this paper is the ERP system implementation, though the initial part of the section “Results and discussion” contains important and clarifying pre-implementation results not described in Bergström and Stehn (2004a).

2.1 Implications

The benefits shown from ERP use in the manufacturing industry also indicate the potential in industrialised housing, provided that an ERP adoption considers the construction industry culture. Adopting an ERP approach has the potential to promote a balance between project and process orientation and facilitate customisation. To date, the main focus of ERP research has been large enterprises within the manufacturing industry. The amount of scientifically reported ERP literature regarding construction or SMEs is relatively limited, demonstrating the need of an increased knowledge within these areas.

3 Method

The research was conducted from mid-2003 to mid-2004 using a single case study research design. Applying a case study research method is appropriate when the research problem requires an understanding of complex phenomena, such as an ERP system implementation, that influences the entire organisation, and is not controllable by the researcher (Meredith, 1998). The data collection (interviews and direct observations) was performed continuously during the case study. The interviewees were selected on the basis of their special knowledge and their ability to provide useful information, thereby enhancing the understanding of the implementation. For case study research, one goal, here expressed as the aim, is to expand and generalise theories, i.e. analytic generalisation (Yin, 2003). No other company among the 48 investigated in Bergström and Stehn (2004b) has the case company’s characteristics considering customisation approach, main product, production method, size, and ERP approach. Furthermore, the case company is an SME in the construction industry, where the reported research is so far limited. This enhances uniqueness, an important feature for case study research (Yin, 2003).
The case company is medium-sized (situated the last few years within the lower quartile of the medium-sized company category, but expanding) and produces customised multi-storey timber frame buildings using an industrialised volume element production. The elements are completed in the factory. Design of the structural system and parts of the technical installations, building element production and assembly, parts of the volume element completion, and on site erection are all done by the company. Typically, consultants design the technical installations while in the volume completion process, subcontractors paint the interior and exterior, finish the surfaces, do the technical installations, and install the heating and water equipment. In 1994, the company performed two major changes regarding their main product and production method. The company shifted from a building element production for houses up to two storeys to a volume element production of multi-storey houses. The transformation required two years of development and preparation and since then, the company has developed their customisation approach, reported in Stehn and Bergström (2002), and their business processes and production system, reported in Bergström and Stehn (2004a). The company uses 2D-CAD for design and separate IT systems for calculus and administration, while production related business processes have so far not utilised IT support. Figure 1 illustrates the key-characteristics for the case company and for the average industrialised timber frame housing company in Sweden, according to Table II.

![Figure 1. Description of case company and the average industrialised timber frame housing company, labels according to Table II.](image)

### 4 Results and discussion

One of the original main ideas for considering an ERP system implementation was the possibility to integrate IT systems for design, production, and supporting processes, while shifting from 2D-CAD to 3D-CAD for design. At the time of pre-implementation it was not possible to identify an IT system for design with sufficient external communication capabilities (i.e. with consultants) as well as sufficient internal information transfer capabilities (i.e. between design and production). Nevertheless, it was decided to continue the ERP preparations and retain the existing IT system for design, with the integration of IT systems for design and production as a long-term goal. During the pre-implementation three ERP systems, with key features shown as relations in Figure 2 on a relative scale.
ranging from low to high (peripheral position in spider diagram) between the three systems, were selected for a thorough evaluation. Each of these systems was regarded as suitable, though system A in Figure 2 was regarded as having the most appropriate overall features. For example, user opinions are considered more important with an increased number of users acting in relevant industries and even more important if they express similar opinions. Modules for purchasing and inventory, production (i.e. planning, controlling, and follow-up), and integration between the ERP system and existing IT systems for administration were included in the initial system implementation.

![Spider diagram showing requirements and performance match.](image)

