Industrialised House-Building

Concept and Processes

Jerker Lessing

Division of Design Methodology
Department of Construction Sciences
Lund University
Lund Institute of Technology, 2006

Industrialised House-Building

Concept and Processes

Jerker Lessing

Licentiate Thesis

Key words

Industrialisation, House-building, Industrialised House-building, Process, Continuity, Development, Platforms, Lean, Process Owner

The English language corrected by Karin Ryde
Layout: Hans Follin, LTH, Lund HF

Printed by KFS AB, Lund 2006

Industrialised House-Building, Concept and Processes.
Department of Construction Sciences, Division of Design Methodology, Lund University, Lund

ISBN 978-91-631-9254-8

Lund University, Lund Institute of Technology
Department of Construction Sciences
Division of Design Methodology
P.O. Box 118
SE-221 00 LUND
Sweden

Telephone: +46 46 - 222 41 63
Telefax: +46 46 - 13 83 58
E-mail: anders.ekholm@caad.lth.se
Home page: www.caad.lth.se

Never mistake motion for action

Ernest Hemingway

Abstract

This thesis presents an overall description and definition of the concept Industrialised House-Building, its process structure and process management.

Today there is a strong focus on industrialised house-building in Sweden. The traditional building industry is mainly project-oriented, which has led to fragmentation and a lack of continuity of the process as well as low productivity development. Other industrial sectors have achieved great benefits by using concepts such as Lean Production and Supply Chain Management. Within several companies in the building sector, industrialisation has become a strategic area of development in order to create business opportunities and more efficient methods for construction. In this context, there is a need of a clear description of the concept Industrialised House-Building, which can be used for further research, development and implementation. Furthermore, the development towards an industrialised house-building process will lead to consequences for the structure and management of the building process, which need to be investigated.

A literature review concerning industrialisation of the house-building industry, theory of industrial processes, as well as production paradigms such as Lean Production, Agile Production and Supply Chain Management, is presented in the thesis. A definition of Industrialised House-Building, and a description of eight characteristic areas that further describe the content and significance of the concept, are developed based on the theoretical framework. The definition emphasizes the complexity of the concept since it includes process, organizational- and technological aspects which need to be developed in order to achieve an industrialised house-building process. This approach differs from the earlier understanding of industrialised house-building, which was more focused on mass production and systems building with prefabricated elements.

Three case studies, on companies working in the field of industrialised house-building in Sweden, were conducted within this research project. In the cases studied, the companies' implementation of the eight characteristic areas, as also their process structure and management were

investigated. The case studies included several interviews and observations made on many visits to the chosen companies, their factories and building sites.

The case studies show that the eight characteristic areas can have reached different levels of implementation within a company. The levels are graded from 0 to 4 and are presented as a radar chart, which gives a good overview of the companies' overall level of implementation of the areas. It also shows that industrialised house-building requires increased continuity in several respects, for instance, continuous processes for the development of technical and process-related issues. A shift from a project focus to a process view is needed.

Based on the case studies and the theoretical framework, a comprehensive model illustrating the concept of Industrialised House-Building is proposed, and presented in the thesis. The model can be used as a tool for assessing the level of industrialisation and it gives a snapshot of the current situation of a company's industrialisation. Companies that are developing in the field of industrialisation can use the tool to document how the levels of implementation are changing over time, and for their strategic choices of further development.

Furthermore, a model illustrating the relation between the house-building process and the continuous development of a Technical Platform and a Process Platform is presented. A Technical Platform is proposed to accumulate technical solutions for building parts, machinery and ICT, while a Process Platform accumulates modules for collaboration, logistics, information flow, etc. The model implies that a Process Owner is responsible for the development of the platforms and their utilization in the house-building process throughout the supply chain. A Project Manager needs to handle all the unique circumstances of a specific house-building project, and use the platforms as a support in this work. An essential part of the model is that experience is systematically brought back from the house-building process to the continuous development of the platforms.

Industrialisation can be assumed to be a key issue for the construction and house-building industry. A successful implementation includes great opportunities, but it also requires thorough efforts by all participants in the various parts of the process. The most important factor for success is perhaps a positive attitude to change and development in the industry.

Contents

Acknowledgements

This research project has been executed at the Department of Design Methodology, Construction Sciences, at Lund Institute of Technology, Lund University. The project has been financed by Sven Tyréns Stiftelse and I am employed by Tyréns AB. The project was initiated by Per Kämpe at Prefabutveckling, a subsidiary to Tyréns AB, to whom I am very grateful.

It has been truly interesting to work with this thesis. I have met many competent, enthusiastic and friendly persons during my work and I would like to express my gratitude to all those who have so generously supported me. I have written this thesis as the sole author, but nevertheless, many persons have contributed in various ways and some of you I want to give special recognition.

First and foremost I would like to mention my supervisor, Professor Anders Ekholm, and my assisting supervisor, Niclas Andersson. Anders, thank you for supporting me throughout this project with your bright analyses and your open mind. I think we have learned a lot together. Niclas, thank you for assisting me, for your valuable advice and all our interesting discussions in the course of this project.

Throughout the project I have had good support from my reference group, where Göran Johansson, Sverker Andreasson, Jan Stenmark, Peter Weidemanis, Per Kämpe and Tomas Alsmarker have participated. In several meetings we have discussed industrialisation and I have appreciated your advice and interest in my work. Thank you, Göran for your support and enthusiasm. Sverker, thank you for all your advice and help, our discussions have given me valuable input and energy. Tomas, my mentor and friend, thank you for always giving me your full support, help and enthusiasm! You have generously given me energy so many times. I am looking forward to new exciting projects together!

I would like to thank all representatives from Peab, Moelven Byggmodul, NCC and Finndomo, who have helped me during my case studies, especially Christoffer Persson, Erling Lind, Per-Erik Bergström and Camilla Persson Lidgren, who kindly guided me through their companies.

I have had an inspiring and fruitful co-operation with Professor Lars Stehn, which hopefully will continue after this project. I also want to thank Henrik Hyll, who reviewed this thesis and gave me good advice, of which I followed many. Another three persons who gave me help in finishing this thesis are Olle Bergman, who did a tremendous job with all the pictures, Hans Follin who did the layout and Karin Ryde who corrected the language. Thank you for saving me many frustrated hours!

Last, but certainly not least, I want to mention my mother, father and sister who always have supported, encouraged and helped me. This means a lot to me!

And Lisa, my lovely wife, thank you for always supporting, encouraging and giving me your enthusiasm! The life together with you is what it is all about.

Barsebäckshamn, June 2006

Jerker Lessing

Preface

The construction and house-building industry is an interesting field. It is often described as a conservative sector, un-willing to change. Often, I think so too. But when changes happen, they happen fast and with power, which is the case now. In recent years interest in industrialisation has grown dramatically, quite literally! There are many initiatives going on, both in the small and within the large companies, among manufacturers, contractors, consultants and client companies. I think we are at the beginning of an historical phase of Swedish construction and house-building story; a time when we are changing from being an industrial sector without industrial processes - to being a developed, competitive and process-oriented sector.

I say we, since I am part of this sector, to which I am truly dedicated. I worked as a consultant in the construction industry for 5 years before I started my research project. My work was in structural design, development of building systems and in logistics for the construction industry. This was a solid foundation of experience for me when I started my research project, and has been an advantage in the execution of the research.

I have spent the last 2½ years working 4 days a week with my research project and 1 day a week at Tyréns AB, since I have had the opportunity to be an industry Ph.D. student, working both in the academic world and in so-called reality. But the academic world is also a part of the reality, and it offers a wealth of theories, models, methods and principles which can be of great use also in the world of practitioners. At a time like this, when there are so many changes going on, the benefits of industry-related research projects are obvious, especially for an applied field such as industrialised house-building. I am eager to apply my academic knowledge to new, interesting assignments when I now get back to Tyréns for full-time consultancy!

I hope this thesis will be found interesting by its readers. Please contact me if you want to discuss the content, the development of industrialisation or other interesting issues!

1 Introduction

This chapter presents the background of the research project its purpose, problem statement and its delimitations.

1.1 Background

The Swedish construction industry has been characterized as a sector with severe problems. Several investigations have concluded that there is great potential for development within this sector concerning aspects of technology, organization, economy, the environment, working conditions, competition, authorities, etc[1,2].The actors in the industry have responded to the criticism and at present many initiatives are being taken within the industry and at universities to solve the problems[3].

Particularly house-building industry has been in focus due to an increasing need for new dwellings. In Sweden during the 1990s and the first years of the 2000s the number of dwellings being built was at an historical low level[4]. During this period the production costs and prices increased dramatically and almost doubled for apartments in the major urban areas[5]. The low level of housing produced over the past 15 years

1. Byggkommisionen, (2002). ”*Skärpning gubbar! Om konkurrensen, kvaliteten, kostnaderna och kompetensen i byggsektorn*”, Statens Offentliga Utredningar 2002:115, Fritzes Offentliga Publikationer, Stockholm, Sweden.

2. Byggkostnadsdelegationen, (2000). ”*Från byggsekt till byggsektor*”, Statens Offentliga Utredningar 2000:44, Fritzes Offentliga Publikationer, Stockholm, Sweden.

3. Boverkets Byggkostnadsforum, (2005). ”*Forum, Magasin från Boverkets Byggkostnadsforum*”, No 1, 2005.

4. Statistics Sweden, (2005). “*Yearbook of Housing and Building Statistics 2005*” Official Statistics of Sweden, Örebro, Sweden.

5. Byggkostnadsdelegationen, (2000). ”*Från byggsekt till byggsektor*”, Statens Offentliga Utredningar 2000:44, Fritzes Offentliga Publikationer, Stockholm, Sweden.

has led to a big demand for dwellings of all categories, especially small rental apartments. The present increase in production is expected to continue over the coming years[6].

The development of productivity in the house-building industry is significantly lower than in the manufacturing industry. Within the house-building industry there is a difference between the building of apartment houses, which has a lower efficiency, while a higher efficiency is noted for the building of single-family houses built in series. This is presumably due to the fact that the production of single-family houses has many similarities to the manufacturing industry, with a high degree of prefabrication with standardized solutions, and hence can benefit from higher efficiency. Apartment houses, on the other hand, are normally produced as unique projects by traditional on-site, craft-based methods.[7] There is a great potential for the house-building industry to increase the degree of industrialisation for the production of residential houses and achieve efficiency benefits by adopting techniques used in the production of single-family houses[8].

House-building consists of a complex set of activities which involves many specialised actors and for which the projects are carried out itinerantly. Unique situations must be handled, and on-site activities are always exposed to the vagaries of the weather. The house-building industry in Sweden is struggling with problems of inefficiency, poor cooperation, lack of commitment, a fragmented building process and lack of a holistic view of the process.[9,10,11]

6. Boverket, (2005). ”*Bostadsmarknaden år 2005-2006 Slutsatser av Bostadsmarknadsenkäten 2005*” Boverket, Karlskrona, Sweden.

7. Byggkostnadsdelegationen, (2000). ”*Från byggsekt till byggsektor*”, Statens Offentliga Utredningar 2000:44, Fritzes Offentliga Publikationer, Stockholm, Sweden.

8. Brege, et al. (2004). ”*Trämanufaktur – det systembärande innovationssystemet*”, Vinnova Analys 2004:02, Verket för Innovationsanalys.

9. Josephsson, P-E. (1994). ”*Orsaker till fel i byggandet*” Institutionen för Byggnadsekonomi och byggnadsorganisation, Chalmers Tekniska Högskola, Göteborg, Sweden.

10. Byggkommisionen, (2002). ”*Skärpning gubbar! Om konkurrensen, kvaliteten, kostnaderna och kompetensen i byggsektorn*”, Statens Offentliga Utredningar 2002:115, Fritzes Offentliga Publikationer, Stockholm, Sweden.

11. Byggkostnadsdelegationen ,(2000). ”*Från byggsekt till byggsektor*”, Statens Offentliga Utredningar 2000:44, Fritzes Offentliga Publikationer, Stockholm, Sweden.

These problems have been discussed in numerous articles and investigations, and various ideas have been presented as solutions.[12] In several publications the term industrialised building is mentioned as a solution to some of the problems. In the governmental investigation of the Swedish construction industry of 2000 it is stated that a development towards industrialised building leads to good quality and low costs by better control of the processes in the value chain. It is described as

> "*a method for transition to more rationally coordinated processes for building in a holistic sense. This takes the form of systems for building technology as well as systems for processes*"

Further, it is stated that industrialised building requires extensive efforts in planning, coordination and control systems since complex products are manufactured off-site and errors in the assembly phase can jeopardise an entire project.[13]

Today there is a strong focus on industrialised building in Sweden and there are great expectations that the development will lead to solutions of many of the problems in the industry[14]. Within several companies in the building industry in Sweden, industrialisation has become a strategic area of development to create business opportunities and evolve better and more efficient methods of construction. An example of this is the Swedish-based, international construction company, NCC that states in its annual report 2004 that[15]

> "*Building costs must be reduced, the building process must be made more efficient and new collaboration methods must be established. NCC's aim is an industrialised and efficient construction with low maintenance costs for the future.*"

Also Skanska, another Swedish-based, international construction company has a strong focus on the area of industrialised construction, especially house-building, and the company has a thorough development program running at present. Its aim is to achieve a more efficient build-

12. E.g Byggkommisionen, (2002). "*Skärpning gubbar! Om konkurrensen, kvaliteten, kostnaderna och kompetensen i byggsektorn*", Statens Offentliga Utredningar 2002:115, Fritzes Offentliga Publikationer, Stockholm, Sweden, and Byggkostnadsdelegationen (2000) "*Från byggsekt till byggsektor*", Statens Offentliga Utredningar 2000:44, Fritzes Offentliga Publikationer, Stockholm, Sweden.

13. Byggkostnadsdelegationen, (2000). "*Från byggsekt till byggsektor*", Statens Offentliga Utredningar 2000:44, Fritzes Offentliga Publikationer, Stockholm, Sweden.

14. Hamrebjörk, L. (2005) "Ett industriellt byggande" *Väg- och Vattenbyggaren*, No 2, 2005.

15. NCC, (2004). "*Annual report 2004*", NCC.

ing process by developing technical solutions and related processes with a holistic approach. This includes several sub-areas such as procurement, prefabrication, IT-solutions, design and logistics[16].

Industrialised construction is a concept under development but is not new as a term. During the 1950s and 1960s the term was used as a synonym to house building methods with prefabricated systems, often on a large scale for the production of large numbers of apartments and big scale residential areas[17]. Today the term has a wider context, including technical and organizational aspects as well as supply chain and information-related issues[18].

Concepts from the manufacturing industry such as Lean Production, Just-In-Time and Supply Chain Management are principles that describe the management of manufacture and production so that effective processes are achieved and customers satisfied. There is now considerable interest in the construction industry as well as in the academic world to apply these principles to construction in order to achieve efficiency and enhance productivity in the same way as in the manufacturing industry[19,20]. Several organizations, both academic and industry-oriented are focusing on applying and implementing lean principles in the construction industry, among others the International Group for Lean Construction[21], the Lean Construction Institute[22] the Danish association Lean Construction-DK[23], as well as the newly founded Swedish association Lean Forum Bygg[24], could be mentioned.

16. Fritzon, M. (2005). ”Industrialiserat byggande i Skanskas tappning” *Väg- och Vattenbyggaren*, No 2, 2005.

17. Jacobsson, M. (1965). *Byggandets industrialisering*, Byggnadsindustrins förlag, Stockholm, Sweden.

18. Olofsson, T. et al. (2004). ”Industriellt byggande byggbranschens nya patentlösning?” *Väg- och Vattenbyggaren*, No 5, 2004.

19. Naim, M., & Barlow, J. (2003). “An innovative supply chain strategy for customized housing”. *Construction Management and Economics*, 21, 593-602.

20. Gann, D.M. (1996). “Construction as a manufacturing process? Similarities and differences between industrialized housing and car production in Japan”. *Construction Management and Economics* 14, 437-450.

21. http://www.iglc.net, International Group for Lean Construction, visited 2006-03-15.

22. http://www.leanconstruction.org, The Lean Construction Institute, visited 2006-03-15.

23. http://www.leanconstruction.dk, Lean Construction DK, visited 2006-03-15

24. http://www.leanforumbygg.se, Lean Forum Bygg, visited 2006-03-15

Changes towards industrialised house-building will have an influence on design, manufacture and site work as a result of an increased use of prefabricated structural elements. Therefore changes in the over-all process are required[25]. New methods for collaboration have great potential for development and include the involvement of key participants early in the process, routines for conflict solving and teams selected on certain criteria with common goals. These have been shown to lead to improvements concerning time, quality and costs[26]. Several companies are developing new collaboration methods concurrently with the development of industrialised house-building in order to create a more efficient building process in which technical development requires process development[27,28].

1.2 Problem statement and research questions

Industrialised house-building is a complex concept consisting of several interacting sub-areas that are needed in order to achieve a well-functioning production system that can deliver the houses desired by customers[29]. Examples of such sub-areas are an increased re-use of reliable technical solutions, a developed process for procurement, alternative collaboration methods, increased planning, control and follow-ups and a simplified authority-process[30].

One basic problem for the development of industrialised house-building is the lack of a clear description of the concept and its related parts, including technical, organizational and process-related issues. This leads to the following research question:

25. Roy, R., Brown, J., & Gaze, C. (2003). “Re-engineering the construction process in the speculative house building sector”. *Construction Management and Economics.* 21(2), 137-146.

26. Kadefors, A. (2002). ”*Förtroende och samverkan i byggprocessen – Förutsättningar och erfarenheter*” Institutionen för service management, Centrum för management i byggsektorn, Chalmers Tekniska Högskola, Göteborg, Sweden.

27. NCC, 2004. *Annual report* 2004, NCC.

28. Hindersson, P. (2005). ”Upprepning och samverkan är A och O” *Byggindustrin*, No 33, 2005.

29. Olofsson, T. et al. (2004). ”Industriellt byggande byggbranschens nya patentlösning?” *Väg- och Vattenbyggaren*, No 5, 2004.

30. Andréasson, I. (2005). ”Behovet av industriellt byggande från byggherrens perspektiv” *Väg- och Vattenbyggaren*, No 2, 2005.

What are the characteristics of industrialised house-building?

A development towards industrialised house-building means that action must be based on a holistic view in order to achieve an effective building process. However, this will lead to consequences for the structure of the building process in terms of changes of organizational- and production-related conditions. This leads to the following research question:

What consequences for the process structure, does industrialised house-building lead to?

Today the general house-building process is not designed to handle the whole process as a system and hence it will require changes both of the process and of the management to get the complex system of industrialised house-building to work effectively with its related parts acting together as a whole and creating maximal value for the customers. This leads to the following research question:

What consequences for the process management, does industrialised house-building lead to?

1.3 Purpose and objective

The purpose of this research project is to express and describe the ongoing development in the field of industrialised house-building in order to contribute to a comprehensive understanding of its characteristics and requirements. Hereby knowledge will be contributed to the development and implementation of industrialised house-building, which will benefit both the industry and the academic research within the area.

The objective of this research project is to establish a conceptual framework for industrialised house-building, including a comprehensive definition, its requirements and consequences. Further, the objective is to describe the structure of the process and the management required to achieve an industrialised house-building process.

1.4 Focus and delimitations

The focus of this study is industrialised building of new apartment houses, hereafter referred to as industrialised house-building, limited to the Swedish housing industry. Building of single-family houses is beyond the scope of this study because of the greater need for industrialisation in this part of the sector, as mentioned above. Despite this delimitation some parallels can be drawn and some references on single-house building are given.

Further, the focus is the process structure and management of industrialised house-building in a holistic view. The use of supporting systems like frame systems or IT systems is discussed in order to show the relations to industrialised house-building holistically, and how it affects process structure and management. However, such systems are not analysed from a technical point of view since this subject is not covered by this study.

The empirical material in this study is based on interviews with people involved in the Swedish house-building industry, and on three case studies carried out in three companies working with industrialised house-building using different approaches.

1.5 A guide to this thesis

1.5.1 Target audience

This thesis is written as an academic assignment for the degree of licentiate of engineering. Since research in the field of industrialised house-building is an applied science and the purpose is to contribute to the development of the area, both academically and to the industry, the thesis is written for university graduates and researchers as well as for practitioners interested in developing the industry. It is hoped that people engaged in planning, design, manufacture and construction work will find the material interesting and inspiring for further development in the area.

1.5.2 Thesis outline

The method used in this research project is described in Chapter 2.

The theoretical frame-work, on which this thesis is based, is presented in Chapter 3, where production concepts from other industries are presented together with a description of industrialised processes. Industrialised house-building is described both in a historical perspective and by its present status.

A synthesis of the theory and a presentation of the concept for industrialised house-building is found in Chapter 4. Interviews that verify the concept are also presented here.

The three case studies are described in Chapter 5. This gives a broad presentation of the companies working within the field of industrialised house-building.

An analysis of the three case studies, in which differences and similarities are discussed and analysed, is presented in Chapter 6.

Models for industrialised house-building, developed in this research project, are presented and described in Chapter 7. The concept of industrialised house-building is thoroughly described as are also its consequences for process structure and process management.

The conclusions of this research project are presented in Chapter 8, which is followed by a wider discussion on industrialised house-building and on further research on the topic, in Chapter 9.

2 Method

This chapter describes the methodological choices made and used in the research project based on a methodological frame of reference.

2.1 Research approach

Research methods are tools to achieve the goals and objectives of the research. To gaing knowledge of methods is not a purpose in its own right but, in the same way as a craftsman must know and be familiar with his tools in order to carry out qualified tasks, also scientists must know the tools in their toolbox and how to use them. Methodology is the foundation for a systematic investigation asking questions like who, what, how and why, while the method is a tool to use when seeking the answers to these questions.[31]

2.1.1 Different approaches

Arbnor & Bjerke describe three methodological approaches that together cover the scientific field[32]. These three approaches overlap somewhat and relate to the two traditional scientific tracks, positivism and hermeneutics as described in Figure 2.1. The three approaches are the Analytical Approach, the Systems Approach and the Actors Approach, which are further described below and illustrated in Figure 2.1.

In the Analytical Approach the general opinion is that a studied object can be divided into parts which are analysed and seen as independent of each other. The whole picture is then built up on these separate parts.

31. Holme, I. M., & Solvang, B. K. (1996). ”*Forskningsmetodik. Om kvalitativa och kvantitativa metoder*”, Studentlitteratur, Lund, Sweden.

32. Arbnor, I., & Bjerke, B. (1994). ”*Företagsekonomisk metodlära*” Studentlitteratur, Lund, Sweden.

Logic and mathematics are essential in the analytical approach where the search and presentation of hard facts are important as is also the discovery of explanations for the problems studied. The over-all goal in this approach is to find explanations, which includes to determine, describe, explain, predict and to guide through problems that often have cause-and-effect connections. The structure of problems and studies are strict and logical and the aim is that one scientist should be able to conduct the same study and come to the same result, meaning that the researcher's influence is low.[33]

In the Systems Approach components in interaction with each other are studied in a complex environment, where the whole is prioritized. Components are described in their contexts in order to be properly explained and understood. To be able to describe the context the researcher must interact with the environment of the components and with the people involved. Then a complex picture of the system can be created and the components and their relations can be described and understood. A consequence of the researcher's interaction is that the picture of the system is dependent of the researcher and on the unique situation prevailing at the time of the study. This means that one study cannot be done in exactly the same way by another researcher and hence the result will not be exactly the same.[34]

In the Actor's Approach the focus is the deep understanding of social situations and human consciousness from the view of individual participants. There is no interest in explanations, rather in an understanding of the holistic expression of the present problems or phenomena. Organizations are regarded as systems but more as consisting of different actors and their actions in the environment of the social context. An organization is not seen as able to act alone, rather that the individual participant is acting.[35]

33. Arbnor, I., & Bjerke, B. (1994). "*Företagsekonomisk metodlära*" Studentlitteratur, Lund, Sweden.

34. Ibid.

35. Ibid.

Figure 2.1 shows these three approaches and the overlap between them.

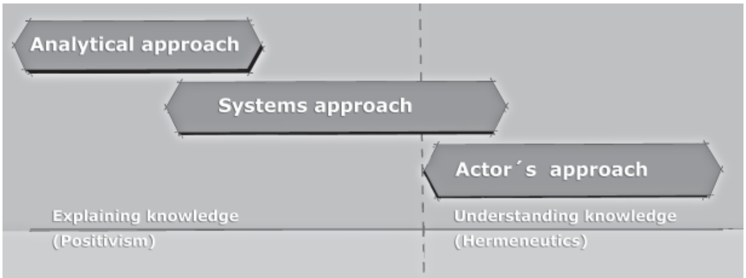

Figure 2.1 *Three methodological approaches related to positivism and hermeneutics*[36].

A system consists of a number of components and the relations between them. Components can be developed and regarded as subsystems with their own components and relations[37]. This is related to the view of processes, described further in section 3.3.1. The systems approach can be described in terms of systems thinking[38] and systems theory[39]. In this context however, they will be treated as one unitary concept described as the systems approach. It can be seen as a concept for seeing wholes in terms of inter-relationships and processes rather than cause-effect chains and static snapshots of phenomena[40]. Senge describes this as the fifth discipline because it is a conceptual cornerstone of how learning organizations think about their environment. Research within this field aims at stating inter-relationships between the components in systems and these components are often mutually dependent on each other, which means that they cannot be summed[41]. A key component of the systems approach is synergy, meaning that not only the content of each individual component but also the way they act together will provide useful infor-

36. Arbnor, I., & Bjerke, B. (1994). "*Företagsekonomisk metodlära*" Studentlitteratur, Lund, Sweden.

37. Ibid.

38. Senge, P. M. (1990). "*The fifth discipline – the art & practice of the learning organization*" Random House business books, London, UK.

39. Thurén, T. (1991). "*Vetenskapsteori för nybörjare*" Liber, Stockholm, Sweden

40. Senge, P. M. (1990). "*The fifth discipline – the art & practice of the learning organization*" Random House business books, London, UK.

41. Ibid.

mation. To explain and understand a certain situation it is not possible to remove any of the factors without risking that the total picture will be seriously affected. Therefore systems should be described both by their components and by their relationships as well as the whole, in order to give as complete a picture as possible[42]. Another key issue in "systems thinking" is feedback, which is stated to be of major importance since it includes the actors in the system, who can change their behaviour and hence influence the total outcome of the system based on feedback[43].

2.1.2 Approach in this thesis

The concept of industrialised house-building is built up of various inter-related sub-areas, all of which are needed for the establishment of a strong holistic concept. The structure and management of industrialised house-building processes, including collaboration throughout the supply chain, require a holistic view in which several areas are developed and put into the right context to create maximum value for the customer. The Systems Approach presented above is therefore a suitable approach for this research project since it is focused on both the components and the relations between them.

Since the aim of the study is to establish a framework for the concept of industrialised house-building and describe its process, a qualitative method is chosen, where I, the researcher, am actively investigating the environment of industrialised house-building in several companies working in this field and therefore am myself an important tool in the study. Here my pre-understanding and earlier experience are factors affecting the study to some extent.

The system studied

In order to establish delimitations for this research project a system was defined and is illustrated in Figure 2.2. The system is confined to the companies' main processes in terms of Design and Preparation, Manufacture, Assembly and Site Work and it also includes supporting processes and management processes. In the system the functions and the processes as well as relations between them, such as internal collabora-

42. Arbnor, I., & Bjerke, B. (1994). "*Företagsekonomisk metodlära*" Studentlitteratur, Lund, Sweden.

43. Senge, P. M. (1990). "*The fifth discipline – the art & practice of the learning organization*" Random House business books, London, UK.

tion, information flow and re-use of experience, are studied. External relations between the system and the environment, such as the relation to customers, suppliers and partners, etc. are also considered.

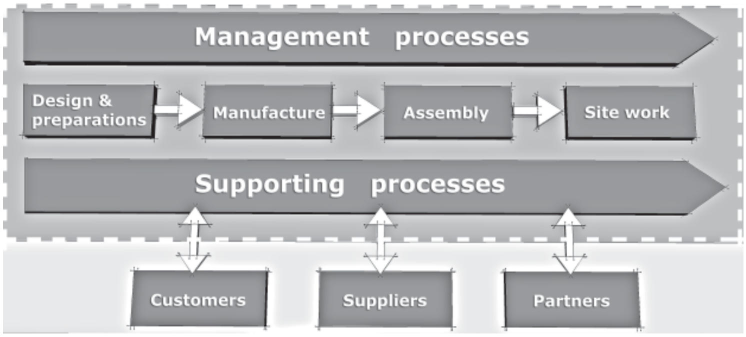

Figure 2.2 The system studied in this research project.

2.2 Collection of data

Several companies are working with industrialised house-building in the Swedish building industry today, albeit with different approaches and with different prerequisites. The aim of this study is to describe the on-going development and establish a framework for the concept of industrialised house-building and therefore it was important to conduct the study in close relation with the companies currently working with this area. This chapter describes methods for data collection for this kind of study and the methods chosen.

2.2.1 Quantitative and qualitative data

Two methodological frameworks are the qualitative and quantitative methods. There is not a definitive difference between these two meta-methods, which are based on different methodological principles and they are not each other's opposites. It can be fruitful to combine the two methods in the same study since weaknesses of the one can be counter-balanced by strengths in the other. The main difference between the methods is that quantitative methods transform information into numbers, diagrams and tables while in qualitative methods the researcher's own interpretations of the information are in focus, but cannot be transformed into numbers. The choice between the methods must be based on the purpose of the study and the most suitable method for achieving the goal.[44] The quantitative methods are more formalized and structured than qualitative methods. A quantitative method is characterized by the researcher's control of the study and some important elements are the formalized analysis, comparisons and testing of results. Also statistical methods are essential in quantitative methods[45]. Quantitative methods are suitable in the natural sciences and in engineering sciences since they include methods for experiments and tests in which information can be measured and collected, and the result is often based on data presented in diagrams and tables[46].

The purpose of qualitative methods is primarily to establish an understanding of the area to be studied. By gathering information in various ways, the problems being investigated can be understood and described from different perspectives[47]. The aim of qualitative methods is to broaden the perspective from a subject-object orientation common in the natural sciences to include the dimensions of social relations, organizational structures and put the study into a holistic context[48]. In qualitative methods the researcher tries to see the phenomena from the inside, which is often achieved in close conjunction with the persons involved in the phenomena being studied[49].

2.2.2 Case study

Case study is a research method with a wide variety of applications, for example in organizational, business and social research. It is commonly used as a research strategy in order to understand complex phenomena

44. Holme, I. M., & Solvang, B. K. (1996). ”*Forskningsmetodik. Om kvalitativa och kvantitativa metoder*”, Studentlitteratur, Lund, Sweden.

45. Ibid.

46. Wallén, G. (1996). ”*Vetenskapsteori och forskningsmetodik*” Studentlitteratur, Lund, Sweden.

47. Holme, I. M, & Solvang, B. K. (1996). ”*Forskningsmetodik. Om kvalitativa och kvantitativa metoder*”, Studentlitteratur, Lund, Sweden.

48. Ibid.

49. Ibid.

studied in a real-life context[50]. As case studies are used in such a variety of situations, it is necessary to definine the method. Yin describes a case study as:[51]

> "*An empirical inquiry that investigates a contemporary phenomenon within real-life context, especially when the boundaries between phenomenon and context are not clearly evident*"

It has also been stated that a case study is an applicable method for investigations of complex situations where the aim is to describe and analyse certain components in qualitative, complex and holistic terms. This is often done continuously over a certain time period[52].

When choosing case studies as the research method it is important to identify a limited system on which to focus the study in which components, relations and people, interesting to the researcher are described. There are three kinds of case studies, useful for different purposes; the Descriptive, the Interpretive and the Evaluative case study, as described below.[53]

Descriptive case study	The main purpose of this case study strategy is to describe a phenomenon or situation. The result is a detailed report which contributes to the understanding of the phenomenon or situation studied.
Interpretive case study	Also this kind of case study aims at describing the phenomenon, and the descriptive information is used to highlight, support or question theoretical assumptions. The case study aims at collecting as much information as possible in order to create an interpretation or extended theory about the phenomena being studied.
Evaluative case study	This kind of case study includes descriptions and explanations in order to form evaluations and judgements about the area studied. Since the case study provides holistic information based on the real case, the strategy is well suited for this purpose.