**Figure 2. Evaluated ERP system key features.**

At the start of ERP system implementation, an implementation project team was formed consisting of two operational managers, one of whom participated in the pre-implementation. Prior to and during the implementation, the company was re-organised to make it possible for the implementation project team to focus on the implementation and the forthcoming ERP usage. The implementation was initiated in mid-2003, comprising of activities according to Table III, and the “go live” phase was aimed for mid-2004. For the “go live” phase, the balance between internal ERP knowledge, confidence in the system, system functionality, and the characteristics of the “go live” project was regarded as important. A project with a relatively long series of volume elements with small variations due to customer choices was preferred. The major implementation parts were hardware and software installations as well as external (led by the ERP supplier) and internal education and training. External education was conducted during each activity in Table III, while internal education and training were conducted in-between the external education. During the implementation, project meetings involving the implementation project team and company top management were regularly held.
Table III. ERP system implementation steps.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic information input</td>
<td>Database installation and registration of information</td>
</tr>
<tr>
<td>Product structures</td>
<td>How to build and organise product structures</td>
</tr>
<tr>
<td>Production 1</td>
<td>How to plan, control, and follow-up the production</td>
</tr>
<tr>
<td>Materials management</td>
<td>How to organise purchasing, inventory, and materials handling</td>
</tr>
<tr>
<td>Administration</td>
<td>How to connect and use ERP system with current IT systems</td>
</tr>
<tr>
<td>Production 2</td>
<td>How to register work hours and handle work orders on the shop floor</td>
</tr>
</tbody>
</table>

Implementation difficulties emerged early on. An exceedingly high amount of work was needed for database handling (i.e. information installation, modifications, and updates). The education conducted by the supplier was considered as non-structured, not adapted to specific company needs, and lacked suitable and user-friendly documentation. The connection between the ERP approach, ERP system use, and improved efficiency/competitiveness was considered as inadequately explained from the ERP supplier during the external education. The system was considered not user-friendly and difficult to handle. As the implementation continued, so did the difficulties. The production planning and controlling capabilities were considered difficult to handle and inappropriate according to company needs. Bugs, errors, and low compatibility between various versions of the system were also identified, increasing the negative attitude at the case company and decreasing confidence in the ERP supplier.

As the implementation proceeded, ERP knowledge within the implementation project team increased and some of the technical difficulties were resolved, leading to a somewhat more positive attitude and recognition of the potential benefits from the forthcoming system use. Parts of the system were gradually improved and adapted to the case company’s needs. A broader education involving more ERP supplier staff was also presented, thereby increasing confidence in the ERP supplier. Still, further improvements and adaptations of the system were needed to make the system functional as per company requirements with even more improvements to possibly achieve more efficient business processes regarding, e.g. purchasing and production preparation, planning, and controlling.

Interestingly, prior to the “go live” process, the discussion of possibly integrating IT systems for design and production was renewed. One driving force was the awareness of the large amount of manual work needed to input information into the ERP system. The complexity of the product yields complex product structures. With a high degree of variation between each volume element, e.g. due to customisation, the amount of product structures needed is large. Without integrated IT systems this information input has to be mainly conducted manually. Preliminary findings indicate that integrating IT systems for design and production is still not directly applicable. However, prior to the “go live” process, the
system functionality and confidence in the system among the implementers was still low. Managing the system was regarded as demanding significantly more work than managing the existing business processes. The implementers also felt that system use might yield a less flexible construction process. Since the system was considered to decrease efficiency, the “go live” phase was cancelled in June 2004 and a comprehensive evaluation was instead initiated: Can this specific system or an alternative system match the company’s needs? Are the company needs sufficiently matched by the re-engineered manual business processes? Implementation aspects other than the systems functionality, e.g. costs, internal knowledge, and awareness of the ERP approach potential, do not currently hinder the implementation.

5 Concluding discussion

From the previous section, two obvious implementation obstacles can be identified: 1) Low functionality of the ERP system and 2) external education not adapted to company specific needs. The low functionality applies to divergences between the expected and the real capabilities of the system as well as technical difficulties like bugs, errors, etc. The external education was not able to increase knowledge of ERP methods and the ERP system to fully motivate the forthcoming system use. The low functionality and inappropriate education led to a negative attitude among the implementers and staff. Some of the difficulties were overcome mainly due to three implementation facilitators: 1) balancing changes in current business processes with adaptations of the ERP system, 2) internal increase of ERP knowledge and skills through training, and 3) internal communication and external communication. The ERP supplier had to adapt and improve the ERP system to be able to meet the performance requirements. These improvements included elimination of bugs, errors, etc., and installations of new, adapted, and improved functions. At the same time, the case company modified their current business processes to meet the ERP system. This was facilitated by increased internal ERP skills and that the real potential of ERP use, beyond the initial obstacles, began to be recognised. Communication with more staff at the ERP supplier and other ERP system users further increased in-house ERP knowledge as well as solutions to technical difficulties and ways of improving the system. Hence, it was not until the end of the system implementation that there was sufficient internal knowledge to really perform an appropriate system selection.