50. Yin, R. (2003). "*Case study research - Design and methods*" Sage Publications, London, UK.

51. Ibid.

52. Merriam, S. B. (1988). "*Fallstudien som forskningsmetod*" Studentlitteratur, Lund, Sweden.

53. Ibid.

Since case studies can be applied in many different areas and for different purposes, there are many methods by which empirical material can be collected. This is regarded as a strength of this methodology[54]. The most common methods by which information is collected in qualitative case studies are interviews, observations and the study of documents. This will be described further below.

Case study characteristics

In a qualitative case study the researcher himself is the tool for the collection and analysis of information. This is considered to be both a strength and a weakness. The strength is that the researcher can design the study according to his possibilities to collect data to maximize the outcome. The weakness is that the researcher is an individual who can make mistakes, lose information and let personal values affect the study. This means that the "instrument", the case study researcher, must ask himself whether he has the right qualities to execute such a study[55]. As pointed out by Yin[56];

> "*The demands of a case study on your intellect, ego and emotions are far greater than those of any other research strategy.*"

For case studies there are no routines or fixed structures for data collection. The researcher must be able to interact between the theoretical issues being studied and the actual collection of the data in a complex context.[57]

Sensitivity

A researcher undertaking a case study has to be sensitive to the context and all its variables, among others, the physical environment, the people, open and hidden agendas, non-verbal messages and much more. It is also a matter of timing and the researcher must have a sensibility for when to ask questions, when to be silent and let others speak, when to pay extra attention to a certain phenomenon. In order to conduct a good case study

54. Yin, R. (2003). "*Case study research - Design and methods*" Sage Publications, London, UK.
55. Merriam, S. B. (1988). "*Fallstudien som forskningsmetod*" Studentlitteratur, Lund, Sweden.
56. Yin, R. (2003). "*Case study research - Design and methods*" Sage Publications, London, UK.
57. Ibid.

the researcher has to be a good communicator and have empathy. It is important to be able to establish contacts with people, to listen, to ask good questions. In short, it means to have all ones senses open and try to register as much as possible.[58]

Collection of information

Qualitative data can consist of many different types, such as detailed descriptions of situations, occurrences, people, interplay and observed behaviours, citations, attitudes, opinions etc. It may also consist of reports, letters, records and other case descriptions. The most common methods for qualitative data collection are interviews, observations and document studies.[59]

Triangulation means that different sources are used to study the same phenomenon and hence the validity is controlled and the researcher can analyse the data in a better way. A common triangulation method is to use both interviews and observations to examine a certain situation or phenomenon, which is possible for the case study method[60].

Interviews

Interviews are used in order to find out things that cannot be observed and it is important to choose a form of interview suited for the purpose in hand. The four main types of interviews are the completely open, the focused open, the semi-structured and the structured interview, as described below.[61]

- The completely open interview is similar to conversation, albeit, well prepared, and is often used together with "participating observations".
- The focused open interview uses prepared questions that are followed-up by questions based on the respondents answer.
- The semi-structured interview has prepared questions and sub-questions which are asked in a predetermined order which can be answered by either open or fixed answers.

58. Merriam, S. B. (1988). "*Fallstudien som forskningsmetod*" Studentlitteratur, Lund, Sweden.

59. Yin, R. (2003). "*Case study research - Design and methods*" Sage Publications, London, UK.

60. Stake, R. (1995). "*The art of case study research*" SAGE Publications, Thousand Oaks, USA.

61. Lantz, A. (1993). "*Intervjumetodik*" Studentlitteratur, Lund, Sweden.

- The structured interview is almost the opposite to the open interview and all questions are decided in advance in a strictly structured form, similar to a survey. This is suitable for interviewing a large number of people when good statistics are required.

Observations

Observations are the primary source of information in case studies. Direct observations can be made at meetings, during visits in factories and other relevant activities in field visits, and can be combined with other information gathering such as interviews[62]. Participating observations take place in the field and are unique since it is a direct source of information that the researcher himself experiences by participating in the events being studied.[63] Observations are regarded as scientific tools if they fulfil a scientific purpose, are planned and registered and controlled regarding validity and reliability[64]. This is an excellent source of information since it enables the observer to see, hear and experience the real atmosphere, which gives depth to the study, particularly since people sometimes tell more in their every-day environment than in an interview situation. The researcher can thus use his own experience when making his interpretations and does not have to rely on second-hand information[65].

Studies of Documents

Documentation is often written material, reports, letters, internal inquires, etc, it can also be drawings, sketches and other graphical material. The value in a source must be evaluated to ensure its relevance and its availability. Documents are good sources for use in triangulation in conjunction with other sources of information.[66]

---

62. Yin, R .(2003). "*Case study research - Design and methods*" Sage Publications, London, UK.

63. Ibid.

64. Merriam, S. B. (1988). "*Fallstudien som forskningsmetod*" Studentlitteratur, Lund, Sweden.

65. Ibid.

66. Stake, R. (1995). "*The art of case study research*" SAGE Publications, Thousand Oaks, USA.

2.2.3 Data collection in this study

An evaluative case study method was chosen as the main method in this study since it is appropriate for a holistic study where the researcher has an active role in the study and where phenomena are studied in a real-life context in order to describe as well as evaluate and explain. Before the case studies were started, interviews with experts in the field of industrialised house-building were conducted in order to assess the model for the concept.

The main data collected in the study are of a qualitative nature, gathered in the case studies for which a holistic view of the cases was sought, in close relation to the studied system, the persons and objects. However, these qualitative data have in part been analysed and structured in a quantitative way, when levels of implementation were assessed in the companies studied. This is not to be seen as a statistical result, rather as a way of presenting an overview of the companies' maturity in the multi-disciplinary field of industrialised house-building.

Choice of cases

In order to get a differentiated view of the area of industrialised house-building, three cases in separate companies were chosen for the study. The choices were made based on my assessment of how far the companies was developed in the field and whether on-going projects and processes were being undertaken. This assessment was based on meetings with company representatives and material describing the companies and concepts.

The companies chosen are Moelven Byggmodul AB, PEAB Sverige AB and the concept Det Ljuva Livet managed by NCC and developed and executed in collaboration with Finndomo. The three cases are mainly based in the south of Sweden which was a practical matter in the selection. The companies and the cases are thoroughly described in Chapter 5. The three cases represent different approaches within the field of industrialised house-building. This is considered as a strength of the research project since it provides a wide view of the area, in correlation with the aim of the study.

Information gathering

Information was gathered mainly by interviews and direct observations and to a minor extent also by the study of documentation.

For the interviews, a focused open interview was chosen, in which questions were prepared in advance and the interviewees were informed of the topic, albeit, no detailed questions, since this could make the interview too narrow. This interview type was sufficient since it is prepared and structured, but still allows deeper questions and discussions during the interview.

One main set of questions was prepared and used in all interviews in the case studies, but in a limited version for interviews with persons on operational levels in the companies. The expert interviews, conducted prior to the case studies in order to verify the model, were based on one set of questions used in all of these interviews. The interviews were recorded and transcribed by me.

The interviewees were chosen by me, based on the aim to get a view of the companies' work with industrialised house-building from different actors in the process. The case study interviews were carried out in the field, in the interviewees' working environment.

Observations made during these visits at design offices, factories and building sites were documented with protocols, in which conversations, impressions, observed phenomena and other related information were summarized in text. The observations were also complemented with a large number of photographs, from which a selection is shown in the thesis.

In the case studies related documents were studied and this provided a source of complementing and describing information.

2.3 Issues of reliability, validity and generalization

2.3.1 General issues

Reliability is an issue of interest in quantitative studies where it is important to question how reliable the measured data are and whether the experiment was executed properly. In qualitative studies this issue is not of the same interest since the aim is mainly to describe and understand certain factors and is not focused on data for of statistical or other quantitative representation[67]. The issue of reliability in qualitative case stud-

67. Holme, I. M., & Solvang, B. K. (1996). "*Forskningsmetodik. Om kvalitativa och kvantitativa metoder*", Studentlitteratur, Lund, Sweden.

ies is more about choosing appropriate cases than questioning the specific data[68]. Validity is the judgment of whether the collected information is valid or not. In quantitative studies this may be difficult since small deviations can result in invalid data. For qualitative research however, where the researcher himself is an important research tool, the problem is of a different nature. The researcher might misunderstand the situations studied and the relation between the researcher and the persons involved might affect the results of the study for instance, by changed behaviour during observations or interviews[69]. As mentioned above, triangulation is a way to increase the validity, by using multiple sources of information about the same phenomena[70]. A common triangulation method is to combine interviews, observations and physical or documented evidence to establish valid information. Here the case study methodology is a suitable approach[71].

2.3.2 Issues in this study

This is a qualitative study based on case studies and the issue of reliability can be directed to the choice of cases. The studied cases represent different actors within the field of industrialised house-building using different approaches. One could argue that there are other initiatives with a higher degree of industrialisation which hence are of greater interest. Some of these initiatives were not started, or at least not officially at the time I was searching for potential cases to study, which can be considered as evident by the relevance and present development of the subject. Another factor is a question of resources; some interesting companies are situated too far from Lund and would require too much time and money to study. A third issue is that some interesting initiatives have been and still are closed for external researchers due to secrecy policies. The three cases that were chosen are companies working with industrialised house-building and cover both small, medium and large companies working with the concept in different ways and thus the selection of cases has a high level of reliability.

---

68. Merriam, S. B. (1988). ”*Fallstudien som forskningsmetod*” Studentlitteratur, Lund, Sweden.

69. Holme, I. M., & Solvang, B. K. (1996). ”*Forskningsmetodik. Om kvalitativa och kvantitativa metoder*”, Studentlitteratur, Lund, Sweden.

70. Stake, R. (1995). ”*The art of case study research*” SAGE Publications, Thousand Oaks, USA.

71. Merriam, S. B. (1988). ”*Fallstudien som forskningsmetod*” Studentlitteratur, Lund, Sweden.

Information in the cases has been collected via multiple sources in order to establish a valid research material. Several interviews on the same topic were conducted with persons in different positions in the same company, at different appointments, and were recorded. I have spent several days in the factories, at the building sites and in the offices and on these occasions I have observed, discussed and participated in meetings and experienced the real environment in which the activities are carried out. I have constantly asked for documentation of various kinds and received several for my study. By doing this parallel collection of information I consider this research project to be highly valid, especially since I have perceived my visits and relation to all people involved as very open and fruitful. I consider myself to be an open-minded person who can easily communicate with people, both listening and speaking. I therefore consider my studies to have been conducted with sensitivity.

The way of describing the concept of industrialised house-building presented in this thesis in terms of models and concept descriptions, is based on the literature and the case studies in this project. These holistic models and descriptions are intended to be of a general nature and applicable for further research and development in the field. It is important to note is that the material in this thesis is highly focused on industrialised processes for house-building, which means that principles and descriptions presented are not fully applicable to all kinds of building processes. However, separate parts can probably be adapted for other parts of the building industry.

2.3.3 Structure of this research project

The structure of this research project has the following sequence for execution, based on a general scientific research methodology, proposed by Bunge.[72]

- The research area of industrialised house-building was identified and found to be of great interest within the construction industry and among researchers in the field of construction research.
- A basic problem was identified, namely the lack of a clear definition and description of the concept of industrialised house-building.
- Existing knowledge was examined by literature studies, participation in industrial seminars, scientific conferences and courses for researchers. The lack of definition and description was verified.

72. Bunge, M. (1998). "*Philosophy of Science, Volume one – From problem to theory*" Transaction Publishers, New Brunswick, USA.

- A seminar and workshop was held in order to gather knowledge, experience and ideas from experts within the field of industrialised house-building and related industries. At the seminar it was stated that a new concept of house-building would lead to consequences for the building process.
- A definition and a description of the concept were designed.
- In order to test these, interviews with experts in the field were conducted.
- A thorough literature study within the field was conducted
- Three different case studies were done to examine how these companies are working on industrialised house-building. The concept and the process were examined and analysed.
- Based on information from the case studies, the concept of industrialised house-building and the process required for it were presented as two complex models.
- New problems were identified during the research project and documented as proposals for further research.

This sequence, in which a problem is identified, tested and adjusted in several steps, is an important factor for the reliability and scientific quality of the project. The research project was initiated in January 2004 and was finished in June 2006. An overall time schedule is presented below to show the different stages of the project.

The research project was carried out at the Department of Design Methodology, Construction Sciences, at Lund Institute of Technology, Lund University. In addition to the traditional scientific supervision, the research project was supported by a reference group, consisting of representatives from the Swedish industry. The persons in this group work with, and have experience of, construction companies, engineering, industrialised house-building and the ship-building industry. This group has contributed useful experience and the research project has been discussed at several meetings throughout the whole project.

2004

Literature studies, seminars, doctoral courses and conferences.

A seminar within the research project was held in September.

A description and definition was proposed and published in a Swedish Journal for the construction industry.[73]

---

73. Lessing, J., Robertson, A., & Ekholm, A. (2005). ”Industriellt byggande är mer än bara prefabricering” *Bygg&Teknik*, No 2, 2005.

2005

Interviews with experts were executed from April to June. One complementing interview was made in October.

Seminars, doctoral courses and conferences

The concept of industrialised house-building was developed in a conference paper and presented at the conference.[74]

Contacts were taken with companies in preparation for the case studies.

First visits for these case studies were made in September, followed by several visits and interviews over the following six moths. A list of the interviews and visits is presented below.

2006

The case studies were finished in March.

One complementing expert interview was made in March.

The data were analysed and the thesis was written during in early 2006.

Expert interviews

April 1, 2005	Interview with expert #1.
April 8, 2005	Interview with expert #2.
May 25, 2005	Interview with expert #6.
June 13, 2005	Interview with expert #7
June 29, 2005	Interview with expert #4
June 29, 2005	Interview with expert #5
October 3, 2005	Interview with expert #3.

74. Lessing, J., Stehn, L., & Ekholm, A. (2005). ”Industrialised housing – definition and categorization of the concept” *Proceedings IGLC-13*, 13th Annual Conference of the International Group for Lean Construction, Sydney, Australia, 2005.

3 Theory

This chapter presents the theoretical framework, on which this thesis is based. The section is divided into three main parts. The first part describes general issues of industrialisation, production concepts and paradigms. The second part presents theory concerning processes. The third part describes industrialisation of house-building in terms of a historical review,the present status and concepts related to industrialisation.

3.1 Industrialisation

Industrialisation in a historical view means that, in the field of manufacture, technology, organization and social relationships have been altered by the development of modern methods of production, mainly factory production, where work is centrally organized, production operations are mechanized and are focused on mass production[75]. Industrialisation has somewhat varying meanings depending on the context. However, the concept includes some characteristics in terms of mechanization and the use of machines to make the work efficient, the recurrence of operations, the fact that the work is carried out in factories, and that operations are co-ordinated within a company as well as between companies[76].

At the beginning of last century the American car industry began to apply mass production principles. This meant that high volumes of products with limited variation were produced, often by narrowly skilled workers using expensive, single-purpose machines intolerant of disruptions. To ensure a smooth production buffers, of materials and staff were used throughout the production lines, and changes to new products were made as seldom as possible, since this involves high costs.[77] However,

75. http://www.ne.se, *Nationalencyklopedin* (2006), visited 2006-05-18.

76. Jacobsson, M. (1965). *Byggandets industrialisering*, Byggnadsindustrins förlag, Stockholm.

77. Womack, J., Jones, D., & Roos, D. (1990). "*The machine that changed the world – The story of Lean Production*". Harper Perennial, New York, USA.

mass production decreased the cost of products which had previously been produced by traditional craft methods. This was a key principle for industrialisation in the early and mid 1900s[78].

Standardization, modularization and platforms

Standardization means the establishment of systematic regulations in order to achieve optimal technical and economic solutions of recurring problems. This is achieved by predetermined sizes, dimensions and interfaces as well as a limitation of variety, which ensures interchangeability and compatibility as well as flexibility. This is done by the use of standardized modules.[79]

Modularization is a way of dividing a structural system into limited and standardized elements, modules that are provided with common interfaces. Modules with the same interfaces are given different content and with a limited set of different module types unique end-products or -structures are designed.[80]

A platform contains a core of technology, and is described as[81]:

> *"A set of common components, modules or parts that form a common structure from which a stream of derivative products can be efficiently developed and produced."*

End-products are configured with components and parts from the platform into unique products, and benefits are gained when the components of the platform, to a high degree, are used to produce a variety of products with a common technological content. In this way the resources spent on developing the platform are spread over many products, and since the platform has been developed and tested, the quality and reliability of the content of the platform is high. This affects the production positively in terms of reduced manufacturing costs and more stable purchasing patterns. The platform needs to be continuously managed and developed in order to be robust and remain as a foundation in a world of ever-changing demands.[82]

---

78. Womack, J., Jones, D., & Roos, D. (1990). "*The machine that changed the world – The story of Lean Production*". Harper Perennial, New York, USA.
79. http://www.ne.se, *Nationalencyklopedin* (2006), visited 2006-05-18.
80. Johnson, T.. & Bröms, A. (2000). "*Profit beyond measure*" The Free Press, New York, USA.
81. Meyer, M. H., & Lehnerd, A. P. (1997). "*The power of Product Platforms – Building value and cost leadership*" The free press, New York, USA.
82. Ibid.

The Swedish company, Scania, a manufacturer of heavy trucks, has developed a detailed design system based on the principle of modularization. Scania's trucks are based on four main elements, which consist of a number of different modules which fit with any of the other modules. For example, any engine will fit on any chassis. Every module is divided into smaller and smaller sub-modules down to a very detailed level. This modular design principle makes it possible to make small changes in the module set-up of the system and achieve the desired difference of the whole. This ability to change the whole with only a small effort enables Scania to configure each customer's truck directly to order. The company incurs no more design work than if all customers ordered exactly the same product, since the design system is built up of interchangeable modules.[83]

3.2 Production paradigms and concepts

This section describes and explains several production paradigms frequently implemented, and referred to as modern principles of production in the manufacturing industry as well as in other sectors.

3.2.1 Lean Production

Lean Production is a term introduced by a research team at Massachusetts Institute of Technology in its work on the International Motor Vehicle Program (IMVP). This research programme investigated the international automobile industry in order to understand the changes taking place in the industry, driven mainly by the growth of the car manufacturing companies in Japan[84]. Lean production was a radical change from the system of mass production which was the predominant way to produce cars in the western world. The lean production concept had a different approach to manufacturing and its fundamental principles include[85];

83. Johnson, T., & Bröms, A. (2000). "*Profit beyond measure*" The Free Press, New York, USA.

84. Womack, J., Jones, D., & Roos, D. (1990). "*The machine that changed the world – The story of Lean Production*". Harper Perennial, New York, USA.

85. Ibid.

- Teamwork
- Communication
- Efficient use of resources and elimination of waste
- Continuous improvement

A somewhat populistic description of Lean Production is the following, presented by Womack et al, its pioneers.[86]

> *"Lean Production is lean because it uses less of everything compared with mass production – half the human effort in the factory, half the manufacturing space, half the investment in tools, half the engineering hours to develop a new product in half the time. Also it requires far less than half the needed inventory on site, results in many fewer defects, and produces a greater and ever growing variety of products."*

To a great extent the fundamentals of Lean Production are based on the principles of the Toyota Production System, a set of techniques and tools combined with a deeply rooted philosophy and the type of leadership developed at the Toyota Motor Company in Japan. The power of the concept lies in the management's commitment to continuously invest in the company's staff so as to promote a true culture of continuous improvement[87]. This concept has been shown to be extremely powerful for the development of the Toyota Motor Company, which is the most profitable car company in the world[88]. The lean production concept has been widely spread and implemented in all kinds of companies all over the world and is applied not only to manufacturing but to product development, design, service, administration etc[89].

An important part of the Lean paradigm is the "pull" system, meaning that material replenishment is initiated by consumption and stocks are filled up when needed. No goods or services are produced until a customer downstream asks for it.[90]

86. Womack, J., Jones, D., & Roos, D. (1990). "*The machine that changed the world – The story of Lean Production*". Harper Perennial, New York, USA.

87. Ohno, T. (1988). "*Toyota Production System- Beyond Large-Scale Production*" Productivity Press, New York, USA.

88. Liker, J. (2004) "*The Toyota Way*" McGraw-Hill, New York, USA.

89. Womack, J., & Jones, D. (1996). "Lean Thinking – Banish waste and create wealth in your corporation" Free Press, New York.

90. Ohno, T. (1988). "*Toyota Production System- Beyond Large-Scale Production*" Productivity Press, New York, USA.

Lean production includes a complex set of tools and techniques used for the purpose of achieving increased productivity, enhanced quality, shortened lead times and reduced costs, and it affects the whole company, its extended network of partners and the way work is done. There are some fundamental principles in the concept of lean production that together constitute the production system. A model with nine variables, developed by Karlsson & Åhlström, describes the fundamental principles in a condensed way;[91]

1. Elimination of waste
   Everything that does not add value for the customer is waste and should be eliminated. Important sources of waste are inventory, work in progress, transportation and inadequate quality.
2. Continuous improvement
   Kaizen or continuous improvement is a fundamental principle of lean production. It involves everybody in the company, in all departments, and is often carried out through quality circles, which are small groups where suggestions for improvements are discussed.
3. Zero defects
   In order to attain high productivity it is essential that the processes deliver fault-free parts and products. This is achieved by a thorough knowledge of the processes and control of processes rather than products. Quality is everyone's responsibility, not of a quality controller.
4. Just-in-time
   The goal is that every process should be provided with the right part, in the right quantity at exactly the right time. The vision is to produce one piece at a time, exactly when it is needed. Different types of products and parts require different levels of JIT.
5. "Pull" instead of "push"
   Pull is closely related to JIT and means that products are produced as a response to actual customer demands.
6. Multifunctional teams
   A multifunctional team is a group of individuals who together can perform a wide range of tasks and each team member can do more than one task. This leads to lower dependence on single individuals but requires efforts in staff training.

91. Karlsson, C., & Åhlström, P. (1996). "Assessing changes towards lean production". *International Journal. of Operations & Production Management* Vol 16 No 2 1996.

7. Decentralized responsibilities
   Responsibilities are decentralized to the multifunctional teams and the role of a foreman is not needed since specially trained group members do this in rotation.
8. Integrated functions
   Different functions are integrated in the multifunctional teams and the team's tasks increase to involve not only the isolated production operation but also materials handling, procurement, planning and control, maintenance and quality control. This decreases the need of support functions.
9. Vertical information systems
   Information is important for the teams to be able to perform according to the goals set. Information must be shared and provided directly in the production flow. Information is both on the overall performance of the whole company as well as detailed information about the team's performance.

The elimination of waste is essential in the Lean Production concept. When processes are studied concerning waste, it is common finding that less than 5% of all activities actually add value, while about 35% are necessary but do not add value and the rest, 60% is waste. This implies that there is often a huge potential for improvement by the elimination of waste in processes.[92]

The lean philosophy can be divided into three areas that are closely integrated, namely,

- Lean factory
- Lean Design
- Lean supply chain

In the lean factory the workers are in focus since they execute the work and hence know the work best. It is important to work with rewards and motivation in order to develop the culture of continuous improvements. The management of the organization supports the workers with training and development of the processes as well as well suitable tools for the tasks. In Lean Design different departments from the whole company and its suppliers collaborate to develop new products. This work is led by a so called shusa or Large Product Leader who has the authority and resources to run this integrated teamwork. A Lean supply chain means

92. Jones, D. et al. (1997). "Lean logistics" *International Journal of Physical Distribution & Logistics Management*, Vol 27 No 3/4, 1997, pp 153-173.

that the company works with long-term, strategic and transparent relations with key-suppliers and partners who have a strong culture of a common responsibility for the supply chain.[93]

3.2.2 The Toyota Production System (TPS)

The Toyota Production System consists of various elements that together constitute a sophisticated system which depends on all its parts that contribute to the whole. All elements must be practiced continuously if the strengths of the system are to be achieved.[94]

The TPS is often illustrated by the "TPS House" in which the different elements of the system are represented by the essential parts of a house needed for the structure not to fall apart.[95] The TPS House is shown in Figure 3.1.

Figure 3.1 The Toyota Production System presented as the TPS House[96].

93. Womack, J., Jones, D., & Roos, D. (1990). "*The machine that changed the world – The story of Lean Production*". Harper Perennial, New York, USA.
94. Johnson, T., & Bröms, A. (2000). "*Profit beyond measure*" The Free Press, New York, USA.
95. Liker, J. (2004). "*The Toyota Way*" McGraw-Hill, New York, USA.
96. Ibid.

The roof of the TPS house symbolizes the goal to be achieved by the system in terms of best quality, lowest cost, shortest lead time, best safety and high morale. The roof is supported by two pillars Just-in-time and Jidoka. Just-in-time is one of the best known parts of lean production and implies having as little inventory as possible for the process and creating continuous flow and a "pull" system by integrating logistics in the production process. Jidoka means never letting defects pass on to coming stations in the process. In order to solve root-causes, machines or activities are stopped and "why?" is asked five times when a defect is identified. The foundation of the house is illustrated by the strong philosophy of the company, visual management, meaning that the managers are involved in the daily work, and stable and standardized processes that the company relies on and that are well-known to the people involved. At the centre of the house are the people who execute the work and have knowledge of the processes. Also at the centre is waste reduction, including the five "why's" and problem-solving to make the processes as effective as possible. This is achieved by continuous improvements of all parts of the system.[97]

In the TPS, the customer's needs are central and the question "*what does the customer want from this process?*" is asked to identify value-adding activities and waste, or "muda" as it is called in Japanese. Taiichi Ohno, the chief engineer at Toyota and the inventor of the TPS, defined seven major types of waste that do not add value to processes, and hence should be eliminated or minimized. The types of waste are applicable to different kinds of processes, such as product development, order taking, service etc and not only to manufacturing. Ohno's seven types of waste are the following.[98]

1. Overproduction
2. Waiting
3. Unnecessary transport or conveyance
4. Overprocessing or incorrect processing
5. Excess inventory
6. Unnecessary movement
7. Defects

This is the basis of just-in-time (JIT) which is a set of principles, tools and techniques allowing a company to produce and deliver products in small quantities, with short lead times to meet specific customer needs.

97. Liker, J. (2004). "*The Toyota Way*" McGraw-Hill, New York, USA.

98. Ohno, T. (1988). "*Toyota Production System- Beyond Large-Scale Production*" Productivity Press, New York, USA.

In short, to work according to JIT, is to deliver the right items at the right time in the right amount, which allows the company to respond to the shifting demands of customers since the production is flexible in its structure.[99]

Kaizen, or continuous improvement is also central in the TPS and is built up around the systematic problem-solving approach known as the Plan-Do-Check-Act (PDCA) cycle illustrated in Figure 3.2. By continuously making small improvements the lean goal to eliminate all waste that adds cost without adding value can be achieved, but it requires that decisions are taken to the workers for an open discussion and a group consensus before new decisions are implemented. Kaizen is a total philosophy that strives for perfection and zero defects.[100]

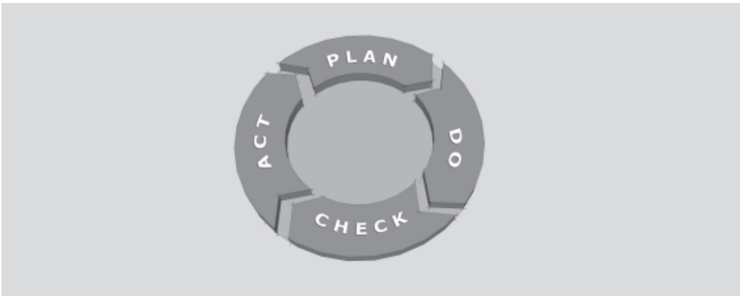

Figure 3.2 *The PDCA cycle which is the foundation for Kaizen – continuous improvements.*

The 4 P model illustrated in Figure 3.3 presents four categories with 14 principles that summarize many of the important elements of lean production and the TPS. The author emphasizes the importance of the inter-relations between the elements and the importance of regarding the system as a whole.[101]

99. Ohno, T. (1988). "*Toyota Production System- Beyond Large-Scale Production*" Productivity Press, New York, USA.

100. Liker, J. (2004). "*The Toyota Way*" McGraw-Hill, New York, USA.

101. Ibid.

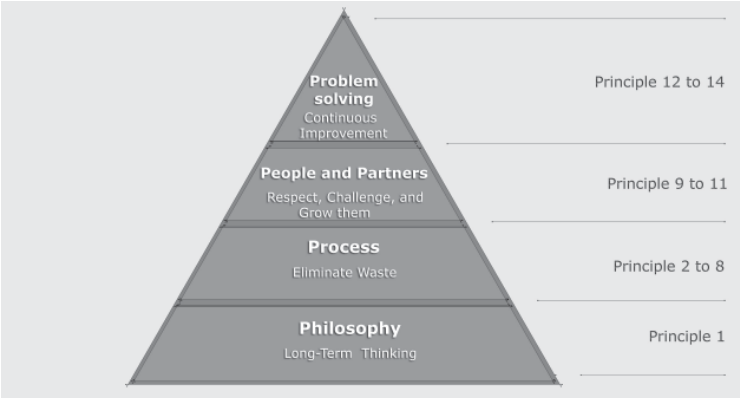

Figure 3.3 The 4-P model of the Toyota Production System[102].

The 14 principles of the Toyota Way are the following;[103]

1. Develop exceptional people and teams who follow the company's philosophy
2. Grow leaders who thoroughly understand the work, live the philosophy and teach it to others
3. Use only reliable, thoroughly tested technology that serves people and processes
4. Use visual control so that no problems are hidden
5. Standardized tasks are the foundation of continuous improvement and employee empowerment
6. Build a culture of stopping to fix problems, to get quality right the first time
7. Level out the work load
8. Use pull systems to avoid overproduction
9. Create continuous process flow to bring problems to the surface
10. Base management decisions on a long-term philosophy, even at the expense of short-term financial goals
11. Respect the extended network of partners and suppliers by challenging them and helping them improve
12. Go and see for yourself to thoroughly understand the situation (genchi genbutsu)
13. Make decisions slowly by consensus, thoroughly considering all options; implement rapidly

102. Liker, J. (2004). "*The Toyota Way*" McGraw-Hill, New York, USA.
103. Ibid.

14. Become a learning organization through relentless reflection and continuous improvement (kaizen)

The first principle stresses that the company must be based on a philosophy beyond making money, a greater purpose that the whole organization can work towards. Value for the customers, the society and the economy is fundamental in the company in which responsible people strive for maintained and improved skills in order to create value.

Principles 2 to 8 focus on the process and are hands-on principles to follow in order to create efficient processes in which waste is minimized and the work flow is optimized. Among these principles many of the well-known tools of Lean Production can be identified, such as the use of a pull system, stopping the process when errors occur and asking “why?” 5 times in order to understand the root of the problem and prevent it, to standardize tasks with best practice and to use only reliable technology in order to ensure a stable production. Further the 5-S-tool is used to minimize waste (Sort, Straighten, Shine, Standardize and Sustain).

Principles 9 to 11 implies the importance of the people in the company and the supply chain. The fundamental principle of “Genchi Genbutsu”, meaning “Go see for your self to understand daily work and related problems”, is applied at all levels of the company. It is important that everybody in the company lives and promotes the culture and philosophy. This is done by grouping people into small teams with clear and challenging goals, which can be measured. Partners in the supply chain are treated as parts of the “family” and help in development is provided since they are just as important for the company’s business as the company’s own processes.

Principles 12 to 14 include the continuous-improvement philosophy, which is a key to the constant striving to attain perfection, in a learning organization. Decisions are based on facts and different options are thoroughly considered but implemented rapidly when the decision is made.[104]

3.2.3 Lean Design

The lean principles are applicable to design work and design processes as well as to production processes. Lean design applied in Japanese car companies has been shown to create better products faster and with less effort than in traditional car companies in the US and Europe[105].

104. Liker, J. (2004). ”*The Toyota Way*” McGraw-Hill, New York, USA.

105. Womack, J., Jones, D., & Roos, D. (1990). “*The machine that changed the world – The story of Lean Production*”. Harper Perennial, New York, USA.

The lean approach to design is to create truly dedicated product teams with skills required for general design, detailed engineering, purchasing, tooling and production planning, with value for the customer as the leading star. The work is done in one room in a short period of time with a standardized decision-making method called the Quality-Function-Deployment, which is followed by every team in the company and hence the different teams' performance can be measured and the method itself can be continuously improved.[106]

The areas of leadership, teamwork, communication and simultaneous development are essential in order to achieve a lean design process. A lean design team has a strong leader who is responsible for the design of the new product and who has the authorization to manage the team. This position is called shusa in Japanese and is the most coveted in the company. The team members come from different departments and have the special skills needed for the design work, and they stay with the team during the life of the project. Early in the project all required specialists are involved and the shusa's role is to encourage the team to agree on all difficult topics. Thus many problems are solved at an early stage in the design project. The difference from a traditional design coordinator is the shusa's power and authority, which is much greater than of a traditional coordinator who often has the frustrating role to lead a group of employees from different departments, with different managers and priorities.[107]

A complex design project requires simultaneous development in different areas in order to be efficient and fast and this requires a direct communication and close cooperation between the design participants. It is important to note that the design team consists not only of designers but also of production, logistics, sales and other specialists so that all crucial competence becomes involved in the design of the product from the start. In this way much waste can be avoided already at the design stage and is not built into the processes.[108]

106. Womack, J., & Jones, D. (1996). "*Lean Thinking – Banish waste and create wealth in your corporation*" Free Press, New York.

107. Womack, J., Jones, D., & Roos, D. (1990). "*The machine that changed the world – The story of Lean Production*". Harper Perennial, New York, USA.

108. Liker, J. (2004). "*The Toyota Way*" McGraw-Hill, New York, USA.

3.2.4 Agile Production

Agile production is a manufacturing concept with many similarities to lean production but with greater emphasis on flexibility and ability to meet customers' exact needs. An agile organization is set up to integrate design, engineering and manufacturing with marketing and sales in order to customize the products according to the exact needs of the customer[109]. In agile manufacturing the production process must be able to quickly respond to changes in the market and rapidly reconfigure the production to meet the new demands. Hence the importance of an effective and reliable information flow is of great importance[110].

To achieve agile manufacturing the organization must be process-oriented with multi-skilled teams that work concurrently (not sequentially) with product design, knowledge of the market segment and production planning, and for this information systems are required[111]. The agile paradigm is multi-dimensioned and is applicable as much to networks as to individual companies and organizations. An important key to success in agile supply chains is the upstream and downstream partners' agility, meaning that a company's own processes will be affected by the partners' responsiveness, and the relations between participants in the supply chain have a great impact on the total outcome of a supply chain.[112]

Comparisons between the lean and agile paradigms show that there are similarities in terms of integration in the supply chain and delivering maximal value to the customer. Differences are most obvious in the ability to handle variations in production volume and the required degree of product variety, which suites agile better than lean production[113]. This is illustrated in Figure 3.4.

---

109. Hormozi, A. M. (2001). "Agile manufacturing: the next logical step". *Benchmarking: An International. Journal*, vol 8 No 2, 2001.

110. Naylor, B. J. et al. (1999). " Leagility: Integrating the lean and agile manufacturing paradigms in the total supply chain" *International Journal of Production Economics* 62 (1999) 107-118.

111. Booth, R. (1996). "Agile manufacturing" *Engineering management journal*, April 1996.

112. Christopher, M. (2005). "*Logistics and Supply Chain Management - Creating value-adding networks*" 3rd Edition, Prentice Hall, UK.

113. Naylor, B. J. et al. (1999). " Leagility: Integrating the lean and agile manufacturing paradigms in the total supply chain" *International Journal of Production Economics* 62 (1999) 107-118.

The following definitions are presented in order to distinctly express the meaning of agility and leanness and hence emphasize the distinguishing features of the paradigms.[114]

- *Agility* means using market knowledge and a virtual corporation to exploit profitable opportunities in a volatile marketplace.
- *Leanness* means developing a value stream to eliminate all waste, including time, and to ensure a levelled schedule

It is important to note that agile manufacturing is not to be seen as a more developed or superior paradigm than lean production, rather as an alternative for supply chains and market places of such a nature that a higher degree of customer service and flexibility is needed. In some cases the lean and agile approaches can be used in the same supply chain, on each side of a decoupling point to get most out of each part of the supply chain. Lean manufacturing can be used as a platform upstream where the demand is stable and produces products to a certain degree of fulfilment, while agile manufacturing can be used downstream in order to handle an unpredictable marketplace. This approach is called leagile.[115]

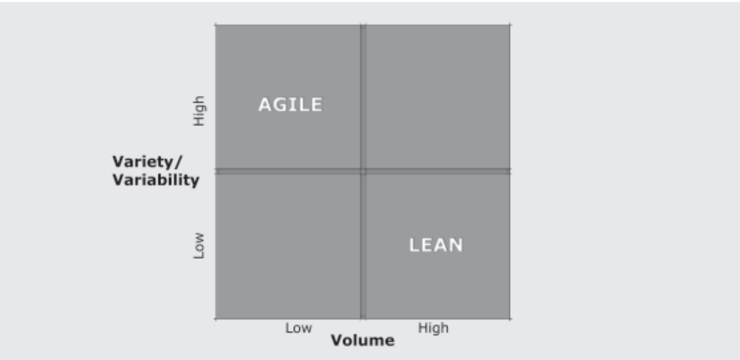

Figure 3.4 Lean and Agile production paradigms suited for different kinds of production[116].

114. Naylor, B. J. et al. (1999). " Leagility: Integrating the lean and agile manufacturing paradigms in the total supply chain" *International Journal of Production Economics* 62 (1999) 107-118.

115. Mason-Jones, R. et al. (2000). "Lean, agile or leagile? Matching your supply chain to the marketplace" *International Journal of Production Research* 2000, vol 38, No17, 4061-4070.

116. Naylor, B. J. et al. (1999). " Leagility: Integrating the lean and agile manufacturing paradigms in the total supply chain" *International Journal of Production Economics* 62 (1999) 107-118.

3.2.5 Six Sigma

Six Sigma is a concept for managing improvements, originally developed at Motorola in the 1980s as a response to the hard competition from Japanese companies and the need to make drastic improvements in quality.[117] The model behind Six Sigma is based on statistical theory, but Six Sigma should be seen rather as a management philosophy. The basic ideas behind the concept is to continuously focus, measure, analyze and decrease the variations in processes, combined with radical and challenging goals for improvements.[118]

Linderman et al define Six Sigma as follows;[119]

> *"Six Sigma is an organized and systematic method for strategic process improvement and new product and service development that relies on statistical methods and the scientific metod to make dramatic reductions in customer defined defect rates"*

The systematic method used in Six Sigma to achieve the goals is summarized in a procedure with Define, Measure, Analyze, Improve, and Control (DMAIC) as key functions and this systematic procedure is the foundation of the concept used in the same way to ensure a common structure in all processes for improvement.[120]

Design for Six Sigma

Design for Six Sigma, DFSS is based on the infrastructure of Six Sigma with explicit roles for the participants in the cross-functional teams, supported by thorough training of the staff, systematic evaluation and fact-based procedures. DFSS is not to be seen as a design principle in its own sight, but rather as a support tool for the design and development process in organizations.[121]

117. Linderman, K. et al. (2003). "Six Sigma: A goal-theoretic perspective" *Journal of Operations management*, 21 (2003) 193-203.
118. Sörqvist, L. (2004). "*Ständiga förbättringar*" Studentlitteratur, Lund, Sweden.
119. Linderman, K. et al. (2003) "Six Sigma: A goal-theoretic perspective" *Journal of Operations management*, 21 (2003) 193-203.
120. Sörqvist, L. (2004). "*Ständiga förbättringar*" Studentlitteratur, Lund, Sweden.
121. Ibid.

3.2.6 Supply Chain Management

Supply Chain Management is widely used and adopted in all kinds of industries. The concept aims at ensuring that products are made available to the customer in a defect-free, efficient and reliable way, which includes the coordination of suppliers and distributors[122]. A related concept is logistics, which is seen as a part of the more comprehensive concept Supply Chain Management[123]. While logistics is the way to plan, implement and control the flow of materials, service and information, Supply Chain Management also includes coordination and collaboration with suppliers and customers in order to achieve integration within and across companies in the total supply chain[124]. The following is important to note; it is the supply chain as a whole system that is to be optimized and not the individual parts, since that leads to severe sub-optimizations. This means that the whole sequence from the raw material supplier to the customer must be considered in order to achieve an efficient supply chain[125].

One established definition of Supply Chain Management is[126]:

> *"The management of upstream and downstream relationships with suppliers and customers to deliver superior customer value at less cost to the supply chain as a whole."*

Another more comprehensive definition is given by Mentzer et al, in order to establish a consistent base for the concept and further research and practice in the field. Supply Chain Management is defined as:[127]

> *"The systemic, strategic coordination of the traditional business functions and the tactics across these business functions within a particular company and across businesses within the supply chain, for the purposes of improving the long-term performance of the individual companies and the supply chain as a whole."*

---

122. Mentzer, J. et al. (2001). "Defining Supply chain management" *Journal of business logistics* , Vol 22, No , 2001.

123. Christopher, M. (2005). "*Logistics and Supply Chain Management - Creating value-adding networks*" 3rd Edition, Prentice Hall, UK.

124. http://www.cscmp.org, *Council of Supply Chain Management Professionals*, visited February 15, 2006.

125. Jones, D. et al. (1997). "*Lean logistics*" International Journal of Physical Distribution & Logistics Management, Vol 27 No 3/4, 1997, pp 153-173.

126. Christopher, M. (2005). "*Logistics and Supply Chain Management - Creating value-adding networks*" 3rd Edition, Prentice Hall, UK.

127. Mentzer, J. et al. (2001). "Defining Supply chain management" *Journal of business logistics* , Vol 22, No , 2001.

> *"A supply chain is a set of three or more entities (organizations or individuals) directly involved in the upstream and downstream flows of products, services, finances, and/or information from a source to a customer."*

As mentioned above, logistics is a part of the supply chain management concept that deals with the management of materials, information and service flow to satisfy customers' needs. Logistics is by its nature a cross-functional concept that seeks to establish cooperation and synchronization between different parts of a company in order to achieve optimal prerequisites for efficient processes. To succeed, this requires thorough planning and information exchange.[128]

In the concept of supply chain management, supplier integration is essential. Strategic suppliers are often included in the manufacturing company's product development processes in order to incorporate suppliers' know-how in the design from the start and hence achieve cost-effective design choices, and select the best components and technologies[129]. Supply chain management can be conceptualized as consisting of three core elements, namely collaboration, value creation and the integration of key business processes, which should be seen from the perspective of the processes throughout the whole supply chain[130].

To achieve a supply chain that fulfils demands of high total efficiency, ability to rapidly respond to changing requirements and deliver maximum value as a whole can only be achieved in close cooperation between participants throughout the whole supply chain, stretching from the point of origin to the end point. This approach has many similarities to the agile paradigm. Seven basic principles that illustrate the corner stones of an agile supply chain are given below.[131]

1 Synchronize activities through shared information

Shared information in the supply chain facilitates a common and effective response to customer demands and changes. Information technology makes it possible for the various participants to share essential infor-

128. Christopher, M. (2005). "*Logistics and Supply Chain Management - Creating value-adding networks*" 3rd Edition, Prentice Hall, UK.

129. Tan, K. et al. (2002). "Supply chain management: a strategic perspective" *International Journal of Operations & Production Management*, Vol 22 No. 6, pp 614-631.

130. Ho, D.C.K. et al (2002). "Empirical research on supply chain management: a critical review and recommendations" *International Journal of Production Research*, 2002, Vol 40, No 17, 4415-4430.

131. Christopher, M. (2005). "*Logistics and Supply Chain Management - Creating value-adding networks*" 3rd Edition, Prentice Hall, UK.

mation such as capacity, time schedules, demand and other related data. A benefit of this is the possibility to achieve just-in-time deliveries since accurate information is provided and is an essential prerequisite for this to work effectively.

2 Work smarter, not harder

A large proportion of the time in processes is non-value-adding, which implies that there is always a potential for time compression and greater efficiency. Inventory is one example of non-value-adding time, when goods and material are being stored instead of moving further in the process. Time compression can be achieved by the elimination of unnecessary activities and fewer things being done at the same time. The structure of the processes must be up-to-date and not based on historical reasons. A continuous improvement of processes is essential.

3 Partner with suppliers to reduce in-bound lead times

Traditionally companies kept a relational distance to their suppliers and the choice of suppliers was based on price only. Close relations with suppliers makes it possible to achieve effective processes within the company, for example, when a supplier takes care of the material supply for the customers' production. This requires close collaboration and trust as well as a reliable information flow.

4 Seek to reduce complexity

Simplification can be achieved by using technical platforms which are used for a group of models or sub-assemblies. The technical content is to a high degree kept the same but is differentiated by exterior design or equipment.

5 Postpone the final configuration/distribution of products

Products are kept non-configured as long as possible in the process in order to maintain the flexibility and minimize the risk of producing products with a configuration that the customer does not want. Postponement can also mean that inventory is held only at a few locations, which allows the company to make rapid shipments when an order is received.

6 Manage processes, not just functions

Functionally based organizations, in which activities take place in separated departments, tend to be focused inwards and to be somewhat slow to respond to changes in the market or business environment. Organizations that are more focused on managing processes that cut across the organization and are organized in inter-disciplinary teams are better suited to respond rapidly to market demands.

7 Utilize appropriate performance metrics

Performance measurement is the key to information on the efficiency of the supply chain. However it is important to use metrics that support desired behaviour and do not lead to sub-optimization in one department just to get good figures. Measures suitable for an agile supply chain are customer-focused, for example to assess whether the customers get exactly what they want, when they want it and at the price they wanted it.

Ideally, supply chain management includes full integration between all participants within a supply chain. However a practical approach to this is to focus on strategic suppliers since most supply chains are too complex to achieve full integration of all members in the chain[132].

3.3 Industrial processes

This Section describes the fundamentals of industrial processes and process orientation, and the principles for managing and structuring processes in organizations.

3.3.1 Process orientation

Process orientation is a way to organize work based on processes and is an alternative to the traditional functional organization with its vertical functions, often illustrated as functional silos, as in Figure 3.5. In such organizations, where different departments work separately with little interaction between them, problems in terms of rivalry, slow response and lack of cooperation between departments are common.[133]

132. Tan, K. et al. (2002). "Supply chain management: a strategic perspective" *International Journal of Operations & Production Management*, Vol 22 No. 6, pp 614-631.

133. Ljungberg, A., & Larsson, E. (2001). "*Processbaserad verksamhetsutveckling*" Studentlitteratur, Lund, Sweden.

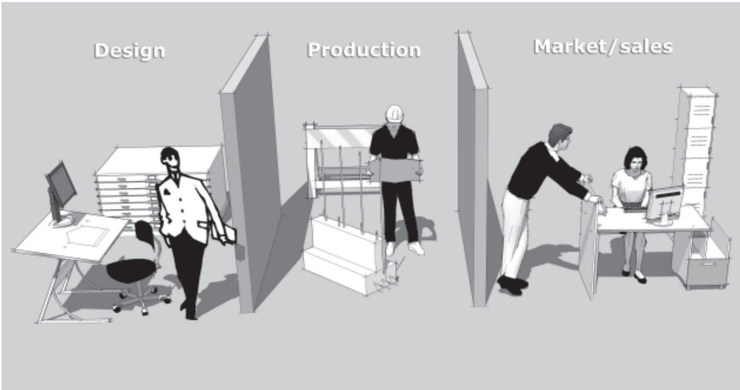

Figure 3.5 Organization with functional silos.

Process orientation is a reaction to this and is based on the principle of creating maximum value for the customer and organizing work in processes that are set up so that necessary parts cooperate and together contribute in the most efficient way to the situation in question. In this way the processes cut across the traditional structure of the organization and involve the departments and functions needed to fulfil the purpose of the process, namely, to have a satisfied customer[134]. This is illustrated in Figure 3.6. Process orientation can be described as a pipeline through the company and all activities required to produce the product or the service, are in the pipeline, ensuring an efficient flow[135].

134. Ljungberg, A., & Larsson, E. (2001). ”*Processbaserad verksamhetsutveckling*” Studentlitteratur, Lund, Sweden.

135. Dicander Alexandersson, M. et al. (1997), ”*Att lyckas med processledning*” Liber Ekonomi, Malmö, Sweden.

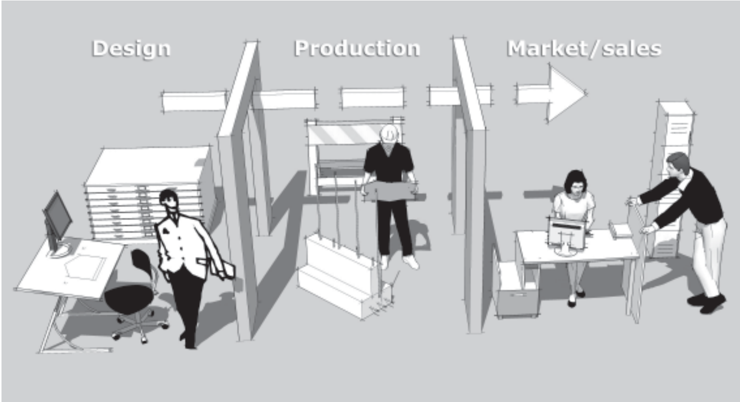

Figure 3.6 A process-oriented organization.

A process can be defined in different ways depending on the context, but fundamental for a process is that linked activities transform input to create output, and that it can be used over and over again. For this thesis the definition presented by Rentzhog is applicable, since it has clear linkages to the supply chain management concept and the customer focus related to the lean and agile paradigms.[136]

> *"A process is a chain of activities that in a recurring flow creates value for a customer"*

It is important to clearly separate the meaning of a *process* and a *project*. A process is used over and over again while a project is defined with a starting point and an end point and with a certain amount of resources. The project ceases to exist after its completion but processes are indefinite in time. This is a very central difference since there are obvious advantages to continuously develop and refine a process because it will be used over and over again, while a project is unique and will not occur again. This implies that the benefits of measurements, improvements and information gathering are scarce for a project, since the unique circumstances are not likely to occur again.[137]

136. Rentzhog, O. (1997). "*Processorientering – En grund för morgondagens organisationer*" Studentlitteratur, Lund, Sweden.

137. Ljungberg, A., & Larsson, E. (2001). "*Processbaserad verksamhetsutveckling*" Studentlitteratur, Lund, Sweden.

Sometimes a process is described as a railway where the infrastructure is maintained and taken care of, improvements are made continuously and at important points technology and routines are developed to create a safe and reliable system. A project in this context is a train using the railway, getting the benefits of a well maintained and developed railway system. The analogy implies that the train-journey has its definition in departure and arrival via a defined route and the railway system is used over and over again with no limits in time.[138]

Processes in an organization can be divided into three types; main processes, supporting processes and management processes.[139]

- *Main processes* are those that generate products or services for the customer and represent the foundation of the business.
- *Supporting processes* are necessary for the main processes to work effectively. These are not critical for the business but still important to support it. Examples of supporting processes are production planning, product development and maintenance of equipment.
- *Management processes* are needed to coordinate and manage the main and supporting processes. These include decision making concerning business directions, to provision of the resources and structures required, and the monitoring of the development of the business.

3.3.2 Process management

The management of processes is essential to get process orientation to work. The leader in a process-oriented organization is the process owner who is responsible for the overall process and its efficiency as well as its continuous improvement. This means that the process owner is responsible for organizing and synchronizing people and activities from different parts of the organization to get the process to function optimally. This responsibility cuts across the traditional and common structure of organizations and therefore it is important that the process owner's authority is clearly related to the participants from different departments involved, and that he/she has the top management's full support. The management of processes can be combined with a process management team, with participants from various sub-processes. Even customers and suppliers can be participants in such a group in order to reinforce the focus

138. Dicander Alexandersson, M. et al. (1997). "*Att lyckas med processledning*" Liber Ekonomi, Malmö, Sweden.

139. Rentzhog, O. (1997). "*Processorientering – En grund för morgondagens organisationer*" Studentlitteratur, Lund, Sweden.

of the process, namely to deliver value to the customer. It is important to get the process management team to act and work for the benefit of the process and not act as representatives of their department, which is a risk, since loyalty to the own department is often very strong. It is therefore important to work for a good team spirit, dedicated to the process and the team, and with its focus on the whole of the process.[140]

3.4 Industrialisation of construction

Industrialisation is used in different contexts and this section gives an overview of the concept applied in the building and housing industry. A historical review as well as a description of the current status of industrialisation is presented together with the core elements of industrialisation of construction.

3.4.1 Historical review

During the 1940s and the 1950s there was a great need for new apartments in Sweden, as in many other countries in Europe, and during the 1950s the building industry started to develop from a craft-based industry to a more automated and technologically developed industry. In 1964 the Swedish government introduced a programme for increased house building in Sweden with the goal to build 100 000 apartments per year over the following ten years, in total one million new apartments. Hence the programme was called the Million programme[141]. During this period the development peaked due to the urgent need and demand for apartments in large numbers in combination with increasing wages for the construction workers and the lack of skilled workers. With higher automation and systems developed for pre-assembly and systems building it was possible to use unskilled workers on lower wages[142]. The government was deeply engaged in the building industry and housing production partly via different kinds of loans and financing concepts that

140. Rentzhog, O. (1997). ”*Processorientering – En grund för morgondagens organisationer*” Studentlitteratur, Lund, Sweden.

141. Statens råd för byggnadsforskning, Moby-kommitén (1975). ”*Monteringsbyggda flerfamiljshus*”.

142. Ibid.

encouraged the production of apartments in large-scale projects with 1000 apartments or more[143]. A large-scale project from the 1960s is shown in Figure 3.7.

Figure 3.7 *Building with concrete elements during the so called Million Programme*[144].

The need of more apartments during the 1960s was huge and the solution was industrialisation of the house-building industry. Industrialisation of building was at this time, just as now, understood as the application of industrial principles to the building industry. However, the dominating industrial principles at that time were focused on mass production with large series, technological standardization, limited choice & variation and coordination of tasks and people.[145] In the opening speech of the 3rd CIB congress on the topic "Towards industrialised building" in 1965 the Swede, Professor Myrdal stated the following[146]:

143. Statens råd för byggnadsforskning, Moby-kommitén (1975). "*Monteringsbyggda flerfamiljshus*".

144. Marmstål, M. (1992). "*Byggarna och maskinerna*" Byggförlaget, Stockholm, Sweden.

145. International Council for Building Research, Studies and Documentation – CIB (1965). "*Towards Industrialised Building*" Proceedings of the third CIB Congress, Copenhagen, 1965.

146. Myrdal, G. (1965). "*Towards Industrialised Building*" Proceedings of the third CIB Congress, Copenhagen, 1965, International Council for Building Research, Studies and Documentation – CIB .

> *"How could it be that in the year of 1965 – in the era of automatic computers and rockets to the moon – the subject of a big congress like this of technicians in a crucial sector of every national economy could be how to proceed towards industrialisation? How can this major sector of economic activity be so retarded that not until recent years has industrialisation been taken up as a subject for serious discussion? How can it be that the problem of building industrialisation has still not been adequately solved even in the most developed countries?"*

During this period the term industrialised building was used frequently and the term was mostly understood as synonymous with systems building, building with prefabricated elements, assembly building or design for production.[147,148,149]

However there were definitions with a wider context. In his book from 1965, Jacobsson presents the following definition;[150]

> *"Industrialisation of construction activities include a striving to develop and make the production effective, regarding quality and economy by the use of scientific knowledge, repeating work processes in factories, design offices and at building sites, and by the co-ordination of different activities within and between companies"*

A dominating aspect of industrialised building was that the production of building parts was moved from the building site to factories where standardized components were mass-produced[151]. There was a marked technological development, and sophisticated solutions for standardized and prefabricated systems soon became available for all parts of a building[152]. For example structural elements, cladding, roof structures, service installations were prefabricated for housing projects[153]. An example

---

147. Deeson, A. F. L. (1967). "*The Comprehensive Industrialised Building Systems Annual*"Product Journals Ltd, West Wickham, UK.

148. Ahrbom, N. (1983). "*Arkitektur och samhälle – funderingar över 50 års svensk arkitektur*" Arkitektur Förlag AB, Stockholm, Sweden.

149. International Council for Building Research, Studies and Documentation – CIB (1965). "*Towards Industrialised Building*" Proceedings of the third CIB Congress, Copenhagen, 1965.

150. Jacobsson, M. (1965). *Byggandets industrialisering*, Byggnadsindustrins förlag, Stockholm.

151. Adler, P. (2001). "*Monteringsbyggda flerbostadshus*", Kungliga Tekniska Högskolan, Stockholm 2001.

152. Skarne, A. (1987). "*Med kran och krok*" Byggförlaget, Stockholm, Sweden.

153. Statens råd för byggnadsforskning (1969). "*Elementbyggnad – problem och forskningsbehov*" Programskrift Nr 10, 1969, Svensk Byggtjänst, Stockholm, Sweden.

of a prefabricated kitchen from 1969 is shown in Figure 3.8[154]. Also aspects of standardization of the information flow were considered at this time, the categorization of drawings and documents, as well as the distribution of drawings well before production start, were stated to be important steps towards industrialisation[155].

The large scale production of apartment houses decreased abruptly in the early 1970s since the need for apartments was in practice satisfied and the Million Programme was fulfilled. This sudden change in demand led to radical structural changes in the house-building industry. Much of the technology and production systems which had been developed, ceased to be used, since they had been dimensioned for the production of large volumes. Using them in small-scale projects precluded the achievement of the same advantages of scale.[156]

The use of technical building systems for apartment houses can be regarded as having evolved through three generations of systems strategies according to Adler[157]. During the 1960s the dominating strategy was to use closed technical building systems for the building of new, large-scale housing projects, and these systems were developed and owned by large companies. When the market changed and smaller projects dominated, the closed systems were replaced by open systems, now possible for smaller companies to use. During the 1980s the third generation of building systems entered the market based on open systems supported by information technology and automation for the production of elements. Instead of having the complete house standardized, the components were standardized and interchangeable. Unique buildings were designed and could be built up of such components.[158]

Single family houses

The production of single family houses was in general extensive during the period from the 1950s to the middle of the 1970s and increased from about 20.000 to about 40.000 houses per year, following the trend of

155. Tyrén, S., & Åkerblad, H. (1965). ” The rationalisation of drawings – Carrying on of rationalisation work” *Proceedings of the third CIB Congress*, Copenhagen, 1965, International Council for Building Research, Studies and Documentation – CIB.

156. Adler, P. (2005). ”*Bygga industrialiserat*”, Svensk Byggtjänst, Stockholm, Sweden.

157. Ibid.

158. Ibid.

increased production of apartments as described above. Also this production was supported by the government by beneficial tax rules[159]. About 2/3 of the total volume of single family houses were manufactured in factories producing complete houses, and the development of technology and methods was intense also for this part of the building sector. The main production method was prefabrication of timber frame elements that were assembled on the building site[160]. The decrease in demand during the 1970s was not as abrupt for single family houses as for apartments. Hence this part of the house-building industry could continue to use the established production methods and systems, which are still in use by companies producing this kind of houses[161].

Figure 3.8 A prefabricated kitchen in a volume element during the 1960s[162].

The part of the Swedish house-building industry that is mainly focused on single family houses is structurally different from the traditional building industry. There are a large number of relatively small companies specialised in producing single family houses based on building systems with timber frames manufactured in the companies' own factories. The level of prefabrication is generally high and a large part of the work is carried

159. Boverket (2005). "*Bostäder byggda med volymelement – En fallstudie av svenska bostadsprojekt*", Boverket, Karlskrona, Sweden.

160. Statens råd för byggnadsforskning (1970). "*40 sätt att bygga småhus*", Svensk byggtjänst, Stockholm, Sweden.

161. Boverket (2005). "*Bostäder byggda med volymelement – En fallstudie av svenska bostadsprojekt*", Boverket, Karlskrona, Sweden.

162. Marmstål, M. (1992). "*Byggarna och maskinerna*" Byggförlaget, Stockholm, Sweden.

out in the factories. The companies often control a large part of the building process, including design, manufacture, assembly and finishing work on-site[163]. This part of the industry is often described as being relatively industrialised with great potential to develop further for the construction of apartment houses[164]. One example of this is the BoKlok concept developed in a collaboration between the large Swedish construction company Skanska and the furniture company IKEA in the mid 1990s. BoKlok is a well-defined product, namely a small, two-storey apartment house which is manufactured as timber-based volume elements in a housing factory owned by Skanska[165]. Another example is Det Ljuva Livet which is a similar concept developed and managed by the large Swedish construction company NCC together with the housing manufacturer Finndomo in 2002. This is also a well-defined product, but nevertheless applicable to houses and apartment blocks of different sizes according to the site in question[166].

Current industrialisation

At present there is a strong trend towards industrialisation in house-building in Sweden. This was initiated in about the year 2000 when the building industry was thoroughly investigated by governmental and industry-commissions which concluded that the industry needed to develop in order to reduce the costs, increase quality and develop production methods, and industrialisation was seen as a means to achieve these goals[167], as described in the introduction in chapter 1.

The contemporary industrialisation of house-building is a complex concept in which several areas have been developed in order to achieve a more efficient, qualitative and reliable house-building process. A key factor is prefabrication together with building systems available, but also advanced IT-solutions and logistics are crucial to a successful development of industrialisation[168]. It also includes systematic use of previous

163. Bergström, M., & Stehn, L. (2005). ”Ett effektivt stombyggande i trä” *Bygg & Teknik Nr 2*, 2005.

164. Brege, S. et al. (2004). ”*Trämanufaktur – det systembärande innovationssystemet*”, Vinnova Analys 2004:02, Verket för Innovationsanalys.

165. Boverket (2005). ”*Bostäder byggda med volymelement – En fallstudie av svenska bostadsprojekt*”, Boverket, Karlskrona, Sweden.

166. Ibid.

167. Byggkommisionen (2002). ”*Skärpning gubbar! Om konkurrensen, kvaliteten, kostnaderna och kompetensen i byggsektorn*”, Statens Offentliga Utredningar 2002:115, Fritzes Offentliga Publikationer, Stockholm, Sweden.

168. Olofsson, T. et al. (2004). ”Industriellt byggande - byggbranschens nya patentlösning?” *Väg- och Vattenbyggaren*, No 5, 2004.

experience to create a continuous work flow. This can be achieved when building parts are manufactured by industrial processes, to which inspiration can be brought from the lean production paradigm[169]. An industrialised house-building process must be focused on delivering apartments and residential areas demanded by the customers, which means that a thorough knowledge of the customer's needs and priorities is essential in industrialised house-building of today[170].

In recent years several companies in the Swedish house-building industry have worked with development programmes aimed at industrialisation with various focuses. The housing company JM has developed guidelines for the design of apartment houses, which has led to decreased variation of technical solutions, with positive effects for the procurement process[171]. The construction company Skanska has an industrialisation programme running which was initially was focused on the building of apartment houses. The aim is to develop the whole construction process and hence several areas are developed together in order to establish a strong concept. One central area of development is modularization of different building parts, which together constitute a platform for apartment houses that will be produced off-site by specialised suppliers. This, together with new global purchase and logistical patterns, advanced IT tools for e-commerce and planning, as well as new routines of knowledge management, constitute the industrialised concept for Skanska[172]. A newly established house-building company called Open House Production has developed a building system based on steel frames, pre-assembled as volume elements with a high degree of completion in the company's own factory[173]. The company controls the whole process, including design, manufacture, assembly and finishing work on-site, which is supported by a thorough documentation of technical solutions as well as of the sub-processes[174].