The company is accustomed to changes regarding technology, business processes, and organisation, as illustrated by, e.g. the major changes in 1994 and the changes regarding customisation, production system, company size, etc. But the company has no previous history of implementing MRP or MRP II systems, thus lacking experience and knowledge within this area. This is possibly the most important underlying single factor explaining the ceased implementation. The system selection was included in the pre-implementation, consequently preceding the re-
engineering. A key feature of the pre-implementation was the recognised need for process change (re-engineering of business processes and production system, adopting an ERP approach, and facilitation of the forthcoming ERP system implementation). Since the re-engineering changed important prerequisites, the system selection should have been preferably conducted after the process change had been implemented, operational for some time, and thoroughly evaluated. If this evaluation demonstrated that ERP system implementation was still needed, the system selection would have included the prerequisites and needs of the new production system.

The selected system was chosen primarily due to a previously experienced match between performance requirements and system performance. At the implementation start, the system was unable to fulfil the performance requirements, as the case study findings clearly show. The gap between expected and real system capabilities illustrates the difficulties in defining and purchasing a set of performance requirements and exactly matching the expected functionality. The ERP supplier must have the competence to be able to fully understand the needs of the customer, the nature and culture of the customer’s industry, and the limitations of the system. Thus, the supplier must be able to provide either a system meeting the expected performance requirements or state that the system currently does not have all of these capabilities and an adaptation will require time and costs. Similarly, the entire implementation program must be adapted to the company’s needs and appropriately link a strategic ERP approach with operational ERP use and the potential ERP benefits.

The system implementation was preceded by a thorough evaluation of the company’s existing business processes and production system along with suitable ERP systems and suppliers. An extensive change process preceded the system implementation. Company top management and most operational managers have been involved during the entire ERP implementation, awareness of the strategic and operational potential benefits from ERP use is high, and the organisation is used to change. Nevertheless, ERP system implementation has currently ceased, demonstrating the complexity of an ERP implementation and the specific difficulties for an SME in the construction industry. With no previous history of implementing systems like MRP or MRP II, an ERP implementation is a big step. A multi-storey house is a complex product yielding a high degree of information flow, as illustrated by, e.g. the complex product structures. Finally, an SME often has limited personnel and financial resources for development projects and has to primarily focus on the day-to-day work.

Although the ERP system is not yet implemented, its possible implementation has acted as a driving force for further developments towards a real enterprise wide IT solution and real industrialised business processes. An integration of 3D-CAD with an ERP system would provide an integrated design – production en-
vironment as opposed to the current situation, where 2D-CAD generates paper drawings used for manual business processes like purchasing, production preparation, and planning. However, this integration, which is a complex task involving many factors (Soliman et al., 2001), must be seen as a long-term goal, with or without the current ERP implementation difficulties. ERP implementation has also generated increased knowledge of IT systems and their implementation, facilitating possible forthcoming IT implementations and integration.

6 Conclusions

An ERP implementation is a major and crucial change for most companies, not the least for an SME (as the case company) in the construction industry (Muscatello et al., 2003; Barhorpe et al., 2004). Many implementation success and hindering factors are identified, Table I. Despite matching most success factors and avoiding most hindering factors, the case company’s ERP system implementation has currently ceased. Clearly, the reported success and hindering factors, mainly addressing large companies in the manufacturing industry, do not completely cover the needs of an SME in the construction industry. Regardless of the similarities with the manufacturing industry, the characteristics and culture of the traditional construction industry are evident in the case company. One illustrating and important factor is the lack of history regarding implementation and use of MRP and MRP II systems as in the manufacturing industry. System replacement is one major reason for ERP implementation in the manufacturing industry (Olhager and Selldin, 2003). Thus, the manufacturing industry has gradually increased the knowledge, experience, and awareness of the advantages of using these approaches and systems over an extended period of time. The complexity of a house compared to e.g. a car, as described in Gann (1996), is also one major complicating factor for frictionless ERP system implementation for a construction company. Many SMEs in the manufacturing industry lack a history regarding the implementation and use of MRP and MRP II systems (Petroni, 2002; Muscatello et al., 2003). From the reversed point of view this implies that most ERP suppliers are unfamiliar with these customer categories and their specific cultures and needs.