---

169. Hellström, A. (2004). ”Att bygga med industriella metoder” *Väg- och Vattenbyggaren*, No 5, 2004.

170. Engström, D., & Claeson-Jonsson, C. (2005). ”Industrialiserat byggande betyder inte nya betonggetton!” *Väg- och Vattenbyggaren*, No 2, 2005.

171. Strand, P. (2005). ”Strukturerad projektering ger ett industrialiserat byggande” *Väg- och Vattenbyggaren*, No 2, 2005.

172. Fritzon, M. (2005). ”Industrialiserat byggande i Skanskas tappning” *Väg- och Vattenbyggaren*, No 2, 2005.

173. Lessing, J. (2004.) ”*Industrial production of apartments with steel frame – A study of the Open House System*” The Swedish Institute of Steel Construction, Report 229:4, Stockholm, Sweden.

174. Åberg, U. (2004). ”En industrialiserad byggprocess – möjlighet eller myt?” *Väg- och Vattenbyggaren*, No 5, 2004.

The client company Svenska Bostäder is working with industrialised house-building in terms of using prefabricated modules to a large extent and developing collaboration methods, especially in the early stages of a project in which the architect, designers, suppliers and contractors cooperate. This company has also developed a standardised apartment house that has been built several times, and which has resulted in substantially decreased production costs[175]. Another Client company, Riksbyggen, is developing a new process for housing projects which focuses on the structure of projects with certain demands on the different stages of the project, and also on documenting and re-using good technical solutions[176]. Over the past four years, the construction company NCC has developed a totally new concept for industrialised house-building which was launched in April 2006. The company has developed a platform, with standardised technical solutions with high flexibility. The production takes place in the company's new factory and about 90% of all required tasks are executed there. The building elements are produced and completed with installations, windows, wall paper, flooring, kitchen equipment etc. Bathrooms are purchased from an external supplier as ready-made volume elements. The site has the character of final assembly and is covered by a large, temporary production hall that ensures a stable and reliable working environment and protects the building elements from weather exposure. The concept is supported by IT tools that use 3D CAD models to supply automated machines in the factory with data and also support the planning and purchase processes with accurate information.[177]

3.4.2 Elements of industrialisation

One important and central part of industrialised house-building is the prefabrication of building parts. However it takes more than only prefabrication to establish a strong industrialised concept[178]. Industrialised house-building is today regarded as a complex concept involving several interacting sub-areas which may have reached different levels of industrialisation. However it is important to maintain a perspective of systems thinking and a holistic view, so that no part is optimized at the expense

175. Hindersson, P. (2005). ”Upprepning och samverkan är A och O” *Byggindustrin*, No 33, 2005.

176. Arnborg, S., Orrberg, L., & Edblom, A. (2005). Presentation at the seminar “*Design i det industrialiserade byggandet – processer och roller*” Vinnova, Stockholm 2005-05-18.

177. http://www.ncc.se, visited 2005-04-25.

178. Lessing, J. et al. (2005). ”Industriellt byggande är mer än bara prefabricering” *Bygg&Teknik*, No 2, 2005.

of the whole[179]. A Danish study on the topic mentions 11 areas that are included in the concept and emphasizes that industrialisation implies the structuring of processes and methods in order to achieve higher quality, fewer defects and fewer non-value adding activities[180].

- Products and processes are explicitly documented
- Suitable and proper production system
- Knowledge about the product and the process
- Repetition and strict methods
- Skilled and trained work force
- Knowledge management for continuous improvements
- Controlled output of product and process
- Repeatable technology
- Market orientation
- Quality throughout the process
- Product development integrated with process development

Standardization

An essential part of industrialisation is the systematic use of technical systems and components with different levels of standardization, that together form the unique end products – the buildings and apartments. Gibb states that the standardization of components and products is a foundation for further development of the house-building industry, achieved through continual improvement, in the same way as in other industrial sectors[181]. An important area for standardization is the interfaces between components rather than the components themselves[182]. Also Crowly states that the interchangeability of parts and the simplicity of attaching them to each other are keys to the industrialisation of construction and requires great attention in the design of systems and build-

179. Gann, D. (2000). "*Building Innovation: Complex Constructs in a changing world*" Thomas Thelford, London.

180. Mikkelsen, M. et al. (2005). "*Systemleverancer i byggeriet – en udredning til arbejdsbrug*" Institut for Produktion og Ledelse, Denmark Technological University, Lyngby, Denmark.

181. Gibb, A. G. F. (2001). "Standardization and pre-assembly – distinguishing myth from reality using case study research" *Construction Management and Economics* (2001) 19, 307–315.

182. Ibid.

ings[183]. However, standardization is applicable not only to technical artefacts but also to processes and methods, as expressed in the following definition[184]:

> *"Standardization is the extensive use of components, methods or processes in which there is regularity, repetition and a background of successful practice and predictability."*

The use of standardized technical systems is closely connected to pre-assembly and off-site production of building parts, which range from the level of component manufacture to a complex level where modular building parts are produced and finally assembled at the building site. Four categories of pre-assembly are specified and described in Table 3.1[185].

Table 3.1 Definitions of pre-assembly terms[186]

Term	Description
Component manufacture and sub-assembly	Many components used in construction are manufactured elsewhere and sub-assembled at the building site. These products would never be considered for on-site assembly.Examples of such products are doors, windows and light fittings.
Non-volumetric pre-assembly	Items assembled in a factory or at least off-site and may include several sub-assemblies and constitute a major part of the building or structure. Examples include wall panels, structural sections and pipe work assembly.
Volumetric pre-assembly	Factory-assembled items that are assembled to a volume element and usually installed on-site within an independent structural frame. Examples include toilet pods, service risers and modular lift shafts.
Modular building	Similar to volumetric units but the units themselves form the building but may be complemented on-site. Examples are office blocks, motels and modular units for residential blocks.

183. Crowley, A. (1998). "Construction as a manufacturing process: Lessons from the automotive industry" *Computers and Structures* 67 (1998) 389-400.
184. Gibb, A. G. F. (2001). "Standardization and pre-assembly – distinguishing myth from reality using case study research" *Construction Management and Economics* (2001) 19, 307–315.
185. Ibid.
186. Ibid.

The combination of standardization and pre-assembly is regarded as a strong concept which leads to possibilities to develop technology and processes for improved productivity, coordination and control. Changes of this kind often require a reorganization of the production system which approaches the concept of supply chain management.[187]

Two strategies in development of building systems are identified in a contemporary Danish study. The first is the "Component & Element Strategy", meaning that various structures are designed with components and elements, based on defined principles, and the second is the "Complete System Strategy" where complete system solutions are used for a complete building, based on rigid building concepts. These two strategies can be seen as two extremes on an axis. Also the elements used in these strategies can be divided in two extremes where one is the open system with flexible combinations of components and the other is a closed system in which the components used are unique to the system. This categorization of building systems is illustrated in Figure 3.9.[188]

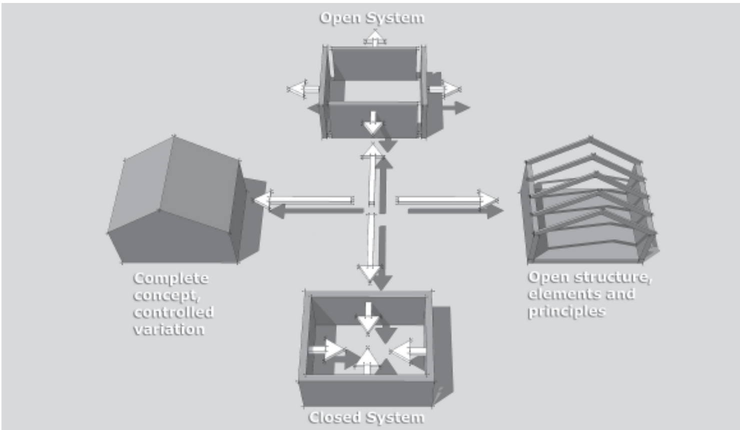

Figure 3.9 *Diagram of the categorization of building systems*[189].

187. Barlow, J. et al. (2003). "Choice and delivery in housebuilding: lessons from Japan for housebuilders" *Building Research and Information* 31(2), 134-145.

188. Mikkelsen, M. et al. (2005). "*Systemleverancer i byggeriet – en udredning til arbejdsbrug*" Institut for Produktion og Ledelse, Denmark Technological University, Lyngby, Denmark.

189. Ibid.

Prefabrication

Industrialised house-building differs from traditional house building in several ways. A central aspect of industrialisation is the pre-fabrication of structural elements, but changes in products and processes are also required to achieve efficient construction methods[190]. For a customer-oriented process it is essential to think systematically of the process as a whole including the structure and organization. Related to this is the question of the level of pre-assembly and standardization and where the value-adding activities are best conducted in order to maximize the benefit in the supply chain[191].

Industrialisation of construction, with focus on prefabrication, can be seen as a structural action to eliminate on-site activities which require a new design of the supply chain. The structure and behaviour of the total process is changed in terms of a longer over-all process, the need for more detailed design, a longer correction cycle and the requirement of higher accuracy. An industrialised building process tends to be complex and must be managed well if the intended benefits are to be gained. If not, the risk is great that waste and non-value-adding activities increase greatly due to badly controlled design, fabrication and site processes thus vitiating the expected benefits.[192]

Information technology

The breakthrough of information technology within the building industry has implied many changes, e.g. in design and production methods, in the automation of the manufacture of products and materials as well as for the improvement of product performance[193]. Information and communication technology (ICT) today provides technical possibilities to support the supply of products and services, manage demands and solutions as well as share knowledge and experience among participants in the building process[194]. In the manufacturing industry information sys-

190. Roy, R., Brown, J., & Gaze, C. (2003). “Re-engineering the construction process in the speculative house building sector” *Construction Management and Economics* 21(2), 137-146.

191. Barlow, J. et al. (2003). “Choice and delivery in housebuilding: lessons from Japan for housebuilders” *Building Research and Information* 31(2), 134-145.

192. Vriejhoef, R., & Koskela, L. (2000). The four roles of Supply Chain Management in Construction, *European Journal of Purchasing & Supply Management*, Vol 6, pp. 169-178.

193. Adler, P. (2005). ”*Bygga industrialiserat*” Svensk Byggtjänst, Stockholm, Sweden.

194. Apleberger, L. et al. (2003). ”*ICT 2008 Informations och Kommunikationsteknologi för Bygg, Anläggning och Förvaltning - Ett Innovationsprogram*” ICT 2008, Stockholm, Sweden.

tems have played an essential role in productivity development and support of processes, such as manufacturing, sales, product development and logistics. The house-building industry has opportunities to benefit from advanced ICT tools such as Product Data Model systems and Enterprise Resource Planning systems. However, this requires a process orientation in the company and developed industrial methods in order to maximize the benefits of such systems[195]. For industrialised house-building the use of product models is useful since it enables effective and accurate exchange and use of information of all types needed in the process e.g. 3D models, calculations, CAD drawings, time schedules and costs, etc[196].

Product development

The actors in the building industry are familiar with and organized for working in projects but are generally inexperienced in participating in product development processes[197]. Product development in the manufacturing industry is today often integrated with the development of production and marketing & sales in order to achieve an over-all, efficient process[198]. One strategy for achieving an efficient, high-quality and flexible building process is to develop new technology as platforms[199]. A platform is seen as a defined set of common components, modules or parts from which a variety of end-products can be developed and launched[200]. The platform or module must be designed to attain an effective and high-quality production of its parts, of the assembly on the building site and of the subsequent complementing in-fill process[201].

---

195. Olofsson, T. et al. (2004). "*Produktmodeller i ett flexibelt industriellt byggande*" Teknisk rapport 2004:06, Institutionen för Samhällsbyggnad, Avdelningen för Konstruktionsteknik, Luleå Tekniska Universitet.

196. Tarandi, V. (2005). "IT-stöd för ett industriellt byggande – ett gemensamt språk" *Väg- och Vattenbyggaren*, No 2, 2005.

197. Mikkelsen, M. et al. (2005). "*Systemleverancer i byggeriet – en udredning til arbejdsbrug*" Institut for Produktion og Ledelse, Denmark Technological University, Lyngby, Denmark.

198. Olofsson, T. et al. (2004). "*Produktmodeller i ett flexibelt industriellt byggande*" Teknisk rapport 2004:06, Institutionen för Samhällsbyggnad, Avdelningen för Konstruktionsteknik, Luleå Tekniska Universitet.

199. Roy, R., Brown, J., & Gaze, C. (2003). "Re-engineering the construction process in the speculative house building sector" *Construction Management and Economics* 21(2), 137-146.

200. Meyer, M. H., & Lehnerd, A. P. (1997). "*The power of Product Platforms: Building value and cost leadership*" Free Press, New York, USA.

201. Roy, R., Brown, J., & Gaze, C. (2003). "Re-engineering the construction process in the speculative house building sector" *Construction Management and Economics* 21(2), 137-146.

Product development requires a dedicated product team with competence ranging from design and production to supply and market knowledge, working together continuously and not only focused on unique projects[202]. For the house-building industry two main development tracks have been identified, one is to develop existing products and modules to fit into technical platforms, and the other is to develop new modules and components to be integrated into the platforms[203]. A process based on technical platforms and module manufacturing will require a new role for managing the platform, a module integrator, who is responsible for the development, design, supply and installation to completion, where the customization for a unique customer starts[204].

The building process

A change towards system integration for industrialised house-building and mass customization will lead to considerable implications for the building process, as it will involve design for modularity and efficient assembly, process engineering and efficient supply chain management[205]. An industrialised house-building process requires a radical change from today's project focused, site-based construction work and culture to a building process that reflects the manufacturing culture in order to achieve the benefits of standardization and pre-assembly. For the concept to be successful, this requires an understanding of and true commitment by the whole project team, as well as early agreement on critical information[206].

Roy et al suggest that the building company should divide the building process into the production of a small number of key modules, and have multi-skilled teams responsible for its completion. This change from a sequential process to modular building simplifies the planning and con-

---

202. The Construction Task Force (1998). "*Rethinking Construction*" Department of Trade and Industry, London, UK.

203. Mikkelsen, M. et al. (2005). "*Systemleverancer i byggeriet – en udredning til arbejdsbrug*" Institut for Produktion og Ledelse, Denmark Technological University, Lyngby, Denmark.

204. Roy, R., Brown, J., & Gaze, C. (2003). "Re-engineering the construction process in the speculative house building sector" *Construction Management and Economics* 21(2), 137-146.

205. Ibid.

206. Gibb, A. G. F. (2001). "Standardization and pre-assembly – distinguishing myth from reality using case study research" *Construction Management and Economics* (2001) 19, 307–315.

trol of the work since multi-skilled teams take care of a wider range of tasks. A pilot use of this method showed a 50% decrease in defects.[207] This change of the process in which technical platforms are developed separately, modules manufactured off-site based on contemporary industrial principles and the unique buildings configured based on customer requirements call for a new management role. This role would be to manage the whole process from development, specific design, manufacture and assembly and see to the holistic picture in order to avoid sub-optimization in any part of the supply chain[208].

A standardization of processes and procedures leads to a more streamlined building process with reduced waste in time and resources and increased confidence in project outcomes, since the actors become more familiar with the processes[209]. Related to this is the fact that standardized tasks and sub-processes enable the implementation of performance measurement, which is a key to learning about the process outcome and to make systematic improvements[210]. Case studies in the UK have shown that industrialised house-building processes in which construction work moved into a factory with a more controllable environment, safety, productivity and quality improved, combined with less waste and less impact on the environment. This environment provides opportunities for processes and procedures to be standardized and systematized, and hence the possibilities to support these processes with IT-systems and management systems increase[211].

207. Roy, R., Brown, J., & Gaze, C. (2003). “Re-engineering the construction process in the speculative house building sector” *Construction Management and Economics* 21(2), 137-146.

208. Mikkelsen, M. et al. (2005). “*Systemleverancer i byggeriet – en udredning til arbejdsbrug*” Institut for Produktion og Ledelse, Denmark Technological University, Lyngby, Denmark.

209. Gibb, A. G. F. (2001). “Standardization and pre-assembly – distinguishing myth from reality using case study research” *Construction Management and Economics* (2001) 19, 307–315.

210. The Construction Task Force (1998). “*Rethinking Construction*” Department of Trade and Industry, London, UK.

211. Gibb, A. G. F. (2001). “Standardization and pre-assembly – distinguishing myth from reality using case study research” *Construction Management and Economics* (2001) 19, 307–315.0

3.5 Production concepts for building

This Section describes several concepts and production strategies applied in the housing and building industry. There are clear linkages and relations to the paradigms used in the manufacturing industry, as presented above.

3.5.1 Production strategies

The set-up of the building process depends on the kind of production to be carried out. This and customer involvement, combined with the limitations associated with the use of pre-engineered systems, have generated four production strategies and process flows. These strategies are suited to different kinds of production and different kinds of project types, ranging from projects initiated with conceptual ideas to ready-made products produced on forecast, as shown below.[212]

Concept to Order

The customer enters the process at the start of the information flow and is the one initiating the process with a conceptual design.

Design to Order

The company has a basic product concept, but extensive engineering work is required for the unique client and the building in question.

Make to Order

The company has a fully detailed design of the product which can be configured according to the client's desire within certain limits. The customer initiates the flow of material when the order is signed.

Make to Forecast

The company produces products without having a customer involved. The product is sold after or during manufacture.

These four production strategies are illustrated in Figure 3.10.

212. Winch, G. (2003). Models of manufacturing and the construction process: the genesis of re-engineering construction. *Building Research & Information* 2003, 31(2), 107-118.

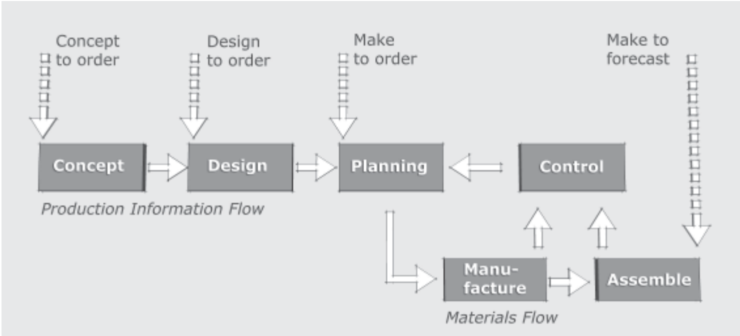

Figure 3.10 *Four production strategies with related information and materials flow*[213].

Winch argues that the production of private housing is well suited to a Make-to-Order strategy which has many similarities to the lean and agile production concepts. He further states that the production of buildings, including residential housing, is traditionally based on a Concept-to-Order strategy but should move towards a Design-to-Order strategy in order to gain the benefits from well developed systems e.g. a rapid and compressed building process. To achieve this it is suggested that concept owners act as "system integrators" who offer modularised solutions that can meet the clients' particular needs. For some actors and products the Make-to-Order strategy is applicable even for residential buildings of standardised building types.[214]

In an extensive study of Japanese housing companies it was stated that it is possible to combine high levels of standardization and prefabrication with customization. However it requires an organization structured and organized according to the manufacturing strategy and the whole supply chain must be designed to support the customer/product concept which the company is using[215].

213. Winch, G. (2003). Models of manufacturing and the construction process: the genesis of re-engineering construction. *Building Research & Information* 2003, 31(2), 107-118.

214. Ibid.

215. Barlow, J. et al (2003). "Choice and delivery in housebuilding: lessons from Japan for housebuilders" *Building Research and Information* 31(2), 134-145.

3.5.2 Lean Construction

In construction the lean paradigm is adopted under the name Lean Construction. Lean Construction is to a great extent based on the fundamental principles of Lean Production and is applied to construction processes on the basic assumption that construction is a special kind of production with its own peculiarities[216]. The fundamental aim in Lean Construction is to deliver maximum value for the customer at the project level, to design the product and the process concurrently, as well as applying production control through the whole life cycle of the project[217].

The Lean Construction concept is mainly focused on the traditional construction process, characterized as the design and assembly of objects fixed-in-place and with a production of unique products, produced by unique teams, where lean principles are applied and developed in order to make this complex environment more reliable and efficient for example, by planning and control methods[218]. Lean Construction has to deal with two parts of the lean approach of which the first is to explore the possibilities to take advantage of lean techniques developed in manufacturing, and the second is to develop lean techniques for the dynamic construction process, which is a great challenge since this type of production is fundamentally different from manufacturing[219].

Bertelsen also argues that the Lean Construction movement is facing a change as two strategies appear, the *product* strategy and the *process* strategy. The product strategy is described as the transfer of increasingly more of the construction work to off-site manufacturing and the construction site is changed to a final-assembly site. The process strategy is based on the idea that construction is a special kind of production where unique large-scale products are built on-site and that methods must be developed to handle this situation in the most effective way. The construction process is in this context understood as a dynamic complex

216. Bertelsen, S. (2004). ”Lean Construction: Where are we and how to proceed?” *Lean Construction Journal* 2004, Vol 1 #1 2004.

217. Howell, G. (1999). ”What is lean construction -1999” *Proceedings IGLC-7*. Seventh Annual Conference of the International Group for Lean Construction, Berkely, California, USA 1999.

218. Ballard, G., & Howell, G. (1998). ”What kind of production is construction?” *Proceedings IGLC-6*, 6th Annual Conference of the International Group for Lean Construction, Guarujá, Brazil, 1998.

219. Ibid.

system where focus is on improving the flow and value generation[220]. The first approach, also described as the product strategy is well suited to the industrialisation movement where initiatives such as manufactured housing are developed[221]. In relation to this it is stated that product and process design can be standardized for standard buildings, while for non-standard buildings it is necessary to standardize at the meta-level of planning and control. This means that it is necessary to develop standard procedures for the planning and control of design and installation of unique facilities[222].

Lean Construction has no clear definition, it is rather based on the fundamental lean principles, mentioned above. However, a wide variety of topics are explored within the area of Lean Construction which implies that the concept affects many different sub-areas needed for the efficiency of the construction process as a whole. Areas covered in Lean Construction are, among others[223];

- *Lean Supply Chain Management*
- *Product Development*
- *IT Support for Lean Construction*
- *Management of People and Teams*
- *Production Planning and Control*
- *Prefabrication, Assembly and Open Building*
- *Flowline*
- *Safety, Quality and Environmental Management Systems*

The Lean Project Delivery System

The Lean Project Delivery System is a model used to describe the construction process divided into inter-connected phases and modules that together form the system, as illustrated in Figure 3.11. The main phases of the construction process are illustrated by four triangles in which nine

220. Bertelsen, S. (2004). ”Lean Construction: Where are we and how to proceed?” *Lean Construction Journal* 2004, Vol 1 #1 2004.

221. Ballard, G., & Howell, G. (1998). ”What kind of production is construction?” *Proceedings IGLC-6*, 6th Annual Conference of the International Group for Lean Construction, Guarujá, Brazil, 1998.

222. Ibid.

223. IGLC-13 (2005). “*Proceedings 13th International Group for Lean Construction Conference*”, Sydney, Australia, 2005.

modules with different functions are placed. The corners of the triangles overlap to illustrate that the various phases are closely linked and must interact to work effectively. The Production Control and the Work Structuring modules support the whole system and are spread over the whole life cycle of the project. The Evaluation module is the link from the finished project to forthcoming projects and represents the fundamental principle of continuous improvements and re-use of experience.[224]

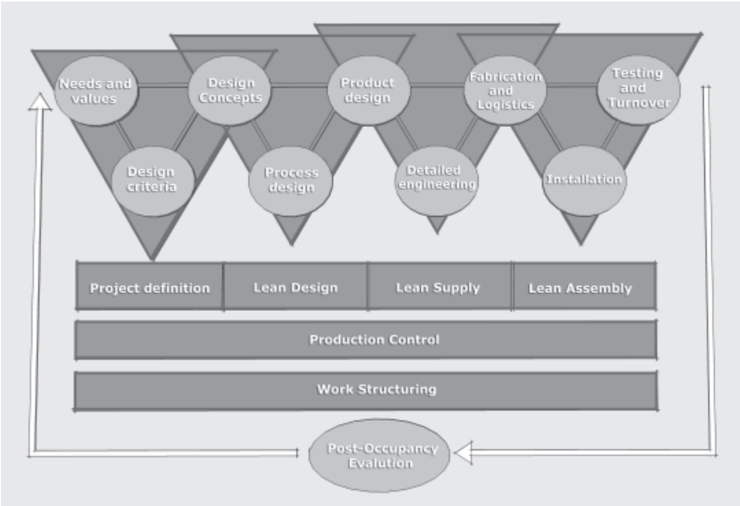

Figure 3.11 The Lean Project Delivery System[225].

3.5.3 Lean Production in construction

In Japan the lean production concept is applied to industrialised house-building, especially for modular unit housing production systems that balance aspects of customization and standardization to ensure that the products – the houses, are competitive on the market, and that the design and production processes are developed to be highly efficient. This is achieved by an over-all management and control of the whole process of house building including design, sales, supply chain management, factory production and erection of the houses on-site[226]. Japanese compa-

224. Ballard, G. (2000). Lean Project Delivery System. *LCI White Paper-8*, Lean Construction Institute.

225. Ibid.

226. Gann, D.M. (1996). "Construction as a manufacturing process? Similarities and differences between industrialized housing and car production in Japan" *Construction Management and Economics* 14, 437-450.

nies producing modular unit housing have adopted techniques and process tools developed in the manufacturing industry, including the Just-In-Time principle, quality circles, advanced, automated machines, automated materials handling and storage of goods as well as training of sub-contractors and partners in order to ensure quality and efficiency in every stage of the construction process[227]. The housing company Toyota Homes even shares and transfers production line workers between its car factories and its housing factory in order to transfer expertise and also level out fluctuations in the demand for labour. In this way the manufacturing culture is spread effectively[228].

A lean producer of buildings needs to form close relationships with its lean suppliers – the architects, engineering design consultants and sub-contractors. These suppliers do not compete on the basis of every project, rather on the ability and willingness to work closely with the main contractor and the rest of the team on a long-term basis covering a number of projects[229]. It is a culture of partnership that must be established in order to improve the performance of the supply chain by continuous collaboration between the participants instead of in short-term contracts[230]. This transformation to lean production of buildings requires organisational change in many companies since this way in working is different from that in a traditional organisational set-up. One trend is that the producing company will merge with architects, engineers and sub-contractors in order to manage and control the building process as a whole.[231] Lean production delivers maximum flexibility, efficiency and quality in an environment where all activities, from design to production and final assembly, take place in close collaboration and where it is easy for the participants in the different stages of the production cycles to meet face to face and share information and together solve problems[232].

---

227. Gann, D.M. (1996). "Construction as a manufacturing process? Similarities and differences between industrialized housing and car production in Japan" *Construction Management and Economics* 14, 437-450.

228. Ibid.

229. Crowley, A. (1998). "Construction as a manufacturing process: Lessons from the automotive industry" *Computers and Structures* 67 (1998) 389-400.

230. Roy, R., Brown, J., & Gaze, C. (2003). "Re-engineering the construction process in the speculative house building sector" *Construction Management and Economics* 21(2), 137-146.

231. Crowley, A. (1998). "*Construction as a manufacturing process: Lessons from the automotive industry*" Computers and Structures 67 (1998) 389-400.

232. Gann, D.M. (1996). "Construction as a manufacturing process? Similarities and differences between industrialized housing and car production in Japan" *Construction Management and Economics* 14, 437-450.

3.5.4 Agile Production in construction

Customers today demand a high degree of choice which has led to the need for a system that can combine the benefits of mass production with systems allowing customer choice to a high degree, as well as total control of the construction process, found in the system of mass customization[233].

Changes in relations with customers and suppliers together with closer integration between market, design, and production and improved information processing are identified as ways of reaching flexibility in production processes to allow mass customization in house-building[234]. Barlow has identified a number of significant requirements for agile production, which are applicable and hold great potential for the house-building industry[235];

- Concurrent engineering, interdisciplinary design and computer-integrated manu-facturing
- Just-In-Time supply of components
- Improved capture of individual customer requirements and increased customer input into the design process
- Customer-centred, rather than cost-accounting, performance measures.

These requirements, ranging over both technological and organisational development, require a flexible organization structure and non-hierachical management style and the support of reliable information flow via sophisticated IT systems[236]. To encourage house-building towards an agile production system which is able to deliver products according to customer requirements, requires more than the implementation of only some of the requirements mentioned above. The concept must be seen as a system in which the parts together form the whole and hence must be implemented as such, based on a strategy[237]. To establish a house-build-

233. Barlow, J. et al. (2003). “Choice and delivery in housebuilding: lessons from Japan for housebuilders” *Building Research and Information* 31(2), 134-145.

234. Barlow, J. (1999). “From craft production to mass customisation: innovation requirements for the UK housebuilding industry”. *Housing Studies* 14(1), 23-42.

235. Ibid.

236. Barlow, J. (1998). ”From craft production to mass customization? Customer-focused approaches to housebuilding” *Proceedings IGLC-6*, 6th Annual Conference of the International Group for Lean Construction, Guarujá, Brazil, 1998.

237. Barlow, J. et al. (2003). “Choice and delivery in housebuilding: lessons from Japan for housebuilders” *Building Research and Information* 31(2), 134-145.

ing process that can offer products in an efficient manner, with high quality and with the capability to handle customization, it is necessary to combine technological platforms in close collaboration between the participants[238]. This does not mean that the only solution is that one large company controls the whole building process. The agile production concept is well suited also for small firms working together in close cooperation, since the concept is built up on collaborative models of organisation[239].

A schematic comparison of house building and car manufacturing is illustrated in Figure 3.13. It can be illustrated that house building to a great extent is still based on craft methods, but by innovations, such as improved supply chain management, supplier relationships and increased customer focus, if combined in a holistic way, can become lean or agile production instead of mass production.[240]

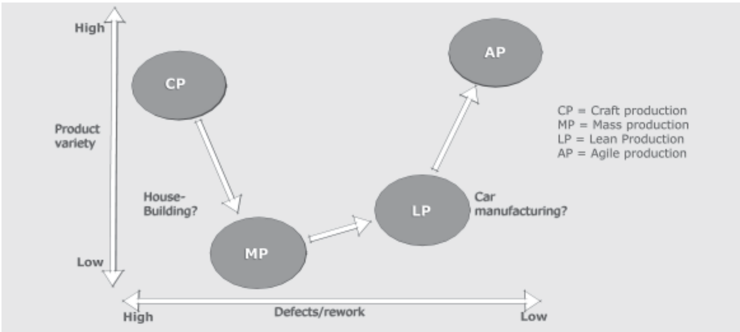

Figure 3.12 Production paradigms in the housing and car industries[241].

Both the lean and the agile approaches are applicable to the house-building industry, albeit, applied to segments with different focus. By viewing the supply chain as a whole it is possible to determine the paradigm

238. Roy, R., Brown, J., & Gaze, C. (2003). “Re-engineering the construction process in the speculative house building sector” *Construction Management and Economics* 21(2), 137-146.

239. Barlow, J. (1998). ”From craft production to mass customization? Customer-focused approaches to housebuilding” *Proceedings IGLC-6*, 6th Annual Conference of the International Group for Lean Construction, Guarujá, Brazil, 1998.

240. Ibid.

241. Ibid.

suitable for a certain part of the house building industry. In some cases a mix between the two paradigms is possible, where the lean principles are followed up-stream to a certain decoupling point and the agile principles are followed downstream of this point, as illustrated in Figure 3.13.[242]

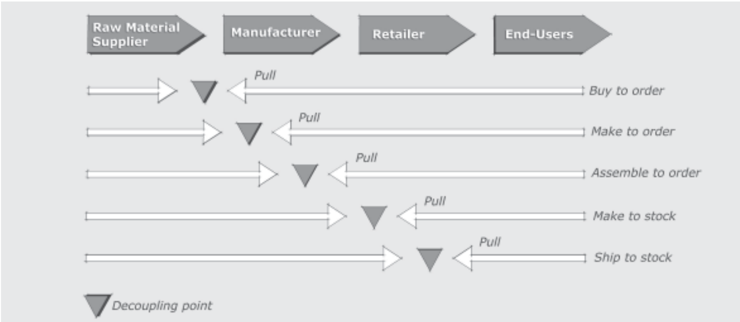

Figure 3.13 The lean and agile approaches used on each side of a decoupling point.[243]

In order to design an appropriate supply chain, the type of product has to be clearly defined in terms of flexibility in design, customer adjustments and market segment. The level of standardized components and elements can then be decided and thus the network of suppliers, contractors, consultants and others will be affected[244].

The mass customization and agile concepts utilize IT support to a higher degree than the lean concept since it enables customization and the related information flow. It also acts as an incentive for organisational change towards agility[245].

242. Naim, M., & Barlow, J. (2003). "An innovative supply chain strategy for customized housing" *Construction Management and Economics*, 21, 593-602.
243. Ibid.
244. Ibid.
245. Sahin, F. (2000). "Manufacturing competitiveness: different systems to achieve the same results". *Production and Inventory Management Journal* 41(1), 56-65.

3.5.5 Supply Chain Management in construction

Logistics and supply chain management are generally unknown and undeveloped concepts within the traditional building industry[246], while the manufacturing industry has achieved productivity gains throughout the entire supply chain via the SCM concept[247]. When applied, the focus has been mostly on the flow of materials with the aim to establish better conditions on the construction site[248], [249]. Nevertheless, by taking an active role in the organization of the logistics on behalf of the construction supply chain, similarly to trends in the automotive industry, the builder will benefit greatly[250]. The logistics and SCM disciplines have shown great potential to increase the efficiency in the construction process and have resulted in benefits such as less waste of materials, a smoother process and reduced working time on site due to better planning and more efficient collaboration between participants established through an improved information flow[251]. In order to improve the supply chain performance a key issue is to strive for a partnership culture in which the relations between participants stretch beyond one isolated project[252]. Improved logistics in the construction process require improved communication and established relations between the parties throughout the whole process. Strategic logistic work has to start early in the process and involve those who design the building, those who design components, those who plan, specify and account for the work, if benefits are to be gained[253]. This is also a key finding of Olsson who states

246. Agapiou, A. et al. (1998). "The role of logistics in the materials flow control process". *Construction Management and Economics* 16, 131-137.

247. London, K.A., & Kenley, R. (2001). "An industrial organization economic supply chain approach for the construction industry: a review" *Construction Management and Economics*. 19, 777-788.

248. Ibid.

249. Hyll, H. (2005). "*Logistical principles in construction supply chains*" Dep. of Industrial Management and Logistics, Lund University, Lund, Sweden.

250. Roy, R., Brown, J., & Gaze, C. (2003). "Re-engineering the construction process in the speculative house building sector" *Construction Management and Economics* 21(2), 137-146.

251. Agapiou, A. et al. (1998). "The role of logistics in the materials flow control process". *Construction Management and Economics* 16, 131-137.

252. Roy, R., Brown, J., & Gaze, C. (2003). "Re-engineering the construction process in the speculative house building sector" *Construction Management and Economics* 21(2), 137-146.

253. Agapiou, A. et al. (1998). "The role of logistics in the materials flow control process". *Construction Management and Economics* 16, 131-137.

that to really benefit from the potential of supply chain management in building processes, aspects concerning supply of materials and components, supplier involvement and methods for storage of goods must be integrated in the early stages of the design phase. He introduces a model for this kind of collaboration between the participants in the construction process (vertical axis) and the material and component supply chain (horizontal axis), as illustrated in Figure 3.14[254].

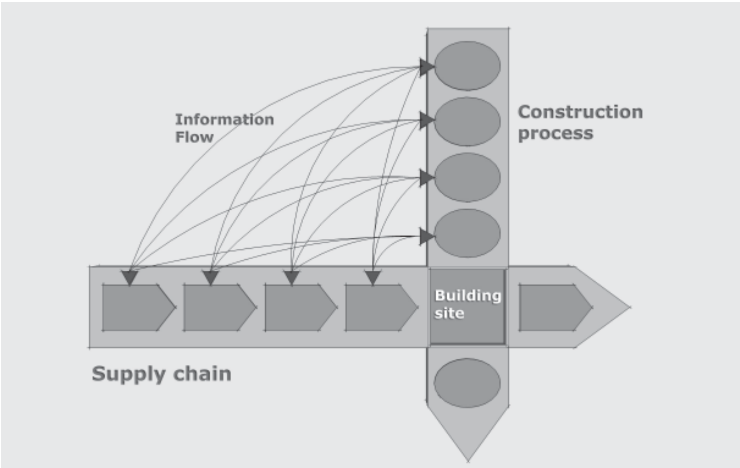

Figure 3.14 The integration between the construction process and the supply chain[255].

Vriejhoef & Koskela introduce four roles of Supply Chain Management for construction which can be seen as approaches for different kinds of construction[256], illustrated in Figure 3.15. Role 1 has its focus on the interface between the supply chain and the building site, an approach similar to the one presented by Olsson as referred to above[257]. Role 2

254. Olsson, F. (2000). "*Supply chain management in the construction industry -Opportunity or utopia*?" Dep. of Design Sciences, Logistics, Lund University, Lund, Sweden.
255. Ibid.
256. Vriejhoef, R., & Koskela, L. (2000). "The four roles of Supply Chain Management in Construction", *European Journal of Purchasing & Supply Management*, Vol 6, pp. 169-178.
257. Olsson, F. (2000). "*Supply chain management in the construction industry -Opportunity or utopia*?" Dep. of Design Sciences, Logistics, Lund University, Lund, Sweden.

focuses on making the supply chain, as efficient as possible. Both these roles focus on the traditional construction supply chain while Role 3 and 4 are focused on the redesign of the construction process .[258]

Role 3 focuses on redesigning the supply chain by transferring activities from the building site to earlier stages of the supply chain in order to gain benefits in producing building parts off-site. In this way the difficult production environment on-site is avoided and possibilities for wider concurrency between activities arise, which is not possible with on-site production due to complex dependencies between activities.

Role 4 has its focus on integrated management and improvement of both the supply chain and the on-site production, meaning that the activities on-site are seen as activities within the supply chain. Initiatives in this direction are often based on the idea that stable supply chains and high degree of standardised products will lead to a more effective process. This, however, leads to restrictions of the end-product and will affect market opportunities and ability to meet customer demands.

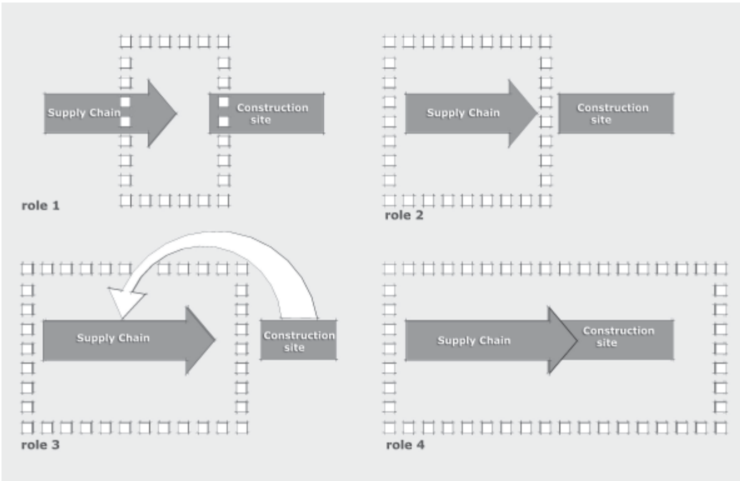

Figure 3.15 The four roles of supply chain management in construction[259].

258. Vriejhoef, R., & Koskela, L. (2000). “The four roles of Supply Chain Management in Construction”, *European Journal of Purchasing & Supply Management*, Vol 6, pp. 169-178.

259. Ibid.

4 Synthesis of the theory

This chapter presents a synthesis of the theory and presents the concept of industrialised house-building, which is the foundation for this thesis. The result of a set of expert interviews is also presented in this chapter.

The Lean and Agile paradigms in conjunction with the principles of Supply Chain management are based on the systems approach, in which the parts of a system must be integrated and managed as a whole in order to deliver maximum value to the customers and by which sub-optimization in sub-processes must be avoided. These production paradigms all require processes which are under continuous development, adjustment and improvement, together with standardized technical systems and solutions used in the processes. (Section 3.2, 3.5)

Another central aspect of the Lean, Agile and SCM paradigms is their focus on the customer. The processes, systems and products must be designed to deliver value for the customer in the most efficient way, which requires thorough knowledge about the customers' priorities and needs, as well as knowledge of the production system's possibilities, strengths and weaknesses (Section 3.2, 3.5). The customers' demands on the house-building industry today is high and must be handled carefully, which implies a major change in approach compared to the 1960s, when the focus was on mass production and house-building was highly regulated. These laws and regulations also had the effect that large-scale production was promoted (Section 3.4).

Lean Production implies that continuous development and improvements of products and processes are important and are natural parts of the system and that all participants must continuously contribute (Section 3.2.1, 3.2.2). It is necessary to have established processes and developed systems as a foundation of continuity in the company and the whole supply chain (Section 3.4.2). By a continuous use of technical systems and platforms the possibilities for pre-assembly are established since this also requires continuity and long-term conditions (Section 3.4.2). Supply chains are built up by several different companies working together to deliver value for the customer. This requires long-term commitment and close collaboration to create effective common processes and knowledge. Continuity of processes, systems and relations creates a demand and an obvious need to make use of experience and knowledge for further development (Section 3.3). This makes the development of performance measurement and knowledge management important for the creation of create industrial processes.

The flow of materials and related information is essential for an efficient production process and accordingly also for a housing production process. The use and integration of tools and principles of logistics and information technology are therefore central for a production system (Section 3.5.5).

4.1 Industrialised house-building processes and projects

This section describes three important issues for the concept of industrialised house-building. The issues are synthesized from the theory in this thesis and the author's ideas for the area. The three issues are the foundation for the case studies described further in this thesis.

4.1.1 Project and Process distinction

Production paradigms and philosophies are based on the idea of continuity and require a long-term process that handles the systems and strategies and improves the quality of products and services. The use of technical systems and platforms, relations between actors, the production system, the logistic patterns, procurement strategies etc. are areas that require continuity and are built up on a long-term perspective.

The traditional house-building process is not designed with continuity as a foundation, it is rather focused on the uniqueness and the singularity of projects characterized by unique choices of technical solutions, a limited use of platforms, uniquely combined teams and scarcely developed logistics and procurement strategies (Section 1.1). In this context the need for measurements and knowledge management, the establishment of developed collaboration, introduction of advanced information technology and other long-term activities are difficult and expensive and the conception of their need and usefulness is limited, because of the lack of continuity (Section 3.3.1).

An industrialised house-building process, however, should be based on continuity and should be designed to continuously grasp new experience and knowledge as well as continuously develop the collaboration between the actors in the process. In the realization of specific projects, technical systems, thorough planning, advanced logistics and procurement should be used continuously and supported by ICT tools. The purpose of such a process is to establish the most efficient and reliable structures for each specific project and hence deliver houses and apartments to the customers' wishes and priorities (Section 3.5).

An industrialised house-building process is undefined in time and runs continuously (Section 3.3). The process handles development and improvement of technical systems, collaboration strategies, production strategies and supporting systems and processes, leading to greater efficiency and reliability. This process provides the foundation for the execution of specific projects in which the systems are used, as well as strategies and tools, to create maximum customer value within the project (Section 3.4.2).

4.1.2 Process and Product Development

In order to establish a new, developed industrialised house-building process, it needs to be developed separately within a process development project in the company or group of companies. In the development of a new process, key personnel from departments throughout the company and its partners should be involved in order to create a process in which all crucial parts are considered and the structure is designed holistically with customer value as its guiding star (Section 3.4.2). The new process needs to be thoroughly documented, discussed and established before being implemented. Without thorough documentation a process will run the risk of not being followed, and the possibilities to make follow-ups and improvements will be limited.

Technical systems and platforms should also be developed separately from specific housing projects and should be treated and managed as product development projects. The solutions must be thoroughly documented in order to establish an efficient flow of information and a base for further development (Section 3.4). The systems and platforms should be developed and tested thoroughly before implementation in real projects, in order to ensure the quality and suitability of the systems. When the systems are in use, they should be continuously developed on the basis of experience gained from the projects, as a part of the continuous process (Section 3.4, 3.3).

The development of technical systems and platforms must be closely integrated and synchronized with the process development since they influence each other greatly. The process will handle the platforms and integrate them with the rest of the production system thus making the need for integrated design obvious (Section 3.5.2, 3.5.4).

4.1.3 Process and Project Management

An industrialised house-building process need to have a clear process management, with an overview of all involved sub-processes and with the authority to manage the process throughout the company's departments. The appointment of the Process Owner should be made by the company's management (Section 3.4.2, 3.3.2).

The Process Owner is in charge of the industrialised house-building process covering the process structure, product and process development and improvements as well as the house-building process. This role requires an overview of the process and its parts, and the holistic synchronization of tasks managed by different managers in the process. The Process Owner is responsible for the evaluation of the collaboration between actors in the process and make the decisions concerning the development of platforms and systems based on experience and assessments made in the process. Further, the Process Owner should manage the improvement of the design, manufacture and assembly processes, the improvement of logistics and procurement in the process and the evaluation of the customers' opinion of the products delivered. In short, the Process Owner should manage the process as a whole, with the help of managers of the various sections and sub-processes involved (Section 3.4.2, 3.3.2).

Another key position in an industrialised house-building process is the Project Manager. This person should manage the production of specific housing projects. This means working with the teams, using the routines, tools and supporting systems of the process, and also handling all specific, unique information in the project in order to deliver the specific building to the specific customer. This position is important since it is the Process Owner's "deputy" in the projects and delivers important information about the platforms and the sub-processes back to the Process Owner (Section 3.5.1).

4.2 Industrialised house-building – definition and categorization

The concept of industrialised house-building lacks a clear definition which is evident since the concept is described in various ways. Prefabrication and systems building are essential parts of the historical understanding of industrialised house-building (Section 3.4.1), while the contemporary understanding is wider and includes more process-related aspects such as collaboration between participants and suppliers. The potentials of ICT is another factor mentioned as being important for the development of industrialised house-building (Section 3.4.1, 3.4.2). The focus on the customer, in order to be able to deliver the desired end-product, is crucial for a process and hence an important part of industrialised house-building (Section 3.4.1). Production paradigms applied in other industrial sectors such as the automotive industry have proved to be applicable, with modifications for the housing industry's peculiarities. These paradigms include several aspects that are suitable for the present application of industrialised house-building (Section 3.5.3, 3.5.4, 3.5.5).

With input from the historical descriptions, the present understanding and with inspiration from production paradigms and concepts, a frame work is of the concept of industrialised house-building is given, on which further work and research in the area can be based.

A definition is presented and eight characteristic areas that together constitute the concept are identified. These will form a foundation for further work on industrialised house-building in this thesis.

A definition of Industrialised house-building is proposed to be the following:

> *"Industrialised house-building is a thoroughly developed building process with a well-suited organization for efficient management, preparation and control of the included activities, flows, resources and results for which highly developed components are used in order to create maximum customer value."*

This definition implies the complexity of the concept by including both process, organizational and technological aspects that must be developed in order to achieve an industrialised house-building process. The mid section of the definition indicates the importance of controlled processes, which are achieved by thorough preparations by a well-suited organization, within the company and throughout the supply chain, where the participants contribute their knowledge and act together as a team (Section 3.2.6, 3.4.2).

There is an important difference between this definition and the historical understanding of industrialised house-building where prefabrication was the most central aspect (Section 3.4.1). Nevertheless the term "highly developed components" is included, which means that prefabrication and developed systems should be used as one important part of the holistic concept (Section 3.4.2). The last section of the definition is fundamental since it states that the whole concept must aim at creating value for the customer, which is the whole reason for the process (Section 3.3.1, 3.5.4).

The definition is complemented with eight characteristic areas that further describe the content and significance of industrialised house-building. These eight areas are listed and described below.

1. Planning and control of the processes
2. Developed technical systems
3. Off-site manufacture of building parts
4. Long-term relations between participants
5. Logistics integrated in the construction process
6. Customer focus
7. Use of information and communication technology
8. Systematic performance measurement and re-use of experience

Planning and control of the processes

The design, manufacture, assembly and other related processes require a coherent struc-ture and management in order to attain the goals and deliver maximum value to the customers. A thorough planning of all activities is therefore required, especially in the early stages of a project where extra attention must be paid to design (architectural as well as engineering), planning and preparation (Section 3.4.2, 3.5.2). By implementing well-prepared processes, with a finalized design at the initiation of the production and the use of separately developed technical systems, supported by structured planning methods, the execution of a process will run smoothly with an overall aim of avoiding defects and errors. The elimination of faults and the minimisation of waste is constantly aimed for (Section 3.2, 3.4.2). Clearly defined roles for process management and project management are crucial for the continuity of the processes (Section 3.3.2).

Developed technical systems

In order to minimise defects and create an effective process, technical systems are developed in separate product development processes, in which the design is tested, adjusted and developed to a high level of completion. These systems are then used in the design and production of unique housing projects. The technical systems include frame solutions, electrical and sanitary installations, façade systems etc. with different levels of flexibility. Experience from previous projects is used as input for the further development of the individual system (Section 3.4).

Off-site manufacture of building parts

Building parts are manufactured in an environment suited for effective production, where advanced equipment can be used and the working conditions are good. The manufactured elements are of a high level of completion in order to minimise work at the building site. As many parts of the building as possible are manufactured off-site and finally assembled at the building site (Section 3.4).

Long-term relations between participants

The participants in the processes are engaged on a long-term basis in order to develop their mutual relations. Better performance and an enhancement of the efficiency of production, in which maximum value is created, is thus achieved (Section 3.4.2, 3.5.4). The team of participating firms is put together on the basis of certain criteria to establish good conditions for cooperation to achieve common goals and to create value for the customer. Long-term relations mean that the team can start projects rapidly, since they have a structure for their co-operation. Thus, since tenders need not to be sought, and contractors and designers do not need to be evaluated, valuable time can be saved (Section 3.5.1).

Logistics integrated in the construction process

By moving construction activities upstream from the construction site to factories where pre-assembly is carried out, high demands will be made on the management of the supply chain and logistic activities. The supply chain is divided into two main parts, the pre-assembly factories and the construction site, which have different demands on the supply chain (Section 3.5.5). Pre-assembly involves purchasing, materials handling, supplier involvement, trans-portation and supply patterns, etc. Activities on the construction site are the final assembly and complementing work. The deliveries of elements and components must be thoroughly planned and work according to the JIT principle, implemented in close collaboration with component and element suppliers (Section 3.4.2, 3.5.4, 3.5.5).

Customer focus

A clear focus on the customer is a necessity in order to ensure that the right products, of the right quality at the right cost are produced for the end-customer as well as the clients (Section 3.2, 3.5.4). This approach means that thorough surveys and investigations must be made in order to perceive the customers' needs and priorities, which are then used as the foundation of the design of the processes (Section 3.4, 3.5). The market can be divided into different segments with different priorities which must be considered when the production concept and related issues are decided (Section 3.5.1). All activities in the processes should be focused on delivering value for the customers (Section 3.5.3, 3.5.4).

Use of information and communication technology

Industrialised processes require accurate and reliable information. Modern ICT (Information and Communication Technology) provides tools that effectively handle, update and change digital material and provide solutions for information exchange and data storage. An extensive use of modern IT-tools supports the different processes with more accurate information and hence good conditions for an effective production in which errors are discovered early and problems in the manufacturing and assembly phases are avoided (Section 3.2.6, 3.4, 3.5.4).

Systematic performance measurement and re-use of experience

Industrialised house-building concerns the use and improvement of effective methods and solutions for house-building. In order to supply information about the processes and the technical solutions, extensive, continuous measurement and follow-ups are needed, concerning both soft and hard parameters (Section 3.2.2, 3.2.5). Experience and measurements are analyzed and the results are the input into the development process and coming projects. Staff from all participating companies should participate in these activities since experience from all parts of the processes is important. It is also important that all participants feel responsible for suggesting and implementing improvements (Section 3.2.2, 3.2.5, 3.2.6, 3.3).

4.3 Concept verification

Experts in the field of industrialised house-building were interviewed in order to get feedback on the definition and description of industrialised house-building. The interviewees actively work as consultants/advisors and as managers of industrialised house-building production and development in the Swedish housing and construction industry. Hence these persons have well-established views of the area and its fundamentals. This section summarizes the input from the interviews and highlights the response the interviewees gave on the description. The interviewees are represented by the following persons.

Respondent no 1	CEO in a newly established small company working with industrialised house-building
Respondent no 2	Development manager in a large contracting company, responsible for a major programme for industrialised building
Respondent no 3	Regional business manager in a large contracting company, member of a development team for industrialised house-building
Respondent no 4	Head of design of a building system for a new industrialised house-building concept in a large contracting company
Respondent no 5	Advisor to the development group for a new industrialised house-building concept in a large contracting company
Respondent no 6	Advisor to several companies working with the development of industrialised house-building
Respondent no 7	Production and design manager in a company working with industrialised house-building
Respondent no 8	Development manager in a large contracting company, responsible for a major programme for industrialised house-building

4.3.1 Perception of industrialised house-building

The interviews started with a discussion on what industrialised house-building means to the interviewee. A majority of the respondents stated that it means a developed and efficient process, and frequently commented that it includes the use of building systems and prefabrication. However, one comment was that it is possible to achieve an industrialised process even without prefabrication and factory production if the focus is set on the process instead of the production method. Another related comment was that thorough preparations are crucial for an efficient industrial process. Respondent 2 emphasized that industrialised house-building includes several areas and he showed an illustration of his company's idea of industrialised house-building which is presented in Figure 4.1. This illustration shows that the company's idea of an industrialised house-building process consists of the areas of developed building systems, prefabrication, logistics and procurement, extensive use of ICT, management by Concept Owners, Systematic measurement and re-use of experience, which to a large extent is similar to the concept presented in this thesis. Respondent 8 also presented his company's idea of industrialised house-building which was illustrated with different sub-areas, such as well-defined building systems, extensive prefabrication, integrated logistics and procurement, extensive use of ICT and knowledge management. He also stressed that the focus on the customer is essential in order to be able to deliver the customers' requirements.

Figure 4.1 *Illustration of an industrialised building process. (Source: Skanska Sverige AB).*

The interviewees made clear that industrialised house-building is an area undergoing extensive development from which the building industry would benefit. Respondent 2 expressed great enthusiasm for this development, illustrated by this comment:

What makes it so interesting for you now, when you are doing your research project, is that you are working in an area at a time when so much is happening. We, the large actors in the construction field, Skanska, Peab and NCC are, more or less, doing the same thing, albeit somewhat differently. And it is happening now! When we start to move something will happen. Probably more development is going on no, than in the past 35 years! Dramatic changes are going on! It is not just talk, it is happening now!

4.3.2 Crucial parts

The interviewees were asked to identify the most crucial parts of industrialised house-building. A common answer was the development and establishment of the control and structure of the processes, especially in the early phases when all decisions, with consequences for the rest of the process, are being made. Thorough preparations and increased time and resources for planning the processes were also highlighted as crucial parts of the concept since they affect the rest of the process and provide benefitsin the whole process.

Respondent 6 thought that all areas are important for the development of industrialised house-building, by saying:

"No area is more important than another since all the areas are required if a new process is to be established."

He stated however that the design of a production system must be based on a clear perception of the customers' needs and priorities. Based on this, the different areas should be developed to certain levels, in balance with each other, in order to deliver the right product to the right customer.

4.3.3 The concept's sufficience

In the interviews the content of the concept for industrialised house-building with its eight areas was discussed in order to assess its completeness and comprehensiveness.

A majority of the respondents thought that the concept covered the area of industrialised house-building. Two of the respondents presented their company's concepts with their own illustrations, as mentioned above, and these have many similarities with the eight-area-model. In the interview with Respondent 2 the eight areas were discussed thoroughly and it was stated that his company is working with all the areas as parts of a whole.

A comment from respondent 7 was:

> *"Yes the eight areas cover it, all these areas must be included"*

Respondent 5 thought that the eight areas cover the concept but should be complemented by continuous improvements. Respondent 1 stated that the eight areas correspond well to their way of handling industrialised house-building, by saying:

> *"What you have written here fits us very well, it describes our way of working on this"*

In the discussions with the interviewees it was made clear that there is a difference between the *industrialisation* of the traditional building process and the concept of *industrialised* house-building. The difference was expressed as the need for a radically changed and developed process for the concept of industrialised house-building while industrialisation is about developing the traditional process step by step.

4.3.4 Managing the process

The management of an industrialised house-building process was discussed in the interviews. A majority of the interviewees were of the opinion that the process should be managed by the main actor in the process, meaning the module and element manufacturer or the main contractor who integrates the various sub-processes. None of the interviewees thought that the client should manage the process. The issue that was seen as most important is that a sufficiently clear and powerful management is in place. The identity of this management was seen as less important.

Respondent 2 and Respondent 8 presented similar ways to handle process management. Their common ideas are that Concept Owners are responsible for a product concept or building system which is used for the creation of certain end-products. The Concept Owner manages both unique projects in which the concept is used and also the development of the concept, in which experience from previous projects is used for further development of both the products and the process.

5 Case studies of industrialised house-building

In this chapter three case studies will be described. They have been carried out at companies working with industrialised house-building in different ways, producing apartment houses for customers with normal incomes.

The case studies were executed in order to apply the model here presented for industrialised house-building, on companies in the Swedish housing industry which are working with industrialised house-building in different ways and to investigate how these actors work, in terms of process structure and process management. The three companies were chosen as case studies since their method of working has aspects of industrialised house-building albeit with different approaches. Hence an overview of interesting initiatives within the field of can be gained.

The case studies had two main focuses; the overall picture of the companies' way of working with industrialised house-building, and the related process. Information was gathered primarily via interviews and discussions with persons working in the companies, observations on visits made to the companies' offices, factories and building sites.

5.1 Case 1

Case 1 was carried out at Moelven Byggmodul AB. This company has about 300 employees and a turnover of 400 million SEK and is a subsidiary of the large Scandinavia-based wood and timber company, Moelven. In total Moelven has about 3200 employees with a turnover of around 6 billion SEK. Moelven Byggmodul AB was founded in 1999 and since then four small companies producing volume elements, have been incorporated in the company as a strategy to integrate forward in the supply chain. For this study the part of Moelven Byggmodul AB called Moelven Byggmodul Sandsjöfors AB (hereafter referred to as MB), situated in the southern part of Sweden, has been the focus.

The company's business is the production of customized, multi-family apartment houses and single-family houses for housing areas under turnkey contracts. Their customers are project developing companies, professional clients and main contractors. Historically, the company has produced volume elements for offices, schools and pre-schools and this remains a minor part of the business.

In Sandsjöfors the company has a factory for the production of volume elements and also an office for structural design, sales and production planning and management.

Figure 5.1 The interior of MB's factory in Sandsjöfors.

The manufacture of building parts takes place at the factory, where wall and floor elements are built from raw material and assembled into volume elements, (Figure 5.1, Figure 5.2 and Figure 5.3). These volume elements are then completed and equipped to a high degree of completion, including flooring, windows, complete kitchens and bathrooms in which all equipment and machines are assembled. Also service installations, including electrical, sanitary and ventilation are made at the factory. The finished volume elements are wrapped in tarpaulin hoods to protect them during storage and transport to the assembly site.

Figure 5.2 Volume elements in production at MB's factory.

The factory has a simple layout and equipment, where wall and floor elements are built with craft methods on working tables with board lifters and an overhead crane as supporting equipment. No automated machines are used. The volume elements are transported through the factory on three parallel rails on the floor.

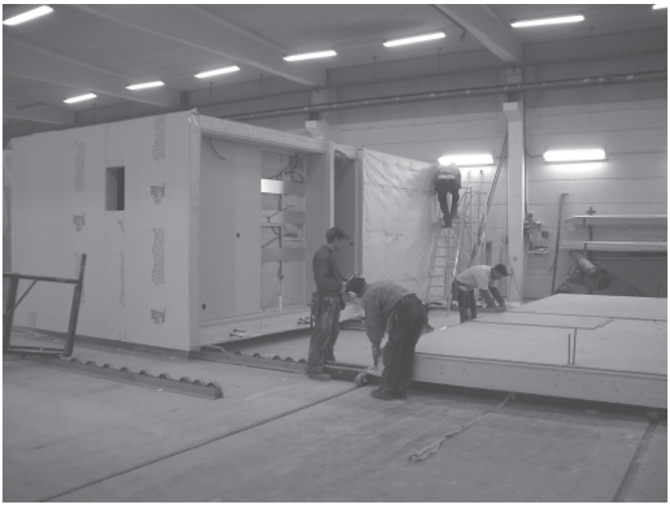

Figure 5.3 Floor and wall elements are pre-assembled to volume elements.

5.1.1 The Svedmyra project

This project is a housing project located in Stockholm approximately 350 kilometres from the factory in Sandsjöfors (Figure 5.4). It is an infill project where four new, three-storey apartment houses with a total of 48 apartments are being built within an existing residential area from the 1950s.

The project was initiated as a design competition by the client, a large public housing company. MB was invited by the main contractor Skanska who had already contracted an architect for the competition and, as the team's contribution won the competition, also for the project.

MB was contracted on a turn-key contract by Skanska to deliver and erect the complete buildings, with the exception of the foundation works, the external staircases and lift shafts, which were built by Skanska. MB was responsible for all activities from structural design, pre-assembly of the volume elements, transportation, final assembly and finishing work on site.

Figure 5.4 The location of MB's factory and the Svedmyra project's building site.

5.1.2 Description of MB's industrialisation

Planning and control of the processes

Structural design, production planning and production are located at the factory in Sandsjöfors providing a good environment for close cooperation and information exchange between the participants. However, these opportunities are not fully exploited, with the result that process control is inadequate. There are no strict routines for information handover and design review, delays are common, resulting in little production planning. Late changes in the assembly sequence lead to changes in the production sequence which affects the material supply. The design of a project is carried out by the design team with little involvement of manufacturing and assembly personnel. In the Svedmyra project many solutions were new and unique to the project but not suited to the production, which resulted in ad-hoc solutions and changes in the design after production had started.

Developed technical systems

MB has a building system for structural units for the volume elements. Some core principles are developed and followed in the company's production of timber frame volume elements, for instance the wall elements are built up of wood studs and plaster boards, floor elements are based on gluelam wood beams and the interface between walls and floor elements are standardized. For the company's production there is a set of preferred solutions suitable for the production system, but often projects are already started by a client and an architect and therefore other solutions must be used because crucial decisions have already been made.

The building system is not clearly defined and is poorly documented. To a great extent the documentation of the building system is embedded in design drawings for previous projects, which are stored as CAD drawings on the company's server. The design crew however is familiar with the preferred solutions of the system and their knowledge and experience is essential for the system's existence. No defined systems are used for service installations, which are designed uniquely for every project, based on basic design principles.

The building system is not developed systematically in separate development processes. Improvements of the system are made within projects, when special needs arise and, if applicable, are used in forthcoming projects.

Off-site manufacture of building parts

The work performed at the factory represent approximately 70% of the resources spent on a project. The volume elements are built and equipped to a high degree of completion with ready-made surfaces, installations, completely tiled bathrooms and fully equipped kitchens (Figure 5.5). The walls are made ready except for the plaster façade which is made on the site. The roof structure, based on pre-assembled roof elements, is delivered by an external supplier to the site and assembled and completed by MB's assembly team.

Figure 5.5 Installations in a volume element at the factory.