The case study findings also show the importance of conducting the overall ERP implementation sequence in the “right” order. Selection of the ERP system is preferably conducted after re-engineering (Muscatello et al., 2003). The case company’s pre-implementation included a comprehensive evaluation of the strategic and operational needs that demonstrated a need for process change, ERP system evaluation, and system selection. Hence, the system selection was based on the production system prior to re-engineering and therefore excluded the prerequisites and needs of the new production system.

Strategic ERP use requires high maturity in IT (Voordijk et al., 2003), generally low among industrialised timber frame housing companies in Sweden, most of
which are SMEs (Bergström and Stehn, 2004b). This implies that IT maturity must increase to possibly utilise the full potential of ERP, while ERP system implementation must be carefully conducted to allow a gradual increase of IT maturity. Many industrialised housing companies in Japan analysed by Gann (1996), and some industrialised housing companies in Sweden, originate from the manufacturing industry. These companies might have the best prerequisites to act as pioneers in the housing industry for ERP adoption, due to the attitudes, experience, and knowledge emanating from the tradition and history of the manufacturing industry. More research is needed to increase ERP knowledge in industrialised housing. ERP implementation follow-ups, among industrialised housing companies with different key-characteristics and histories than the case company, would provide useful insights. More empirical findings and theory building regarding SME and ERP in the manufacturing industry are also needed for an increased understanding of ERP system implementations.

7 Acknowledgements

The author greatly acknowledges the fruitful discussions with the case company and access to case company material.

8 References


Appendix A – Mail questionnaire

Mail questionnaire sent to industrialised timber frame housing companies in September 2002.

This questionnaire has been translated and edited to fit the format of the thesis, but the content remains the same.
Appendix A – Mail questionnaire

Survey regarding enterprise resource planning in industrialised timber frame housing in Sweden. The questions below were used in the mail questionnaire sent to industrialised timber frame housing companies in September 2002. The findings are reported in Paper III. Fixed answer categories are shown in Italic characters in parentheses.

1) What is the annual turnover*  
2) Which types of houses are built and what are the largest number of storeys, annual production volume, and export share per house type?  
   (One-family detached houses, Terrace houses, Multi-family houses (≤ 2 storeys), Multi-family houses (>2 storeys), Multiple detached houses, Schools, Hotels/Offices, Cottages, Garages/storerooms, Sheds)  
3) Which type of frames are used, please state production share for each type  
   (Lightweight frame, Solid wood frame, Other, please state what type)  
4) What is manufactured in the factory?  
   (Building elements, completed with technical installations at the construction site, Building elements, completed with technical installations in the factory, Volume elements, completed (technical installations, painting, surfaces finishing, fixed equipment etc.) at the construction site, Volume elements, completed (technical installations, painting, surfaces finishing, fixed equipment etc.) in the factory)  
5) How many variants are manufactured per building element type?  
   (1, 2, 3-7, 8-14, 15-)  
6) What is the customisation approach regarding layouts  
   (Standard models, Customised standard models, Customised models)  
7) In which parts of the construction process are computer support used, multiple answers are possible  
   (Design (calculus, architectural design, dimensioning, drawings (structural and technical installations)), Production (purchase, planning, preparation, manufacturing, follow-up), Maintenance, Administration, Marketing/Sales)  

If ”Production” is checked in question number 7), please continue with questions number 8-16, otherwise please continue with questions number 17-22  

8) Which MRP/ERP system is used for business process support, please state vendor and model  
9) Who uses/use the system (multiple answers are possible)  
   (Administrating personnel/controllers, Production managers, Production personnel)  

* Turnover values were confirmed from archival records after the questionnaires were collected
10) For how many years have MRP or ERP systems been used 
\(0-1, 1-3, 3-6, 6-10, 10-\)

11) How many systems have been used prior the current system 
\(0, 1, 2, 3, 4-\)

12) What was the most important reason for implementing the system

13) What is the major advantage yielding from system use

14) What is the major disadvantage yielding from system use

15) How satisfied/dissatisfied are you with the current system 
\(\text{Very dissatisfied, dissatisfied, neutral, satisfied, very satisfied}\)

16) Comments

Questions number 17-22, to be answered if “Production” not is checked in question number 7)

17) What is the main reason for not implementing a MRP/ERP system

18) Is an MRP/ERP implementation planned \(\text{Yes, No}\)

19) What is the main reason for the answer in question 18)

20) What could be the most significant advantage yielding from MRP/ERP use

21) What could be the most significant disadvantage yielding from MRP/ERP use

22) Comments
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