Long-term relations between participants

MB has a network of consultants and sub-contractors with whom they cooperate continuously. The collaboration is, however, not developed in a systematic way and the relations are not established on a long-term basis. The collaboration continues because it works well, not based on a strategy. MB has long-term contracts with some key suppliers, primarily chosen on price and with limited collaboration. Neither new nor existing suppliers and partners are systematically evaluated on performance and there is no collaborative development of products or systems between MB and a partner. The collaboration with main contractors, such as

Skanska in the Svedmyra project, is not established as long-term partnerships, with the consequence that there is a lack of insight into each other's routines, building systems and work flow.

Logistics integrated in the construction process

Some key materials are purchased in adjusted dimensions and geometry to improve the flow at the factory. Kitchen equipment is delivered once a week based on the expected flow in the production. MB handles the material and components in the temporary storage and within the factory, no suppliers deliver directly to the work place in the factory. Subcontractors such as tilers and electricians purchase and handle their own material.

The volume elements are delivered on trucks from the factory to the site, lifted directly from the truck to its final position in the building, which keeps the risk of damage due to storage and handling low.

Complementary material needed at the site is packed into the volume element at the factory and is delivered together with it. In this way the material required is at the right location immediately when the volume element is assembled and thus internal transport on the site is kept low. The material handling on the site is ad-hoc, with limited planning and is not based on any strategic logistical principles.

Customer focus

MB has no contact with end customers and considers the client and the main contractor as their customers. As a consequence MB does not perform any customer surveys.

MB produces unique buildings based on customer requirements and is flexible in adjusting the building system to fit these requirements. MB has no defined target segment on the market and delivers to a wide range of projects, from upmarket single-family houses to multi-storey apartment houses, hotels and schools. The company's production system is very flexible.

Use of Information and Communication Technology

3D CAD is used in the design phase within the company but the benefits in terms of quantity and production planning are not gained. There are separate systems for purchasing, project accounting, project planning and financial accounting. Since there are no automated machines in the factory there is no use for digital material in the production phase.

Solutions for the building system are embedded in project drawings and are not stored in any product data base.

Information exchange between participants in the process is based on e-mail correspondence, personal meetings and printed documents e.g. drawings and descriptions.

Systematic performance measurement and re-use of experience

All the time spent on the tasks necessary in the manufacture of the volume elements is logged and is a source of feedback on spent resources which is used when projects are summarized. The economic issues are followed in all projects.

Apart from this the measurement of performance is scarce in the company and its supply chain. There is no measurement of process performance, no measurement or evaluation of partners' and suppliers' performance and no evaluation of internal processes.

Systematic gathering of experience and knowledge is also scarce since there are no systematic routines or strategies for this. Knowledge is established individually but there is no established forum for sharing and spreading information and experience, and information is shared on an ad-hoc basis when needed.

5.1.3 Process management for MB

There are several key persons in the company working in the process, as presented below.

Business and sales manager

MB has a business and sales manager who manages the market contacts and initiates contracts with customers such as clients and contracting companies. This person sets up the deal and manages the early discussions related to production with the customers, by describing MB's production concept and its limitations. When a contract is signed and defined the business manager hands the project over to the design and preparation manager manager.

Design and preparation manager

The design and preparation manager manages a department with a team of in-house structural designers and purchasers. This team collaborates with external designers specialized in electrical and other service installations. The design and preparation manager is responsible for the technical design of the apartment houses, purchases and time scheduling of the project.

Local manager

The local manager has an overall responsibility for all functions based at the factory, i.e., the design, production and assembly team. His role is to ensure that the functions work together as a whole and is responsible for the economy. This person does not participate operationally in the projects, but he has an overview of the whole activity of the departments in Sandsjöfors.

Production manager

The production manager is in charge of the production at the factory, which includes the planning and preparation of the production work, scheduling, work structuring and responsibility for resources spent in the production. He has two foremen at the factory who assist him in the operational work.

Assembly manager

The assembly manager takes over the responsibility for the project when the volume elements leave the factory. His role is to manage the assembly and finishing work at the building site in order to complete the volumes to a complete apartment house. He manages a team of assembly workers and sub-contractors who perform the work at the site.

Site foreman

On a project of the size of Svedmyra, the assembly manager has a foreman based at the site to help him with the operational work.

5.1.4 The process for MB

MB is often involved in projects at a stage where some limits have already been set and the buildings are already defined to some degree. MB's building system and production system are based on the production of volume elements and for optimal use of these, the layout of the apartments must be based on some core principles. In the Svedmyra Project, Skanska had already involved an architect who had started the design process before MB was involved. Some key decisions were already made but it was still possible to build the apartment houses with MB's concept.

The project studied was considered as strategically important for the company since it could lead to procusing future projects from the client.

MB´s process in the Svedmyra Project is illustrated in Figure 5.6 and described below.

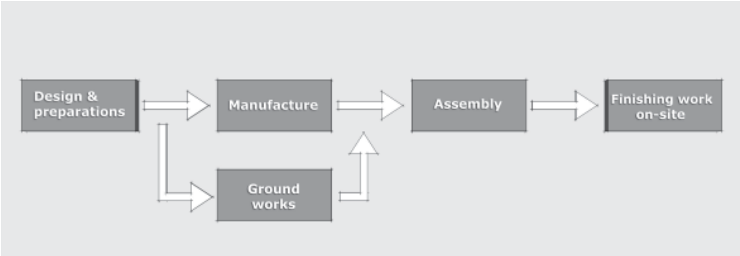

Figure 5.6 Schematic description of MB's process in the Svedmyra project.

Design and preparations

Input to this process is the order in which the project is defined concerning size, contract limitations, rough layout of the apartments, exterior architecture and the client's specific preferences for the project.

An initial meeting is held as the first step after the order is signed. At this meeting a project manager and team members are picked out for the design and preparation phase. Team members are one or more designers and one purchaser. The team starts with an "early preparation phase" where all details are defined together with the client, concerning choice of kitchen and bathroom equipment, flooring, type of windows and doors and other related issues. This information is used for the production preparation, which includes establishing a time schedule for the internal work, (the deadline for the project is often set in advance), purchase of components with long delivery lead times and the schedule for the manufacturing procedures at the factory.

The designers continue with two main tasks, namely, the structural design of the whole building, including creating solutions for all specific details in the unique projects and the creation of manufacture drawings. As mentioned above, MB's building system is based on some core principles but standardized solutions are not systematically documented and are only available as project-unique solutions embedded in earlier projects. Hence the solutions are not standardized in a consistent way and modifications are made for each unique project. The design manager commented on this by saying;

> "*We have gone through almost all required details*"

However he also stated that the design process is complex and requires a lot of effort and resources, with this comment;

> *"We create an incredible amount of drawings in our projects"*

The persons working at the design department are familiar with the preferred solutions and much of the crucial information is personal knowledge and experience without systematic documentation.

In the Svedmyra project there was a need for new solutions concerning soundproofing of the floor elements. This required new, un-tested, solutions designed by MB's designers together with an external consultant, and required resources beyond the ordinary project-design budget. These solutions are supposed to be used in forthcoming projects as standardized solutions. The design manager comments;

> *"This will definitely be standard for future projects with the same demands, we will now test and measure it to see how it works"*

There is limited exchange of information between the design team and the production management team during the design and preparation phase. There are no routines for the design team and the production management team to meet to exchange information and to discuss solutions for the project. The design team delivers the drawings and related documents to the production management close to the scheduled start of production. There are no fixed routines for the delivery of drawings in a defined number of days before production starts. In the Svedmyra project the production drawings were delivered to the production management after the internal deadline, due to the heavy work load on the design team. This led to a very tight schedule for the production, from the start.

The output from the design and preparation process is in the form of detailed drawings for the manufacture and assembly, purchase orders to suppliers for the delivery of material and components to the factory and time schedules for the whole project.

Manufacture

The input to the manufacturing phase is the manufacture drawings and information concerning material and components ordered. Before the production starts the production manager and the assembly manager discuss the assembly sequence of the volume elements at the site, based on the conditions and layout of the building site. The assembly sequence leads to a corresponding sequence for the manufacture of the volume elements.

The production starts with the floor and wall elements at one end of the factory. These elements are built of materials such as wood beams and studs, plaster boards, chipboards and mineral wool. The elements are also equipped with pipes and electrical installations for all service installations. The wall and floor elements are assembled into volumetric elements at the centre of the factory and then spread out on three parallel assembly lines. On these lines the volume elements are equipped with kitchen equipment and machines, flooring, windows, doors, internal walls and bathrooms which require cycles for both walls and floors (Figure 5.7). These include moisture sealing, tiling and finishing the seams and time for drying. The last task performed at the factory is to cover the volume elements with tarpaulins to protect them during storage and transport to the building site.

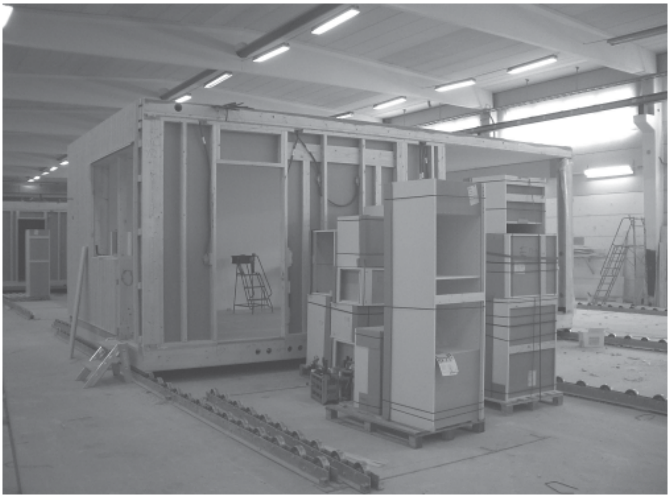

Figure 5.7 The volume elements are equipped with kitchen equipment.

The overall structure of the work is based on the flow in the factory, where certain tasks must be done before others. However, within this overall structure changes in the work sequence are made constantly to momentarily optimize the work flow. The foremen and the production manager spend much time at the factory to assess how the work is flowing and to find solutions to the problems that arise.

During the study of the manufacture for the Svedmyra project some illustrative issues were identified which had consequences for both production and the finishing work on-site.

The first issue was that the volume elements containing kitchen had been designed in such a way that the lower cupboards could not be assembled in the factory since they were placed right on the seam of the volume element. This led to severe consequences in the assembly phase since the wall above the cupboard could not be completed either, because the tiling had to be done after the assembly of the cupboards. This is further described below.

The second issue was that one of the walls in the bathrooms had to be left open because all the service installations were placed there. The pipes were installed after the assembly of the volume element, which meant that the plumbing had to be done from inside the bathroom. In the limited space in the bathroom, many other tasks had to be performed in the cycle of tiling the floors and walls, and the extra plumbing tasks delayed the flow of the whole assembly line. The wall could not be closed and completed at the factory because the pipes had to be available for connection at the building site. This also led to severe consequences at the building site, as described below.

The third issue was that one of the internal walls, equipped with several electrical installations, was designed with too narrow a space between the boards for the installations to fit. The problem appeared when the production was running and the consequence was that the wall had to be redesigned by the designers, with input from the production foremen, and the volume elements that were already built with the wrong solution had to be modified, thus delaying the flow in the factory.

The production manager commented these issues with;

> *"Unfortunately the designers do not think about the production when they do the drawings"*

On the question of whether is possible to standardize tasks even if the technical solutions are not documented and standardized, the production manager answered;

> *"I think we suffer from the lack of standardized technical solutions. Since we don't have documents to relate to, it is hard to standardize the task."*

Even if the schedule was good in this project, with a long lead time from order to start of production, these positive prerequisites were not taken advantage of, and the process became stressful and tight when the start of production approached. The delivery of drawings and information to the production department was delayed and hence the production management did not get the opportunity to thoroughly examine the drawings before the production was to start. The routines for the design, production and assembly team to meet to discuss and plan the project are scarce and are held on an ad-hoc basis rather than on a fixed and scheduled basis. The Local Manager has identified this problem and has taken action to establish weekly discussion meetings. He commented it like this;

> *"We have started to standardize the process and are on our way. Unfortunately we have not worked in this way in the Svedmyra Project, where we had little planning and much ad-hoc."*

The production manager has the ambition to document design errors and solutions which require development and examine these with the design team after the completion of the project. However there are no routines for this and it is not always done. When he was asked whether they systematically develop the building system based on their past experience, he answered;

> *"No, since we don't really have a system, we cannot develop it continuously, either."*

There is no programme to actively collect ideas from the workers concerning the building system or the production system. However, the foremen are present daily in the production and get ideas from the staff in an informal way. A flow of information back to the workers, if their ideas are to be realized, is rare and only occasional.

Ground works

Ground works are executed by the contractor Skanska which is also responsible for external stairs and elevators. The ground works include excavation, building of foundations and preparation of sanitary, electrical and other installation connections. The ground works were not sufficiently synchronized with MB, which resulted in delays and unnecessary work, as described below.

Assembly

The volume elements are transported on trucks to the building site and arrive early on the day they are to be assembled. The assembly is fast and between 8-12 volume elements can be assembled on a working day. The roof elements are assembled directly after the volume elements and hence the interior of the building is protected from weather immediately after assembly (Figure 5.8).

The assembly is done by MB's own staff who know the building system well and have the knowledge required for the task.

The assembly process requires that other tasks have been done in advance and in a sequence corresponding to the assembly pace. In this project, Skanska, the company responsible for the foundations and for the assembly of stairs and elevators were behind schedule, which led to consequences for the assembly process. The assembly manager commented it like this;

> *"Skanska were surprised at how fast we assembled the volume elements. They couldn't really keep the same pace."*

One consequence of this was that the assembly of external stairs was not done in time and hence MB had to organize scaffolding as an ad-hoc solution to this problem. This led to unnecessary work, delays and waste of money for the project. The reason given was that the contractor did not think that the schedule presented by MB was correct and did not work according to it.

The preparation between MB and Skanska before the operational work started was inadequate. Also MB's own site foreman was unprepared and entered the project only one week before the start of the work at the site.

Figure 5.8 The volume elements assembled at the building site.

Finishing work on-site

The volume elements are completed to a high degree when delivered to the building site. The main tasks remaining are the completion of the cladding with plaster, the connection of pipes and other installations, the completion of the roof with roofing-tiles and the painting of the interior walls. This is not done at the factory due to the risk of cracks developing during transportation. The tasks performed at the building site are done by both sub-contractors and staff employed by MB. For example, the electricians are MB employees while painters and service installers are sub-contractors, though they work almost exclusively for MB and hence they are familiar with both the systems and the staff.

Decisions taken in the design phase and in the production phase obviously have consequences, occasionally severe, for the final assembly steps and finishing work on-site. Two of the issues mentioned above led to severe consequences for the work on-site as described below.

The first issue was that since the cupboards could not be assembled at the factory this task had to be done at the site after the volume elements had been assembled. The cupboards and components required were packed and transported in the volume element in order to get the right items to the right place without internal distribution. A cycle of various tasks followed, performed by different categories of staff;

- Pipes were connected
- Floor was completed
- Cupboards were assembled
- Tiling above the cupboards was completed
- The walls beside the cupboards were painted

The three last tasks were direct consequences of the fact that the cupboards could not be assembled at the factory (Figure 5.9).

The second issue was that one wall in the bathrooms was left open for the pipes to be connected. The bathrooms were finished except for this wall which required the following tasks to be completed:

- Connection of pipes
- Building the wall of wood studs and plaster boards
- Moisture proofing
- Tiling
- Completing the seams of the tiled wall

None of these tasks would have been necessary on-site if the wall could have been completed at the factory (Figure 5.10).

Figure 5.9 Complementing work with the kitchen equipment, at the building site.

Figure 5.10 Complementing work with a bathroom wall, at the building site.

There are no routines for collecting the experience gained in the course of a project and for later use by the design team and production management team.

5.1.5 Supporting processes

The company does not work strategically with product or system development and no member of the staff has the responsibility to do so. Improvements to the building system and the production system are not systematized and are made only occasionally and not based on a concept of continuous improvements. The local manager stated that;

> *"No one has that responsibility, we don't have that kind of resources"*

However, he is convinced that the company must work towards a higher degree of standardized technical solutions and that the building system needs to be thoroughly documented. He comments it in this way;

> *"I think we must have standardized technical solutions and offer a number of concepts to the customers"*

The assembly manager states that the gathering of experience and knowledge from the production and site work is not done systematically. There are no routines for doing so and he also mentioned that even if information is brought back the company has no routines for using it. His comment was;

> *"Even if we bring back things to discuss with the persons in the factory, they are so busy with new stuff when we come back from an accomplished project"*

The process is not evaluated in order to be improved. The local manager states that;

> *"The development of methods is zero, completely"*

5.1.6 Standardized sub-processes

The sub-processes are generally not standardized in a systematic way by the company.

The local manager has identified this as a problem and he is planning to standardize the main sub-processes. His idea is to establish a structure for each sub-process which is to be followed in all projects. He presents the idea in this way:

> *"We want to get to the level where we have check-lists showing the flow, with gateways which cannot be passed before the demands are fulfilled"*

The assembly manager has a further idea for standardized sub-processes concerning the early phase of a project, where more effort should be spent on defining the end-product and that knowledge from design, production and assembly should be used in the early phase so that the product is designed with regard to the limits and possibilities of the system.

Figure 5.11 One of the finished houses in the Svedmyra project.

5.2 Case 2

Case 2 was carried out at PEAB Sverige AB (hereafter referred to as Peab). Peab is a large Swedish contracting company within the construction and civil engineering sector, with about 11.000 employees and a turnover of 25 billion SEK.

The company is divided into geographical regions and set up to work almost exclusively in projects. In each of these regions there are several business managers who are responsible for a number of projects, to which they assign site managers and foremen from their staff. The projects in a business manager's group are run individually and with limited connection with other projects in the company. The company has not developed building systems as a foundation for the production, and different suppliers are used for different projects. The company however owns a newly established concrete element factory which is often used as supplier of these components.

The company has a programme for development towards industrialised building which is managed by the company's development manager. The newly established concrete factory is one essential part of the company's development towards industrialised house-building, however, the development also covers the areas of procurement, logistics, production methods, building systems and platforms, market and customers, planning and preparation methods and collaboration with the participants in the process. The aim is to achieve an industrialised building process radically different from the present, in 3 to 5 years. The development process has started and both process and technological innovations are being tested in different pilot projects in order to be further developed and adjusted for forthcoming use on a larger scale. One of these pilot projects is the Solfångaren project described below.

5.2.1 The Solfångaren project

The project Solfångaren has been developed by Peab, which participated in a competition for land development, arranged by the municipal authorities in Lund. Peab involved an architect to design a proposal for the section of land, which resulted in eight apartment houses with both rental and owner-apartments. Peab won the competition and then involved the Real Estate Company Brinova. Together they established a commonly owned subsidiary called Brunnshögs Bostads AB, to act as a client company. After the project is completed, three of the apartment houses with 83 rental apartments will be owned by Brinova, and the apartments in the five remaining apartment houses will be sold to individual tenants. The project is located in the outskirts of the city of Lund, in the southernmost district of Sweden (Figure 5.12).

Peab is the main contractor for the project, based on a turnkey contract in which the client's demands on the project are defined, meaning that Peab has the responsibility to deliver the product ordered with its specified functions and qualities. To accomplish this, Peab involved other participants for example the architect, consultants and sub-contractors for different tasks in the project on a traditional basis. A key factor is that Peab has been involved in the project from the beginning and is in control of the project by its role of turnkey contractor.

The buildings are based on a building system of concrete elements in an open structure, uniquely designed for this project (Figure 5.13). This concept was chosen by Peab and designed by the project's structural engineer. The building system has been used in a project recently completed in the same vicinity. Thus the experience gained is re-applied in this project.

However the use of this concept is not based on a long-term, general strategy in the company, rather as a consequence of good experience of the system by the present business manager's team.

Figure 5.12 *The location of the Solfångaren project.*

Figure 5.13 *One of the apartment houses of the Solfångaren project, based on an open building system.*

The Solfångaren project has been used as a pilot project to test some of the innovations in the company's development towards industrialised building. The project has been studied thoroughly by researchers who performed time studies of all activities to investigate sources of non-value-adding activities. The material from these measurements has been used by the company's central development team working with the development programme, but not by the site management to further improve the project.

5.2.2 Description of Solfångaren's industrialisation

Planning and control of the processes

The design phase is planned and structured according to a process in which the project manager, site manager and all designers participate in an innovative design process, called Visual Planning. This concept includes a structured design phase where the participants together construct the time schedule and collaboration pattern. Frequent meetings lead to a shorter design phase with few errors and less time spent in total. Peab controls the project from start to finish but no individual person is the manager of the project from start to finish. One person is responsible for the design phase and another for the activities on-site. The activities on-site are based on traditional site management methods.

This project is similar to a recently completed project, with partly the same staff. Hence the project is well planned and well structured. Since the project consists of eight almost identical buildings, built in sequence, the process and routines are adjusted and improved in the course of the project. This has led to a high level of predictability and good control of the production phase.

Developed technical systems

The frame structure in the buildings is designed uniquely for this project, and is based on standardised components (Figure 5.14 and Figure 5.15). The documentation of the system covers the solutions for this project and no other documentation is available since it is not an established developed system. Service installations are also designed uniquely for this project and built up of standardised components but not in a developed system. However, the service installations are co-ordinated in the design phase and thus the concrete elements are already prepared for the installations, when manufactured.

Figure 5.14 Assembly of concrete elements.

Figure 5.15 The structural frame of concrete elements is assembled at the site.

Off-site manufacture of building parts

The concrete elements are semi-prefabricated. They include electrical, pre-assembled installations and are accurately dimensioned when delivered to the building site where they are assembled by Peab's staff. Non-structural cladding panels are also semi-prefabricated and consist of a wood frame with external plaster board when delivered to the site. These are completed with windows, insulation and plaster boards after assembly. All equipment for kitchens and bathrooms are assembled at the site, as well as all service installations except the electrical.

Long-term relations between participants

In this project a majority of the sub-contractors, consultants and suppliers are the same as in a similar recently completed project. Cooperation with the participants is not based on a long-term strategy, partners are chosen with price as the main factor, but also references and earlier relations are considered. No team activities have been developed nor is there a continuous development of the collaboration methods.

Logistics integrated in the construction process

Generally the logistics of this project is managed in a traditional way meaning that this is not an area of special attention. However the site management has planned the deliveries of key components and material in a supply plan and, for example, the concrete elements are delivered just-in-time to the site and are unloaded directly from the truck for assembly. The majority of deliveries are temporarily stored at the site before use, however. During the assembly of the structural frame key components such as windows and wall materials are lifted and placed into the right position by crane in order to keep internal transportation of bulky and heavy goods low. Thefts, disappearances and damages of material during storage at the building site have been a problem.

Customer focus

This project was initially based on a customer survey done for a recently completed project and used again in this project. For the rental apartments, no individual customization is done, but for the owner apartments the customers have had opportunities to choose some of the kitchen equipment, wallpapers and other materials. The project is to a great extent defined by its cost levels and thus focused on a segment of customers with normal incomes.

Use of Information and Communication Technology

Generally the level of IT use is low in this project. The technical designers use AutoCad as a platform for design documents while the architect uses ArchiCad and the supplier of concrete elements use 3D-Cad material for their digitally controlled machines. The participants in the project share information and distribute documents via e-mail and no document server solution is used.

Systematic performance measurement and re-use of experience

Apart from the financial side of the project, which is followed up, few other performance results are measured. There are no systematic measurement of performance or process efficiency, no feedback system, no documentation of learning in the project and no forum for the systematic sharing of knowledge gained. Such knowledge and experience remain with the individual and is shared only on an ad-hoc basis without an underlying strategy.

5.2.3 Process management for Solfångaren

The management of the Solfångaren project is traditional in its set up with a clear project focus. The different key management roles involved in the project are described below.

Business manager

The business manager is responsible for the financial aspects of several building projects within a certain geographic area, in this case for several projects in the vicinity of the City of Lund. The business manager is in charge of a group of site managers and design coordinators who actively operate in the projects.

Design coordinator

This person is active in the early stage of a building project and is responsible for managing the design team, consisting of consultants namely architects, structural engineers, electrical engineers, ventilation and service installation designers. This role includes the management of the design process, which means that the design coordinator must ensure that drawings and related documents are delivered according to the overall time schedule for the project. In this project an innovative design process is applied, which requires extra attention by the design coordinator, as further described below. The design coordinator also coordinates traditional client issues such as contacts with tenants, authorities and so forth.

Purchase manager

The purchase manager is responsible for all purchases in the project. This is done in close relation to the site manager and the business manager.

Site manager

The site manager has a broad area of responsibility at the building site covering production management, financial matters, the work environment and quality aspects. He is also involved in both the design and financial planning phase. One specific and important task is the overall planning of the work on-site which is done with a 3 month horizon.

Site foreman

The site foreman helps the site manager with operational tasks on the site. He is responsible for the forward planning of tasks for up to 3 months (after which the site manager takes over) and does much of this planning with the staff who are to perform the tasks. The foreman is also responsible for the on-site deliveries of materials.

5.2.4 The process of Solfångaren

As indicated above in the description of process management, there is no person or group actively involved in the project with the responsibility for the continuous process. The current process is highly dominated by a project focus in which the main is the delivery of the current unique project.

The process of a turnkey contract, which is a common type of contract for Peab, has a general, overall structure common for the company which has been developed over time within the company. The overall phases of the project process are illustrated in Figure 5.16 and are described below.

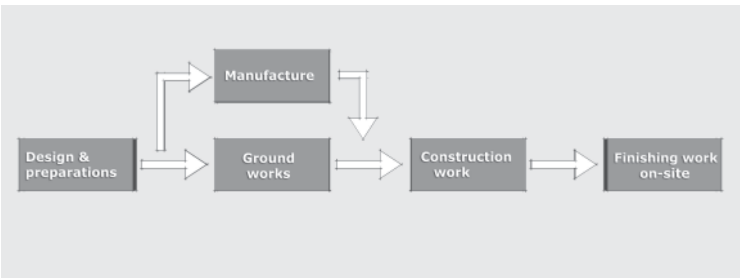

Figure 5.16 Schematic description of the process in the Solfångaren project.

Design and preparations

The product is defined in terms of the number of apartments, the overall layout and size of the apartments, equipment and materials standard and an overall exterior design and architecture, and is presented in the contract between the client and the turnkey contractor.

When the contract is signed the main contractor starts the planning and preparation of the project. Financial calculations are made for different solutions and the choice of structural frame and other key decisions are made in this early phase. These kinds of decisions are made on the basis of economy, earlier experience of the systems, availability of components on the market and other aspects. Key decisions are made during this phase concerning the structure of the buildings and the whole project. These decisions are the input to the design team whose task it is to solve all technical, architectural and functional problems in the project.

A process innovation in this project is the implementation and testing of a new and innovative way of managing the design phase. This was introduced and used in this project in order to test this sub-process which is planned to be one part of the industrialised concept in the company. The concept is called Visual Planning and is based on Lean principles used in the design of new products in the automotive industry. The design phase was compressed in time by having, twice-weekly short design meetings, in combination with a set of new tools to encourage the participants become involved by share information. The concept is described further in chapter 5.2.6.

The design phase is managed by the design coordinator and executed by a team of designers from different companies. This team is uniquely put together for this project and not engaged on a long-term basis. However most of the designers were also involved in a similar project completed prior to this, as mentioned above. The design team is complemented by the site manager and the foreman who participate during the whole design phase in order to contribute their knowledge and get crucial information from the design team, not only the documents that the design phase results in. The design phase was short; only 12 weeks for this project and the site management considered the design documents to have few errors and that they were produced in a less time in total, not only compressed. The site manager commented this:

> *"I thought it was great, I think we shortened the design phase to half the time and the architect claimed that he had spent fewer hours in total than usual on this kind of project. But it requires a structure for this to work, it takes much time to check drawings and this must be done intensively in this phase."*

During the design phase the buildings are designed in detail in close cooperation between the participants. The designers of electrical, ventilation and sanitary installations come from the subcontracting companies that are to execute the work on-site, which means that there are clear linkages between the design and the operational work. Crucial information needed by suppliers, such as the concrete element supplier, is established early in the design phase in order to allow the supplier to prepare and produce the components in time for delivery to the site.

Ground works

The foundation work is executed by Peab includes excavation, building of foundations and preparation of sanitary, electrical and other installation connections. This is done according to traditional methods and is synchronized and managed by Peab's site management team.

Manufacture

The concrete elements are manufactured in a factory owned by Peab. The relation to this is a traditional purchaser-supplier relation and Peab's staff is not involved in this manufacturing process. This is also the case for the other components manufactured off-site such as the cladding walls and balconies.

Construction work

The construction work is partly an assembly process since the structural frame and the cladding walls are prefabricated. However, the slabs are semi-prefabricated and require concrete casting on traditional construction principles. The assembly is prepared by the site management team together with the staff in order to achieve an effective assembly and construction process and get the staff engaged and committed to the work.

The processes for the assembly of prefabricated building parts, such as concrete flooring and wall elements, cladding walls and balconies, have developed in the course of the project. The first cycles in the first house took approximately 14 working days to finish, while in the last houses the cycle time for one floor of the house took 7-8 working days. The assembly of elements takes approximately half the cycle time, followed by complementing work with reinforcement, piping and other installation work, and finally the completing concrete casting in the shell walls and on the semi-prefabricated floor elements (Figure 5.17).

The process has been adjusted in many ways, for instance, the crane is used to set out windows and packages of plaster boards before the next roof elements are assembled (instead of using a fork lifter which takes more time). Further, the assembly order for floor and wall elements have been optimized in cooperation between the construction workers, the crane operator and the site foreman. Here small changes have made it possible to decrease the assembly time and establish an efficient and stable process.

Figure 5.17 The slabs are casted with concrete.

The crane operator is hired as a sub-contractor but functions as an integrated team member together with the assembly team from Peab. He is the only person who participated in the previous similar project and has brought in valuable knowledge. He is very involved and enthusiastic about the work and proud of the fact that the team managed to decrease the assembly cycle time so much. Many of the members of the assembly team are enthusiastic and proud of their work and contributions to making the process effective and there is a strikingly positive atmosphere in the team.

Finishing work on-site

When the structural frame is erected to a certain level other site work is begun. The first tasks are to set the windows and doors into the walls in order to close the house off, and turn on heaters, so that the newly cast concrete can dry. Seams between the concrete elements have surface differences and must be ground and plastered before the surfaces are smooth enough to be covered with flooring and wall paper. Kitchen equipment is assembled and built into the apartments (Figure 5.18). The bathrooms are built from scratch in a cycle with several different work categories involved.

Figure 5.18 Kitchen equipment before assembly in an apartment.

5.2.5 Supporting processes

The process in this project is to a major extent project-oriented with limited connection to other projects, systems or processes. However some tools have been developed in the company to support its project-oriented organization and these are employed in this project. Such tools are the Intranet with information about different production methods, a production handbook describing the project process, routines for purchasing, routines for production planning, routines for production economy, routines for quality insurance and other related tools.

The building system used in this project is uniquely designed for this project, but is based on components and sub-systems familiar to the project management group. The only documentation concerning this system is the drawings and documents for the apartment houses built in this project. Concerning this the business manager states that there is no person in the company working continuously to develop and improve this building system or the houses as products. And since the system is not established as a continuously used system in the company, no process related to it has been developed and documented. The business manager comments this;

> *"There is no person responsible for the concept. We who work on the project are the ones that handle it. The concept was invented within the project and we develop it further and share it with colleagues, but we don't have a process owner or something like that."*

Experience learnt in working with the project concerning the building system and concept are not collected and handled in a systematic way. This is confirmed by all participants in the project. The construction workers have had ideas for improvements for the concrete elements but have not had the opportunity to pass this on to the supplier of the concrete elements. One of the workers commented this;

> *"I have tried to forward some ideas that would increase the quality and simplify the work with the elements. But I have resigned; I don't care any more since they don't listen anyway."*

The business manager confirms that systematic knowledge management is scarce and is not a part of the process, by saying;

> *"No, we don't have any document that specifically describes the process for this kind of projects. In Svedala [the similar project prior to this] the site manager made a summary of the project with his ideas for improvements and so on, but that is very rare. He had a special interest for such things."*

5.2.6 Standardized sub-processes

The most central sub-process that is standardized and structured in this project is the design process which was separately developed and implemented in this project as a pilot test of the method.

Visual Planning

The design method is called Visual Planning and was developed by a consultancy firm with experience of the automotive industry, and adjusted it for construction design in a development project together with Peab. Visible Planning is based on Lean principles and was originally developed for product development at Toyota.[260]

Visual Planning is a tool for reducing the lead time in the design phase and increase the productivity in this phase. This is done by making the plans and goals visible. Before the design work starts the team members meet to become acquainted with each other and to establish common goals, rules and time schedules. The team consists of all the designers from all areas, the architect, structural engineer, electrical and installations engineers and also the site manager and foreman as well as the design coordinator and the purchaser.

Some core principles are established for Visible Planning, the first being that all meetings are held in the same room called "the head quarters". In this case the room was situated in the site management's office at the building site. The second principle is that meetings are frequent and kept short. In this project the design meetings were scheduled for twice a week and were planned to take no more than one hour. If further discussions between participants were required they were postponed and held with only concerned participants. The third principle is that focus is on the people involved and the process they participate in. The participants are encouraged to contribute and be active in the process in order to create maximum value, and in that way also get the most out of it themselves. The focus on the process has had the consequence that no protocols or meeting reports are written, the only document distributed is a list of decisions taken at the meeting. Other information is given at the meeting. The fourth principle is that all participants are involved from the start and participate in establishing the rules, goals and plans for the project.

At the first meetings the team members get to know each other and learn about the project by the project management and the architect presenting the visions and overall goals of the project. Together the team members discuss and establish some ground rules for the collaboration concerning distribution of information, participation at meetings and related issues. The time schedule is established in a general discussion concerning mile-stones for crucial events in the process (Figure 5.19).

---

260. Dalman, C. (2005)."*Visuell Planering*" Peab Projektrapport 2005, PEAB Sverige AB, Stockholm, Sweden

Figure 5.19 *The time schedule is established during a design meeting, using Visual Planning.*

Four big notice boards, which remain in the headquarters between meetings are used as tools in the process. The information on the notice boards is the following:

- The time schedule
- A To/From matrix
- Tough questions
- A list of decisions

The time schedule is established by the group and documented with Post-it notes on the time schedule board. The To/From matrix is on which Post-it notes with questions from one team member to another are attached to act as reminders, and the answer is expected at the next meeting. The board with tough questions is used to present problems that are difficult to solve by an individual team member. By bringing the problem up as soon as it appears it is likely to be solved by the team together, or if not, the question is transferred to a person or group to be solved separately. The decision list is just that, a list of decisions made during the meeting and is also distributed to the team members via e-mail as a reminder.

Erection of the structural frame

As mentioned above the assembly team developed the process for the assembly cycle. This became a standardized sub-process that was continuously developed throughout the project. This was possible and useful since there were to be built eight identical houses within the project This development of the sub-process was made to increase the productivity in this particular project. The process was based on the project's unique circumstances in terms of design, layout and configuration of components. The process was a collaboration between the assembly team, the crane operator, the suppliers of components and the site management, and was very fruitful and inspiring for the participants. However it required some effort from all involved. The foreman was both proud of the process and tired of working with the same thing for a long period of time, and commented it in this way;

> *We have shaped the production process from the start, not big stuff but it feels like a huge difference now compared to when we started. I cannot see what we could do more. I've run out of ideas now.*

The sub-process developed has not been documented and no systematic action has been taken to transmit it to other departments or teams in the company since there is no strategy for the concept. Staff from other parts of the company, with an interest in the concept have been to visit the project, but no systematic transfer of knowledge or process design is done.

Figure 5.20 Houses of the Solfångaren project.

5.3 Case 3

Case 3 was carried out at Det Ljuva Livet (hereafter referred to as DLL). DLL is not a company but a concept, developed and managed by two Swedish companies, the construction company NCC and the housing company Finndomo. NCC is a large construction company based in Scandinavia with about 7,700 employees and a turnover of 19 billion SEK for the Swedish construction division. Finndomo is a Finnish-Swedish company with about 850 employees and a turnover of 1.5 billion SEK in total for the whole company.

The concept was initiated as a contribution to a competition, arranged by a group of public housing companies in Stockholm, with the aim of finding concepts and solutions for cost-efficient apartment houses. NCC and Finndomo won this competition in 2002 and have built several projects since then and developed the concept further. DLL is a well defined product with a fixed design but the mix of apartment sizes and the number of apartments can be combined in several ways. The product is a two-storey apartment house with wood cladding.

The concept is managed by NCC, in close collaboration with Finndomo. NCC's role is to manage the business, find customers and sites and manage projects from start to finish as well as to develop the product and the process around it. NCC also builds the foundations and ground work in DLL projects. Finndomo's role is to manufacture, assemble and complete the buildings above ground and participate in the development of the product and process around it.

5.3.1 The Älta project

In Älta, a suburb of Stockholm a new residential area is being developed (Figure 5.21). A part of this area with 36 apartments is built with the DLL product and the apartments will be sold individually as owner apartments.

Figure 5.21 The location of the factory and the Älta project's building site.

5.3.2 Description of industrialisation of DLL

Planning and control of the processes

DLL is a highly defined product and the process for a DLL project is structured in the same way in all projects, with clear descriptions of each party's responsibility.

Finndomo's part is the manufacture, assembly and finishing of the buildings. They have all key design competences in-house including structural, electrical and service installation designers, who know the product and the production system. The production is done by skilled employees and to a minor extent, sub-contractors at the factory. The factory production is planned and controlled by a production manager and a team of 5 foremen. There are fixed routines for meetings every week between the design, planning and production management. Assembly is done by specialised sub-contractors in close partnership with Finndomo. This phase is however the least planned and controlled.

Developed technical systems

DLL is a developed product based on a wood frame building system. The product is defined and documented by standardised drawings of all its building parts. The service and electrical installations are built up of standardised components, individually designed for the product. The foundation is based on a system of concrete elements.

Figure 5.22 A volume element at the factory.

Off-site manufacture of building parts

Generally the level of off-site production is very high. The volume elements are manufactured in Finndomo's factory and are complete with windows, doors, cladding with painted wooden panel work, all interior surfaces including completely tiled bathrooms, kitchen and bathroom equipment and machines, electrical and service installations (Figure 5.22 and Figure 5.23). The roof is manufactured by Finndomo in wood elements which are assembled and completed with roofing-tiles at the site. Stairs and balconies are also manufactured at Finndomo's factory in Hässleholm. The foundation is manufactured off-site by a supplier to NCC and the elements are cut to exact so that an efficient assembly at the site is possible.

Figure 5.23 Production of a wall element at Finndomo's factory.

Long-term relations between participants

The relation between NCC and Finndomo is a long-term collaboration for their common product DLL, established already in the development of the product. The collaboration is defined and structured in a long-term contract. In DLL projects the same architect undertakes the planning of the housing area and the mix of apartments. The assembly sub-contractors work exclusively for Finndomo.

Logistics integrated in the construction process

When the volume elements are ready for delivery, the material and components necessary for the assembly and completing works of that particular unit, are packed inside the volume element in order to minimize internal transportation at the site and ensure that the right material is at the right place (Figure 5.24). When the volume elements are delivered, also roof elements and additional material necessary for the assembly work are delivered from Finndomo's factory. The volume elements are lifted from the truck directly into the position for assembly and are not stored at the site.

The factory takes care of internal materials handling and suppliers do not participate in activities at the factory. At the building site the assembly sub-contractor handles the flow of materials for the houses, mainly roofing material and material for external stairs. The contractor for the ground work handles the material for the foundation. There is no developed strategy for the logistics at the building site.

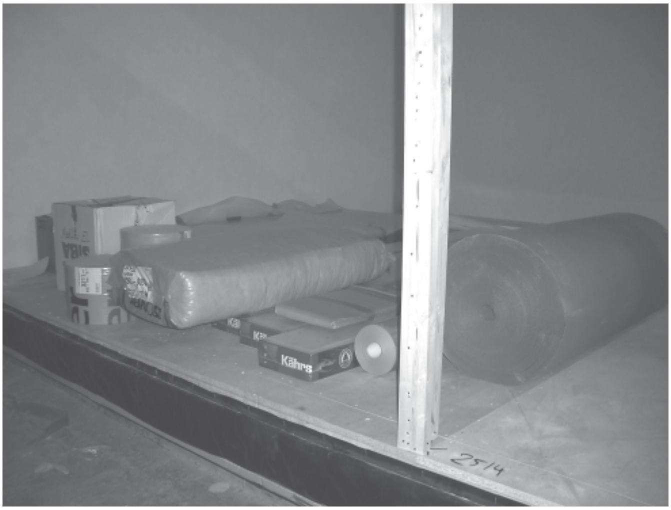

Figure 5.24 Material is packed in the volume element before it is shipped.

Customer focus

The product was developed and designed for a defined customer segment and based on the criteria set up in the competition. The design of the apartments is of high standard and makes efficient use of space. When the product is applied to rental apartments the variation is very limited and decisions are made by the client. When apartments are sold individually the variation is greater and the customers can choose colours and equipment from a defined selection.

Use of Information and Communication Technology

NCC has a product data server where all information about the product and the projects are stored and Finndomo has full access to this server. Finndomo has all drawings stored as standardised drawings, in a database for the product. Neither multi-dimensional product models nor digitally controlled machines are utilized in the production.

Systematic performance measurement and re-use of experience

The use of performance measurement is generally low. Experiences are captured at meetings held after the completion of every project, where the product owner from NCC, the member of staff responsible for the product at Finndomo and representatives of the divisions of design, production and assembly participate. Experience from the finished project is collected and used in further development.

A reference team in the factory meets regularly to discuss production-related issues for improvement. An ERP-system is being installed at the factory in Hässleholm and will provide the possibility to make time studies for each task performed in the factory.

5.3.3 Process management for DLL

The management of DLL is divided in different groups with various tasks and described below.

Executive Management Group

This group consists of executive managers at NCC and at Finndomo who are responsible for the business agreement, contract and overall collaboration between the companies.

Work Group

This group consists of persons from the department of industrialized house-building at NCC together with staff from design, assembly, sales and project management from Finndomo. The purpose of the group is to work with continuous improvements of the product DLL.

Concept Owner

NCC has a member of staff who is the Concept Owner for DLL at the department of industrialised house-building at NCC. He is responsible for the management of the concept at NCC, including technical improvements, collaboration with the partner Finndomo, internal marketing within NCC and for providing process support for project managers in housing projects.

Project manager at NCC

For housing projects based on DLL, NCC has a project manager. The project manager can either come from NCC Construction (the contracting division of the company), when the project is being built for a housing company, or from NCC Client (the project development division of the company), when the apartments in the project are to be sold to individual tenants. The project manager is responsible for the specific project for which DLL is used as a product and is supported by the Concept Owner.

Project manager at Finndomo

This person is always the project manager for Finndomo's part in projects using DLL, and he has had this role in all executed DLL projects. He supports NCC and the client with knowledge in the definition phase and manages the design and preparation process at Finndomo. This person is also key account manager for DLL and is the link between Finndomo and NCC.

Project management group

In a project using the DLL concept, a project management group is set up with NCC's project manager, Finndomo's project manager and NCC's Concept Owner. This group supports the project management with knowledge about the product.

Design manager at Finndomo

Finndomo has a design manager who is responsible for the design and production preparations of all products produced at the factory in Hässleholm. She is part of the work group for the DLL product.

Production manager Finndomo

The factory in Hässleholm has a production manager who is responsible for the production process. He manages the whole production at the factory and has five foremen working for him at the factory with hands-on management of the production. The production manager keeps an overview of the production at the factory, schedules the production and he is the main link between design/preparation and production.

Assembly manager at Finndomo

Finndomo has a manager for assembly and complementing works at the building site. He is the only person from Finndomo working at the site and he manages the team of sub-contractors and is the link between the factory and the site.

5.3.4 The process for DLL

The overall process for DLL concerning the collaboration between the two main participants NCC and Finndomo is thoroughly documented and specified in a process scheme. The process structure is established and documented to guide the participants in the process and show the order in which the different tasks are to be done and by whom. This document is considered important since it illustrates the process and makes it easier to communicate about the document. The Concept Owner had this comment on the documented process structure:

> *"It has definitely been useful for us to document the process, otherwise people wouldn't know what to do. It elucidates the boundaries for each party's responsibility."*

DLL projects are organized according to different models depending on the project's customer as mentioned above. When the project is built for external customers such as housing companies, the project manager comes from the local NCC Construction division and does not necessarily have any experience of the DLL concept. If the project is for apartments to be sold to individual tenants, the NCC Client division has project managers for the project who can be chosen on the basis of his/her experience of the concept since the NCC Client division is not as strictly divided in geographical regions.

Nevertheless, the DLL group at NCC supports to the project managers in several ways. The process documentation is useful, overall information that illustrates the process and the collaboration among the DLL participants. Supporting tools are gathered in an "information binder" where crucial information and check lists are provided for the project manager to follow throughout the DLL process. The DLL group's individual knowledge and experience of the concept are discussed at meetings with the project managers. The DLL Group does not have the power to control the process, only to provide support to the staff executing the DLL projects. Finndomo's Project Manager for DLL states that his work load and need of support from him is much greater when NCC Construction division manages the projects than when the NCC Client division acts as client and project manager.

The process for DLL in the Älta Project is illustrated in Figure 5.25 and described below.

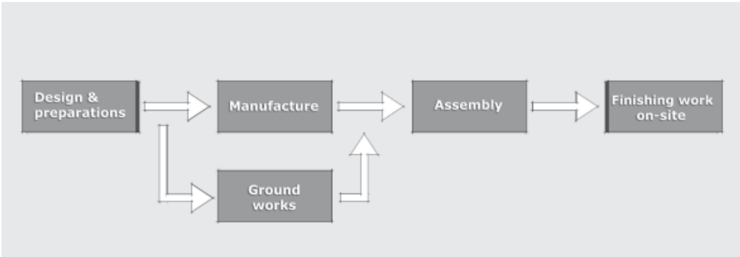

Figure 5.25 Schematic description of the process for DLL in the Älta project.

Design and preparations

When NCC has received an order for a DLL project the production preparation is started. NCC's project manager, supported by the Concept Owner, makes the overall planning, following the structure in the "information binder" for the project. Finndomo is contacted and informed about the order. An architect designs the housing area with the mix of apartments and location in a dialogue with NCC and Finndomo. A meeting with NCC's project manager, the Concept Owner, Finndomo's project manager and the client is arranged where all details and unique circumstances for the housing area are covered.

Design and production documents for foundations and ground work are provided by NCC and all documentation concerning the buildings is done by Finndomo. During the design phase meetings with the project group are held to synchronize the project.

Finndomo establishes a Manufacturing Order (MO) for the project which is a document containing all details concerning equipment, colours, machines, etc for all apartments. At Finndomo their project manager holds a meeting with the design team and the purchaser at which he informs them about the details of the project. The MO is used by the designers to establish the manufacturing drawings. Also the purchaser uses the MO for all purchases.

The design manager holds a meeting with the production manager to inform him about the project.

Manufacture

The manufacture is planned based on the production drawings and MOs delivered by the design team and the project manager. One line in the factory is dedicated to DLL and similar projects and the staff is familiar with the product. Every Monday morning a production meeting is held at which the production management and the design manager participate to plan the coming week's production. Dates when documents are required are set and when document deliveries are lagging behind, the most crucial information is identified and gathered, in order to keep up the flow in the production.

The MO's are used in the production of the volume elements and are attached to the volume element (Figure 5.26).

Figure 5.26 A Manufacturing Order attached to a volume element at the factory.

Complementing material to be used at the site is packed inside the volume elements. Additional building parts such as balconies and roof elements are manufactured in a separate part of the factory.

The project manager is involved in the process until the volume elements are ready and leave the factory after which the control is transferred to the assembly manager.

Ground works

The first activity in a DLL project is when the foundation and ground works are executed by NCC. The foundation is built with a system of prefabricated foundation elements which are assembled at the site (Figure 5.27). All installations are prepared for in the foundation.

Figure 5.27 The foundation for DLL is built with prefabricated concrete elements.

Assembly

The volume elements and the additional building parts are transported on trucks to the site, in a predefined sequence corresponding to the assembly order. The assembly manager and his team use instructions from the design team for the assembly of all elements. The volume elements are lifted from the truck directly to their final position and hence temporary storage on the site is avoided (Figure 5.28).

The assembly of the volume elements and roof elements is rapid, for example, one of the houses in the Älta project, with 8 apartments consisting of 14 volume elements, was assembled in two days. The roof elements are assembled directly after the volume elements are in place in order to minimize exposure to the weather.

Figure 5.28 A volume element is being assembled at the Älta project.

The assembly team is a sub-contractor to Finndomo and executes both the assembly work and the following finishing works on the houses.

Finishing work on-site

When the volume elements and additional building parts are assembled, the finishing of the apartments and buildings are carried out. The work done at the site is the connection of service installations, finishing floor surfaces, completing the roofs with tiles and building external stairs and other minor tasks (Figure 5.29). All these tasks are done by Finndomo's sub-contractor responsible for assembly and finishing site works.

When the project is completed a meeting with the project managers at NCC and Finndomo, the design and assembly manager, is held in order to document the knowledge and experience gained from the project. Occasionally a meeting has also been held internally at Finndomo with its focus on their part in the project. At such meetings the project manager, design manager, assembly manager and production manager and the team members from the different divisions have participated.

The production manager had this comment on such meetings:

> *"We have had some meetings with the assembly team after a completed project and discussed their experiences. This is extremely important and we cannot get too much of this. I am sure we can improve this and get better response from the assembly team."*

Figure 5.29 A kitchen in a DLL-apartment, ready for installation.

5.3.5 Supporting processes

Concept Ownership

NCC has a Concept Owner who supports the concept in several ways, as mentioned above. He is involved in knowledge management, product development and improvements, and he participates in marketing the concept internally at NCC. He also has an important role in supporting the project managers at NCC who are not familiar with the concept and this support includes help in the early stages of projects, participation at meetings with clients and with Finndomo. An important tool is a binder containing all crucial information, developed as support for the project managers at NCC, as mentioned above. This person has been involved in DLL since its initiation and therefore it is very important to reap the benefit from his knowledge of projects based on the DLL Concept.

Product development

The product DLL was developed in two stages; the first was a broad design phase where the outlines of the product were defined with some core limits set up for the competition. In this phase there was an intense collaboration between representatives of NCC and Finndomo, including architect and engineers. The result of this stage was presented as a contribution to the competition mentioned above. The second stage was a detailed product development which was undertaken when the first order was signed and it was certain that DLL would be realized. At this stage the close collaboration continued and the product was defined in detail, where by Finndomo was responsible for the buildings above ground and NCC was responsible for the foundations. When the design was ready, a full-scale prototype was built at the factory in Hässleholm, a two-storey unit with two complete apartments and exterior materials, fully detailed. This prototype was used for two purposes; firstly to make all details visible and to identify complicated solutions for further improvement and secondly to show customers the prototype and give them the opportunity to see the product before ordering. To build this prototype was considered as very useful for the detailed design of the product and many corrections were made and hence avoided in the production of the real buildings.

When there is a need for new technical solutions in a specific housing project according to DLL, for example when one project required piling for the foundation which had not previously been used, then new technical solutions are developed within the project in order to solve the problem. The costs are split between the project and the department of Industrialised House-building at NCC (owning the product DLL). In this way the solutions are developed for the project but documented and stored for use in coming projects.

Continuous improvements

The product is continuously improved and developed. The work with continuous improvements is managed by the Work Group with representatives from both NCC and Finndomo. The work is systematically structured and every six months there is a modification point at which improvements accomplished during the past six months are implemented in the product and used as default solutions from that point.

The group members bring their experience of the product and the process to the group and improvements are discussed, resulting in separate improvement projects. Such improvement projects are carried out in different parts of the organizations. Examples of improvements are new solutions for stairs, foundations, kitchens, cladding etc.

One important source of information for the Work Group is the meetings held after every accomplished project at which the project manager and Project Owner from NCC and the project manager, design manager, and assembly manager from Finndomo participate. On these occasions the project is evaluated and feedback is collected and documented to be used as input for further improvements of both the product and the process connected with it. Reports from the project are used to examine changes, finishing work and deviations from the overall plan. These may be technical or logistic matters or matters concerning the information flow or the cooperation between the participants discussed at these meetings.

At Finndomo separate meetings are held with all participants involved in DLL after the completion of a project to experience and gather knowledge. At these meetings staff from the design, production and assembly divisions, participate together with the project manager. Information from these meetings is used for internal improvements as well as input to the Work Group.

5.3.6 Standardized sub-processes

The design process at Finndomo follows a standardized structure to a high degree. In the early stage of a project the design manager is involved in the layout of the housing area and the chosen mix of apartments, in order to minimize complicated solutions. When the project is defined with Manufacturing Orders the detailed design work to produce manufacturing drawings starts. This can be seen as a process of configuration of the building system for unique solutions for the current project. Even if the product DLL is highly defined several unique solutions must be handled for instance, details on the façades and the roof or in the service installations which have consequences for the building elements. Depending on the number of unique solutions, the final design of the building elements can vary from project to project. The delivery of manufacturing drawings is scheduled to synchronize with the production planning However these deadlines are sometimes exceeded which leads to consequences for the manufacturing process.

The production is structured in standardized sub-processes within the factory where the different building parts are manufactured and put together according to a factory layout. After the building parts are assembled to form a volume element,10 days are needed to finish it, and during this time it is placed on the moving assembly line. When a volume element enters the assembly line it is crucial that all information needed for the finishing work is available, otherwise the flow of the line is jeopardized. This is well established facts at the factory but occasionally it happens that manufacturing drawings are late. Then the most crucial information is gathered to keep up the flow and remaining information is delivered later for coming tasks. This however requires unnecessary coordination and control between production management and the design team.

Figure 5.30 *All kitchen equipment is pre-assembled in the volume element, at the factory.*

Within the manufacturing process certain sub-processes are being developed. One of these standardized processes is the assembly of kitchen equipment (Figure 5.30). In order to establish a standardized process, meetings have been held with the assembly staff, the production management and the purchaser at which this process was discussed and documented in detail. The reason was that there were individual differences in how details were solved and this action was taken to institute one common way. The result is that the purchased components correspond with the components used and the kitchens look the same no matter which person assembled it. Furthermore the staff likes this way to work, according to the production manager who commented it in this way:

> *"The guys think it's great! OK, there is always someone claiming that their method is the best but when we have discussed it we agree on one way to do it and then that is accepted"*

The process and methods are documented in order to keep it established over time. The design team contributed by doing sketches illustrating the way the equipment should be assembled. This method is planned to be used for many sub processes such as plumbing, floor laying and electrical installations.

Figure 5.31 One of the DLL houses of the Älta project.

6 Case study analysis

This chapter includes an analysis of the case studies where levels of implementation and process-related issues are discussed.

6.1 Levels of implementation

The concept of Industrialised house-building is described as consisting of eight characteristic areas that together constitute the whole. These eight areas can be developed and implemented to different levels in the company, or collaborating group of companies, depending on the company's business choices, core activities, history and so forth. The company might have focused on some area, resulting in a high level of implementation for that and lower levels in other areas. Some areas are closely related which means that a level of implementation in one area possibly will affect the related area's implementation level as well.

In the analysis of the three cases, a model was required for assessing the levels of implementation of the different areas of the concept. In order to establish such a categorization model, for assessing levels of implementation and achievement in the different areas, key factors for the development of the areas are suggested and presented in Table 1. Generally the levels are graded from 0 to 4, as described below.

Level 0	No efforts in the area.
Level 1	The area is identified. Implementation is planned for.
Level 2	Efforts in the area in some aspects. Partly implemented.
Level 3	A clear strategy for the whole area. Implemented.
Level 4	The area is fully implemented and integrated with other areas.

The different areas are presented with examples for each level, where complexity and implementation increase with the grade, as described in Table 6.1.

Table 6.1 Industrialisation characterization and exemplification of level of achievement.

Area	Levels	Characteristics
Planning and control of the processes	0	Little structure of process planning and control. Time schedules are not definite, unclear responsibilities and management has poor control of the process.
	1	A clear holistic structure of the project processes. All participants respect delivery dates and schedule.
	2	Developed planning in early phases of projects where key participants collaborate to give input to schedule. Developed structure for design delivery.
	3	Clearly defined gates between sub-processes at which certain tasks must be fulfilled. Detailed planning of all processes supported by a structured planning system. All tasks in manufacture and assembly are thoroughly prepared for.
	4	Planning and control systems supported by advanced ICT tools and integrated with planning of supply chain activities. Performance measures give important input to planning.
Off-site manufacture of building parts	0	No off-site production
	1	Simple parts of the building are manufactured off-site. Examples are roof trusses and concrete elements.
	2	More advanced parts are pre-assembled off-site. These are, among others, façade elements, complete wall- and slab-elements and stairs with ready surfaces.
	3	Advanced parts are pre-assembled and integrated with other pre-assembled parts. It can be volume-elements with all surfaces completed, completely equipped bathroom modules and pre-assembled service elements.
	4	Advanced parts are pre-assembled, design and manufacture are supported by IT tools, advanced logistics principles and planning system.
Developed technical systems	0	Minimal use of developed technical systems. Hand craft methods dominate.
	1	Developed technical systems are used occasionally but without a clear strategy. These may be the frame-, façade- or service systems.
	2	Developed technical systems are designed and used for certain parts of the building, based on a technical strategy.
	3	Complex technical systems used for a majority of the parts of the building. Sys-tems are designed to fit to each other and developed in partnership with suppliers.
	4	Complex technical systems are used, continuously developed in partnership with other participants, based on experience from projects and supported by IT tools
Long-term relations between participants	0	No long-term relations are established.
	1	Some relations are identified as more important than others. Relations are estab-lished but not in a systematic way.
	2	Long-term relations are established with key participants, with activities to strengthen the relations. The partnering concept is used occasionally
	3	All participants are involved on long-term basis. The participants work together as a team. Strategic partnering with key participants
	4	A structured programme is used to work actively to develop relations and coope-ration. Evaluation is supported by IT tools. Strategic partnering is used comprehensively.

Area	Levels	Characteristics
Supply chain management integrated in the construction process	0	Logistic activities are not on the agenda.
	1	Solutions for better materials handling are used. Sufficient storage, delivery patterns and information exchange with key suppliers are examples.
	2	Just-in-time principles are applied. Strategic work with low storage levels, adjusted deliveries, packages and relations with key suppliers are established.
	3	Supply chain activities integrated in the construction process. Developed supplier services and information flow are included, enabling advanced technical solutions.
	4	Supply chain activities are fully integrated as natural parts of the construction pro-cess. Supported by ICT tools for planning, purchasing, scheduling and design.
Customer focus	0	The customer is anonymous and unknown.
	1	General insight into basic end-customer priorities, e.g. equipment preferences, apartment size. Clear perception of who the company's customer is.
	2	Basic investigations about end-customer needs and priorities for different cost levels and customer segments. Topics for investigation are, for instance, equipment, service needs and apartment layout.
	3	Systematic investigations about customer needs and priorities, follow-ups with tenants. ICT tools supporting investigations and analysis of the material.
	4	The customer investigations and follow-ups are integrated with other areas, e.g. the technical development, manufacturing and assembly process and project planning. ICT tools make the information transparent in the whole process.
Use of information and communication technology	0	No ICT tools are used.
	1	ICT tools are used by some participants in the process.
	2	All participants use ICT tools to support their own activities. No common strategy is used.
	3	All participants use ICT tools, integrated with each other. A common strategy is applied for the area.
	4	Advanced ICT tools used by all participants to support other developed areas. ICT tools support and integrate design, manufacturing, planning, performance measuring and purchasing.
Systematic performance measurement and re-use of experience	0	No measurement and no systematic re-use of experience.
	1	Experience exchange in some parts of the process for instance, at regular meetings with manufacturing staff or the design team. Limited documentation.
	2	Measurement of tasks of some parts of the process, such as key activities in manufacturing, assembly time, follow-ups in design. Documentation is handled by individual participants.
	3	Performance measurement of all parts of the process but limited co-ordination. Ex-periences well documented by process owner.
	4	Performance measurement of a number of areas, experience collected and distributed systematically, with ICT tools. This supports work with the customer in focus, relations, planning and the industrial manufacturing.

In the three cases studied an assessment of the levels of achievement was made in order to test the model and illustrate the differences between the companies' method of working in the areas of industrialised house-building. The assessment is based on the description of the sub-areas in each company and the exemplification above. The assessment of the levels is shown in Table 6.2.

Table 6.2 Assessment of the level of industrialisation for the three cases studied.

Area	MB	Sol-fångaren	DLL
1 Planning and control of the processes	1	3	3
2 Developed technical systems	2	2	3
3 Off-site manufacture of building parts	3	2	3
4 Long-term relations between participants	1	1	3
5 Logistics integrated in the construction process	1	1	2
6 Customer focus	2	2	3
7 Use of information and communication technology	2	1	2
8 Systematic performance measurement & re-use of experience	1	0	2

6.1.1 MB's level of industrialisation

In Table 6.2 and in the radar chart presented in Figure 6.1 the overall picture of MB's level of industrialisation is shown. The levels are generally low, with the exception for some areas showing the company's strengths. The two closely related areas of Developed Technical Systems and Off-site Manufacture can be seen as the core of the company, supported by ICT tools. The customer focus is relatively well-developed since the company's concept includes an extensive flexibility and the possibility to meet individual customer's needs.

MB has many excellent prerequisites for industrialised house-building, however some of these benefits are not used to their full potential. One example is collaboration and knowledge exchange between the departments within the company, which could be developed further and provide good opportunities to evolve a more efficient process. The fact that Design & Preparation, Manufacture and Assembly are based at the same location is unique but is not integrated and process-oriented, meaning that benefits in terms of a smooth, error-free process are not achieved.

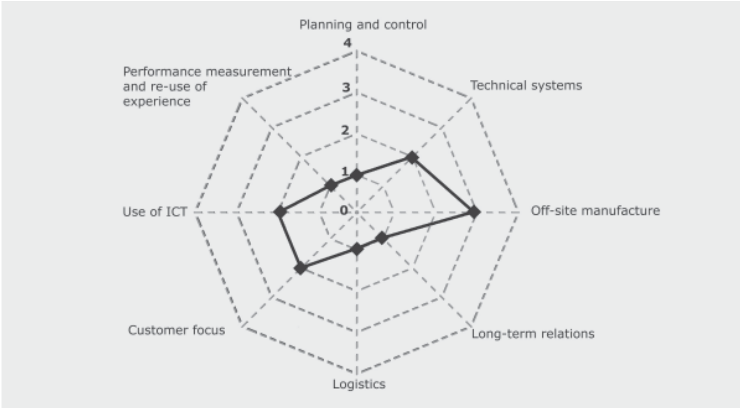

Figure 6.1 Illustration of MB's level of industrialisation.

6.1.2 Solfångaren's level of industrialisation

The overall picture of Solfångaren's level of industrialisation is shown in Table 6.2 and illustrated in the radar chart in Figure 6.2. The project is carried out by Peab, the firm in which a development towards industrialisation has been initiated. This is obvious in some areas while many are still at a low level of industrialisation and should be developed further in order to gain the benefits of industrialised house-building. It is not sufficient reaching high levels only in some areas, since there are numerous inter-connections at which the areas depend on each other.

The concept used in the design process is a very interesting one, showing a concrete application of Lean principles in the building process. The two areas of Developed Technical Systems and Off-site Manufacture include great opportunities for the company to develop technical platforms and a production system in which good solutions could be distributed throughout the large company. A particularly weak spot is the area of Performance Measurement and Re-use of Experience, which is probably a consequence of the strong focus on the project. Here the continuity is weak because this is a uniquely combined team for a unique product with a unique production system. Hence the incentive to spend resources on follow-ups and measurement of performance is low, especially since there is no natural receiver for this kind of information.

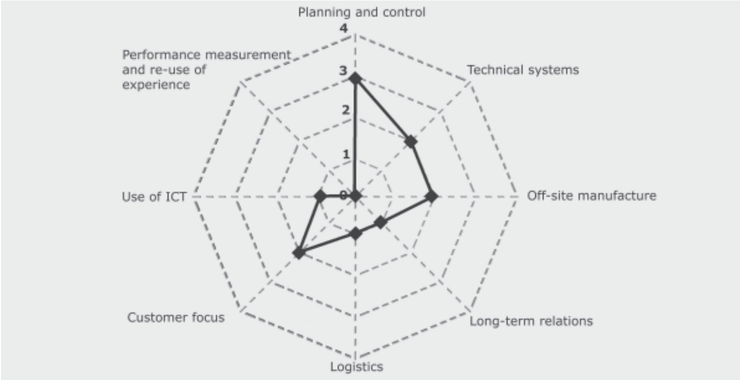

Figure 6.2 Illustration of Solfångaren's level of industrialisation.

6.1.3 DLL's level of industrialisation

The level of industrialisation for DLL is shown in Table 6.2 and illustrated in the radar chart in Figure 6.3. DLL as a concept developed as a collaboration between NCC and Finndomo and has achieved relatively high levels of industrialisation. The relations between the participants are established on a long-term basis, which is rewarding in many respects, for instance re-use of experience and continuous improvements which are made fairly systematically with benefits for the whole system. The strength of the concept is the manufacturing system which has strong connections to the building system, in symbiosis with a developed and documented process. This facilitates thorough planning and control. DLL is a highly defined product, developed in a process of product development, with a clear perception of the customer, making it a good example of Customer-focus for a special product targeting a special segment of the market.

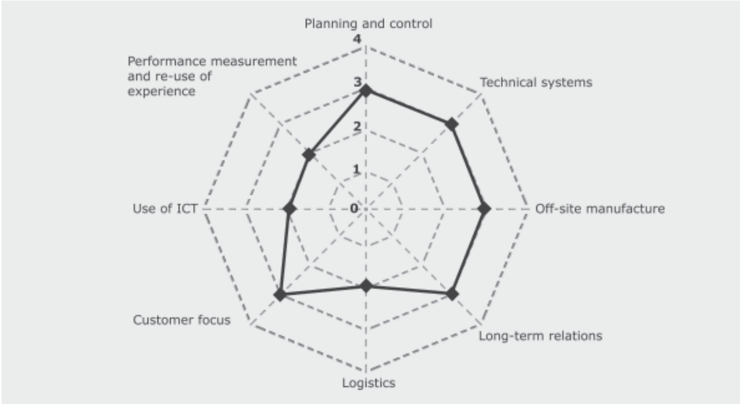

Figure 6.3 Illustration of DLL's level of industrialisation.

6.1.4 Cross-case analysis of industrialisation

MB and DLL have achieved similar levels in the areas of Developed Technical Systems and Off-site Manufacture and both the building systems and the production systems have many similarities. However, significant differences are apparent in the areas of Long-term Relations as well as in Planning and Control. The fact that DLL is a well defined product and MB produces unique buildings is probably one reason for the differences, since long-term relations are natural for the manufacture of a defined product, while it requires a strategic choice and efforts to achieve this for a company like MB. The differences in the area of Planning and Control might be explained by the fact that NCC and Finndomo both have a long experience in house-building production and hence have routines and tools for the planning and control of the processes. MB is relatively young as a housing producer and is a small company even though it is part of a large company, and thus less experience of house-building production is available both in the small (former family owned) subsidiary and the larger wood and timber producing company. Peab also has a high level of achievement in the area of Planning and Control which probably is due to the fact that this company is experienced in house-building and controls the whole process in a turnkey contract in the Solfångaren project. MB has very good prerequisites for thorough control of the process since they have all the key activities within the company.

An interesting relation between two different areas of industrialisation can be noted in the case studies concerning the areas of Long-term Relations and Performance Measurements and Re-use of Experience. These two areas are highly connected with continuity and hence companies that have worked with, and developed, continuity also achieve higher levels in both of these areas. This is the fact for DLL, while both MB and Solfångaren have low levels in both of these areas.

None of the companies reaches level 4 in any area. This implies that industrialised house-building requires thorough efforts over a long time period for the concept to be developed to high levels of achievement and integration between the areas. Integration is an important issue since several highly developed areas that are integrated are likely to lead to greater output than the areas can achieve separately, in analogy to the systems view.

Companies in the building sector are generally not used to working in a continuous, industrialised process, where performance measurement and continuous improvements are fundamental and the basis for development. This was found in these case studies and even companies with good prerequisites such as MB and the DLL concept are generally weak in these matters.

The three cases studied show different patterns in terms of the levels of implementation achieved, which is a snapshot of the companies' industrialisation at the time of the study. Are these patterns the result of strategic choices or merely coincidental circumstances? Generally, it is likely that a high level of implementation is the result of a strategic choice since it requires efforts in development to achieve this. A low level in an area may either be the result of low prioritization, based on a strategic decision, or may indicate a lack of awareness of the area's effects and opportunities. The radar chart presents an overview of the whole concept of industrialised house-building which also emphasizes that all of the eight areas are parts of the concept and all contribute to the whole.

The cases studied show examples of both strategically developed areas as well as areas under development which will probably achieve higher levels when changes are implemented. However, all of the companies would benefit from developing a holistic strategy for their industrialisation development, where strategies for all the separate areas are included and assembled within the company's context. This would be likely to lead to positive synergy effects since the different areas would reinforce each other's development.

6.2 The industrialised house-building process

6.2.1 Process structure

The process for DLL and the collaboration between NCC and Finndomo are thoroughly documented, which is regarded as being useful for the work in the process. Also the building system and the product as a whole is well-defined and documented, which has clear linkages to the process. Since DLL is a product with limited variation, the process is almost identical for all projects. The continuity is high and hence documentation of the process is regarded as useful and the resources spent on documentation are small compared to the benefits gained.

MB is also continually using its building system and the process is similar in different projects. The big difference between DLL and MB is that DLL is a defined product while MB produces individually designed buildings. However, MB's building system is not systematically defined and described and the documentation of the process is sparce. Some effects of this are shown in the examples where project-unique solutions for kitchens and bathrooms gave rise to serious consequences for the manufacture and assembly processes, in terms of unstable flow, additional tasks, additional coordination and changed flow of materials. This must be regarded as waste with no value for the customers. A possible reason for these problems, is that it is easier to deviate from, and do changes in, processes as well as in technical systems if these are not thoroughly defined and documented. The lack of documentation also makes it more difficult to show partners and customers the boundaries and possibilities of the systems and the processes.

Peab does not have a thoroughly documented process for the Solfångaren project. The project lacks the continuity needed for a developed industrial process and hence the process is not documented. Furthermore the technical solutions are not assembled in a platform and documented in a separate process. The buildings produced are not treated as products or end-products based on developed platforms but rather as a unique one-of-a-kind project, and the company does not have the infrastructure to handle products of this kind in a continuous process. Within the project the use of Visual Planning as a tool to make the design process more efficient, is a very interesting initiative. It is indicated that this standardized process will be used as one part of the company's industrialisation programme and hence continuity will be achieved in this area. This kind of tool is likely to be even more powerful if it is used in long-term relations which reinforce the continuity of the process. This was actually the case in Solfångaren since many of the actors involved had worked together in a recently accomplished project.

Within Peab's Solfångaren project continuous improvements have been made with substantial benefits for the project, e.g. the cycle for erection of the structural frame, which was improved by many small adjustments and by many staff members being highly engaged. However, there is a great risk that much of the knowledge and innovations developed within this project will be lost when the project is finished, since there are no routines for systematically reporting such knowledge. Furthermore there is no receiver for this kind of information through which it could be incorporated for further development and implementation in other, similar projects.

The design and manufacture processes for DLL are well structured and contain systematic documentation of experience at regular meetings in the course of the process and after finished projects. A continuous development is maintained in the process where experience gained is used as a source of input for the Work Group which is managing development and improvement issues for DLL.

MB owns the process from design and preparation via manufacture to assembly and finishing work on-site. This gives MB uniquely good circumstances for an industrialised process, as previously mentioned. The structure of the process is, however, somewhat undeveloped and there are no clear routines for the internal collaboration concerning information exchange, hand-over of drawings and related preparations. The different departments are relatively separated and functionally divided in contrast to the concept of process orientation. The company has an excellent situation for continuity since their business is based on a production system and a building system and, further, has its own design department, factory production and staff for assembly & site work based at the same location in Sandsjöfors.

In the Solfångaren project Peab owns the whole project, from early conceptual discussions, via design and building to the completion of the housing area. The project is large and has the character of a process in its own right due to its size. This implies that experience from the first houses built is transferred to the later phases of the project. But the project is not part of a process in which experiences from this project are systematically used as input for the further development of a platform or concept that will be applied in the same context again. Peab has a strong position in this project but since there is no strategy to re-use the team, the technical solutions or the product itself, the company has no obvious advantage from this project, due to the lack of continuity and industrial processes running in between the projects.

For the DLL concept, NCC and Finndomo control the whole process as well as the projects in which the product is delivered to customers. This is partly achieved due to the fact that DLL is a defined product controlled by the two companies, and variations are not allowed either of the product or the process. For MB the situation is different even if the company controls the process to a large extent. Since MB produces unique buildings for clients or main contractors, designed by different architects and hence are based on different designs, the conditions vary from project to project. However, the production process is controlled by MB thus facilitating extensive continuity, with the result that an effective production process based on a flexible building system can be achieved.

6.2.2 Product and process development

MB has a building system that has been developed within different house-building projects over a period of time. However, there is a stated need for further development and thorough documentation of the system in order to establish platforms for different kinds of buildings, as pointed out by the managers of the company as well as noted in the case study, where unique, un-tested solutions led to severe complications in the project's execution.

DLL was developed as a product in a separate development process. A full-scale prototype was built and enabled the development team to analyze the solutions and improve the design before the product was to be manufactured, in analogy to the concept of Lean design, where waste is avoided already in the design phase. During the life cycle of the product improvements have been made continuously based on experience gained in previous projects and this has affected both the product's design and the design of the production process.

The Solfångaren project was not based on technical platforms or complex concepts developed in separate processes. There are great opportunities to do this, which however, requires strategic choices at a high level in the company in order to make its implementation throughout the organization possible. However, the technical components used in the project, such as the prefabricated concrete elements, required quite a lot of supplementary work, such as grinding and plastering. This is an example of waste that ought to be minimized by continuous improvements, which would require a systematic flow of information between the manufacturer of the elements and the staff who handle the elements on site. This is naturally also a matter of continuity, which has to do with the permanence of the relations between the suppliers and the contractor.

Technical development in the companies is closely related to the development of the processes, which need also to be developed separately in order to achieve suitably advanced and sophisticated processes. This was done for the DLL concept parallel with the product development. Within the factory production in Finndomo some standardized sub-processes have been developed for equipment assembly, which can be seen as examples of process development with a close connection to the technical systems. This could be applied to many sub-processes in order to achieve more suitable and reliable processes in the DLL concept as also in Peab and MB. Process development or improvements need to be a natural part of the process in a similar way as technical development is part of the industrial process.

6.3 Process management

Process management covers all parts of the industrial process, the design and production process, product development, continuous improvements, partner relations and related issues concerning the process. This is in contrast to project management which is more limited and focused on a single project as described in Section 3.3.2.

As described above, MB owns a large part of the process based on the production system and building system. However there is no role in the company that manages the whole process, which is rather traditionally divided among the departments and functions in the company, with a focus on separate projects. The need for process oriented-management is evident, for instance, by the scarce collaboration and information exchange between the departments. Here is an area which has the potential to be radically improved. It was also stated in the case study that there is no-one in the company who actively demands information and feedback from the process, for further application. Hence this important issue of continuity, as well as other related supporting processes, is not being sufficiently dealt with.

Peab has a similar situation and does not have a manager with the responsibility to improve platforms and processes over time, also those separate from the projects. This is understandable since the company is highly project-oriented and does not manage technical platforms or continuous processes which recur. This lack of continuity also makes it difficult to have a role for process management.

NCC has a Concept Owner who manages the concept in terms of technical improvements as well as process-related issues. This and the Work Group (with representatives from both NCC and Finndomo) that handles improvement issues for the concept is an example of continuous, holistic management. However, neither the Concept Owner nor the Work Group controls the projects applying the DLL concept, which are managed differently by different departments within NCC. This limits the process management of the important projects and creates a distance between the Concept Owner and the actual project managers.

7 Models for industrialised house-building

This chapter introduces models illustrating the concept of industrialised house-building and its related process, based on the material presented in this thesis.

7.1 The Industrialised House-building Process Model

Industrialised house-building is based on eight characteristic areas that together constitute the concept, as already described. This way of describing industrialised house-building has been discussed and tested in the expert interviews reported, as well as in the three case studies. In order to clearly describe the concept, a model is designed that summarizes and illustrates that the eight areas should be treated as inter-dependent parts that should be continuously improved in strive for perfection. The model is called The Industrialised House-building Process Model, (the IHP Model) and is designed as a wheel with the eight areas as sectors of the wheel. Continuous Improvements is illustrated as the tire covering all the areas and makes the wheel run smoothly (Figure 7.1). The wheel analogy is illustrative since a wheel runs continuously and is not defined in time and resources, just as a process, and it can run slowly with limited energy input, as well as at high speed, which requires much energy and effort.

The model is applicable to companies working in the field of industrialised house-building as single actors covering the whole concept by themselves as well as to collaborating groups of companies with different core competences that together work with the concept throughout the supply chain.

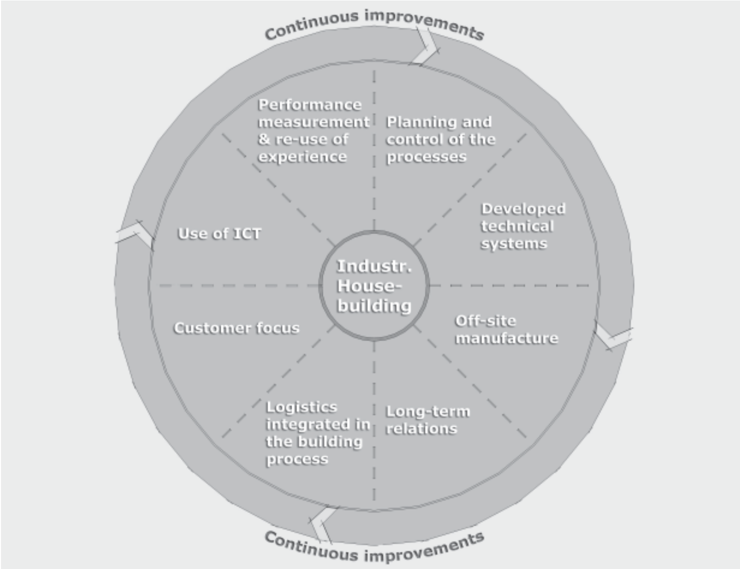

Figure 7.1 *Illustration of the Industrialised House-building Process Model.*

The areas of the concept can be developed and implemented to different levels, ranging from 0 to 4 as presented in Section 6.1. The levels suitable for a certain company or network of companies differ from case to case and must be based on the aim of the process and its demands. The aim should obviously be to achieve high levels, preferably level 3 or 4 in the key areas of the company, and establish a balance between all areas in order to create an effective process fulfilling the customers' demands and which is amenable to continuing improvements. There are several inter-connections between the different areas, as shown in the case study analysis. Hence the development of the different areas must be done according to a holistic strategy in which the inter-connections are analysed, otherwise there is a great risk of sub-optimization.

Figure 7.2 The Industrialised House-building Process Model, in which the areas can be developed to different levels.

The model works as a tool for assessing the level of industrialisation in the eight characteristic areas of industrialised house-building and gives a snapshot of the current situation of a company's industrialisation. Companies that are developing in the field of industrialisation can use the tool frequently over time in order to document how the levels of implementation change, and use this for strategic choices of further development. Figure 7.2 shows the IHP Model with levels from 0 to 4.

In the case studies the model was applied to different companies with different approaches to industrialisation which also included both project- and process-focused business. The model was found to work for both of these directions, since the areas can be implemented to different levels. The model is based on a process-oriented approach and hence project-oriented organizations must have supporting processes and concepts for continuity in order to achieve high levels of implementation in this model, otherwise the model will indicate weakness in those areas. This is an important and useful strength of the model, namely, its capacity to indicate and illustrate the weaknesses and strengths of a company's industrialisation. It can also illustrate that industrialised house-building includes all the eight areas and that weaknesses in some areas affect the overall pattern and level of achievement. The model is applicable to companies or collaborating groups of companies involved in the whole building process. For individual companies involved only in limited parts of the process the model is not fully applicable because it is based on the holistic view. However, for separate actors it can illustrate the context of industrialised house-building, and how the separate areas influence of the whole.

The model has been shown to function for companies working with industrialised house-building today, at levels of implementation graded from 0 to 4. The eight characteristic areas are of a general nature and will remain valid for house building over time. The model might, however, have to be complemented in future if the overall level of industrialisation in the house building sector undergoes a strong development. A natural complement would then be to introduce a level 5, representing examples of developments achieved by leading industrial actors within the building industry or possibly by other industrial sectors with applicable technology or processes.

7.2 Platforms for technology and process

Industrialised house-building covers a complex field of both technological and process-related issues as described and illustrated in the IHP Model. Platforms are suitable tools for use in the development of industrialised house-building in order to establish a foundation for the work. A Technical Platform and a Process Platform developed in close collaboration would be a powerful and concrete way to accumulate solutions, methods and tools in a context where they are designed to fit together and collaborate in a system.

The content of the platforms need to be developed in separate development projects, in which a multi-skilled team of experts from different areas collaborates. When the platforms are launched and are in use they need to be continuously improved in a process in which experience and knowledge are collected from the specific housing projects for which the platforms are used.

7.2.1 Technical Platform

A Technical Platform needs to be developed according to the demands of the company's business direction, that is, the kind of products that are to be produced, and ultimately to the customers' demands. The content in a Technical Platform obviously consists of modularized solutions for building parts of various kinds e.g. structural elements, walls, roof solutions, installations, bathrooms, equipment and so forth, with interfaces that allow interchangeability and parts that can be combined to create a variety of end-products. The platform also requires technology in terms of machinery and production tools, as well as ICT tools needed for effective production and the handling and flow of related information.

The Technical Platform needs to be thoroughly tested and adjusted before being applied in full scale production in order to minimize problems and waste in the process. It should also be thoroughly documented so that both technical experts and partners who will be working with the platform as well as customers and clients all have a clear understanding of the possibilities and boundaries of the platform.

In the case studies it was found that DLL is based on a building system for houses with well-defined solutions for apartments. This building system could be further developed into a technical platform which could be used for building other products than those using the DLL concept in its present form. For example it would be possible to develop a multi-storey apartment house based on the same components, which would represent another product based on the same platform and hence the product family would increase and thus cover another segment of the market. MB also has a building system that could be developed into a platform. This would be appropriate since MB's business idea is to build unique houses based on its building system and its production method. A technical platform would decrease the design work and ad-hoc solutions in the specific projects and would probably increase the efficiency and reliability of the solutions since they would have been tested before applied in full scale projects.

7.2.2 Process Platform

A Process Platform is developed in the same way as a Technical Platform, albeit with somewhat different methods. Demands on the platform should be based on the main process in the company and then different process modules can be developed to establish concrete process tools to support the process. In such modules process-related issues are accumulated and integrated with the Technical Platform to really support each other and establish a strong concept for both technology and process.

In the case studies some examples of process modules were identified, which could constitute parts of a Process Platform. One example is the concept of Visual Planning used by Peab in the Solfångaren project. This is an effective tool for managing the design process and which could be further developed also for the production process. This concept was developed separately and then applied in full scale projects. Another process module identified in the case studies is the way experience is collected and used for the DLL concept, where meetings are held after every project and information is used in continuous improvements. This module could be systematized to a higher degree and would possibly benefit from being thoroughly documented and thus facilitate its establishment. Other examples of process modules suitable for industrialised house-building are be the following;

Customer information	Routines and methods to investigate customers' needs and priorities, holistically and detailed for different purposes. Routines for how this information is used as input to product development.
Information flow	Routines and tools for sharing information within and between companies combined with defined stages in the process where certain information is to be shared.
Logistics module	Integration of logistic issues with the planning and control of the processes and the Technical Platform in order to get an effective and reliable flow of material throughout the supply chain.
Collaboration module	Establishment of routines for setting goals for the process holistically and for detailed goals for sub-processes. Implementation of methods for team work, motivation and trust. Devel opment of a company and supply chain culture in which everyone contributes to improvements.

7.3 Process ownership

The industrialised house-building process needs a role for strategic and continuous work on the process, including the Process Platform, the Technical Platform, the unique projects and all supporting processes required, in order to maintain the focus on the whole and attain the integration between the parts and the relations in the processes. The position of Process Owner cuts across the traditional structure of the company or network of companies and demands the responsibility and authority to manage the whole process as it is described above.

Important tasks for the Process Owner are to manage the development of the Technical Platform and the Process Platform and ensure that these are thoroughly integrated and sufficiently applied in the process. The Process Owner should also ensure that projects using the platforms are highly integrated in the process and that knowledge, experience and data from the projects are systematically processed and used as input for further development and improvement of the platforms. The Process Owner's relation to the Technical Platform and the Process Platform is illustrated in Figure 7.3.

The Process Owner works closely with the managers responsible for specific parts of the process such as product development, design, manufacture and assembly & site work. The Project Manager has also an important role, since he is responsible for house-building projects and uses the Technical Platform and the Process Platform and manages all unique issues in the projects. The Process Owner's role is to develop, establish and maintain a process, including supporting processes and tools, as well as technical solutions that the Project Manager uses in the execution of the projects. The Process Platform and the Technical Platform are therefore the foundation for the Process Owner's work, as illustrated in Figure 7.3.

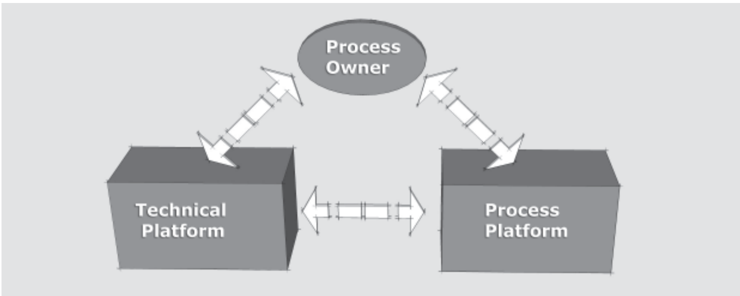

Figure 7.3 The relations between Process Owner, Technical Platform and Process Platform.

7.4 Process structure

A developed industrialised house-building process, as descried in the IHP Model, requires a process structure that enables the company, its partners, suppliers and other participants to work according to this concept. A company or group of companies, working with industrialised house-building develops the areas of the concept to high degrees in a balance according to the business direction and chosen customer segment. Platforms for both process and technology are used to create unique buildings or well-defined products within a product family. The process structure and the relations between the main process, supporting processes and the management processes are described below to illustrate an example of an industrialised house-building process.

7.4.1 House-building projects and the development process

The process and the projects have a different structure from traditional house-building projects as illustrated in Figure 7.4. A large part of the design work is executed in the continuous development process in which technical solutions are developed and structured in different modules as parts of the Technical Platform. The design phase for a certain project is characterized as a great deal of configuration of modules from the platform to form unique buildings. The design/configuration phase is executed by using process modules such as Visual Planning, that leads to a concentrated and reliable sub-process in which tested and functional solutions are used to a high degree.

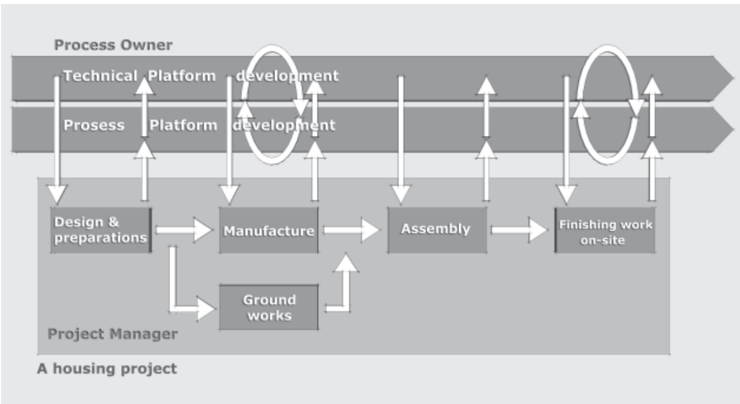

Figure 7.4 The relation between a specific house-building project and the development process.

The Project Manager handles the project, the relation to the customer and all unique circumstances related to the project. The Project Manager is engaged from the start to the end of the project, supported by the Process Owner and the processes in the company.

As a part of the process, when the work for the current project is fulfilled, sessions at which experience, performance measures and ideas for improvements of the sub-processes and its tasks, are discussed and systematically documented. The Process Owner and the Project Manager participate and analyse the information for further improvements.

Design/configuration and preparations

Modules from the technical platform are used in the configuration of a unique building. The designers are familiar with the solutions and the platform's limitations. The members of the design team work in close collaboration and include participants from Manufacture and Assembly as well as key suppliers in order to ensure that the information required is used in this important phase and that the participants are prepared for the following phases.

The planning and preparation of Manufacture and Assembly is well structured and based on project information and the documentation of the platforms. Representatives of Manufacture and Assembly participate in the planning and preparation activities in order to be well prepared when production starts. New solutions are tested and evaluated before full scale production starts and hence the team becomes familiar with them.

Manufacture

The manufacture of modularized building parts takes place in the company's factory which is equipped for efficient production. Digitally controlled machines are used for certain operations. Production-related information is distributed and processed well before production starts and the staff involved is prepared for their tasks. The production staff is encouraged to contribute to the efficiency of the process and to the improvement of both technical and process-related issues.

Ground works

Ground works are executed by a partner who is familiar with the concept in which the technical solutions are parts of the technical platform. These works are synchronized with the following assembly phase to facilitate the flow in the process.

Assembly

The Assembly is undertaken by the company's own staff or by an established partner familiar with the Technical Platform as well as the Process Platform. The staff are prepared for the assembly since they are familiar with the concept and the assembly manager has participated in the planning and preparation. The Project Manager can supply crucial information where necessary.

Finishing work on-site

Finishing work on-site is limited since the manufactured parts are completed to a high degree. However there are tasks to be executed and this work follows a systematic structure as a part of the Process Platform and technical solutions are parts of the Technical Platform.

7.4.2 Projects as a part of the continuous process

As the platforms continuously need to be improved and further developed this is an essential part of the process in an industrialised house-building company. The improvements to the Technical Platform are closely integrated with the improvements to the Process Platform. Projects are based on the platforms when executed, in order to achieve effective flow in the project and to deliver buildings of high quality at the right cost. The projects are systematically evaluated and these data are used as input to the improvements of the platforms, as described above. Major developments of the platforms require separate development projects, and new versions of the platforms are launched according to a strategy and time schedule. This continuous process is illustrated in Figure 7.5.

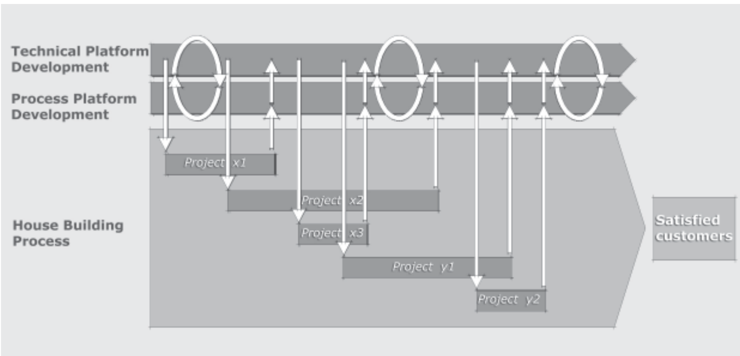

Figure 7.5 *The Process Model for Industrialised House-building. Continuous improvements of the platforms and its relation to the house-building process.*

In this model house-building projects, that have various degrees of uniqueness, are parts of the company's main process – house building, however with strong and systematically defined connections to the supporting processes.

The Process Owner and the Project Manager are key actors in the industrialised house-building process as described above. However, such a process requires full support also from the company's top management and that the structure of the organization allows and supports process-orientation. This achieves effective processes and strong continuity, providing many benefits and contributes to the learning organization.

8 Conclusions

This chapter presents the conclusions of the research project.

8.1 The concept of Industrialised house-building

Industrialised house-building is described as a complex concept consisting of eight interdependent areas and is proposed to be defined as follows:

> *"Industrialised house-building is a thoroughly developed building process with a well-suited organization for efficient management, preparation and control of the included activities, flows, resources and results for which highly developed components are used in order to create maximum customer value."*

The eight characteristic areas that together constitute the concept are:

1. Planning and control of the processes
2. Developed technical systems
3. Off-site manufacture of building parts
4. Long-term relations between participants
5. Logistics integrated in the construction process
6. Customer focus
7. Use of information and communication technology
8. Systematic performance measurement and re-use of experience

The Industrialised House-building Process Model emphasizes that, to create a strong industrialised process, all these areas must be developed. The eight areas can be implemented to different levels in a company or collaborating group of companies and a scale from 0 to 4 is developed as a part of the IHP Model (Figure 8.1). This scale is useful for assessing the levels of implementation in companies and the result is presented in a radar chart, showing weaknesses and strengths. This assessment gives an overview of the present situation and may benefit a company aiming to improve its industrialised processes.

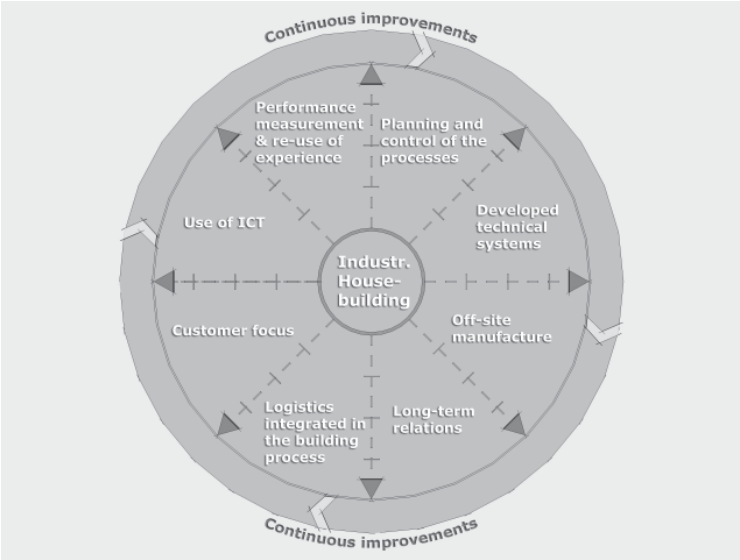

Figure 8.1 The IHP Model with its eight characteristic areas.

Platforms are tools for technical solutions as well as for process-related issues. A Technical Platform includes standardized technical solutions for building parts that can be combined to form unique buildings, and can be supported by other technological facilities such as ICT tools and suitable production machinery. A Process Platform consists of a set of process modules that are applied in the process to ensure a standardized procedure to execute the tasks in hand. One example in this thesis is the concept for structuring the design phase, called Visual Planning, which includes close collaboration, high frequency of meetings, early problem solving and so forth. Other modules suitable for a Process Platform could include logistics, collaboration, customer investigations and information flow. This would be expedient since they include the documentation of procedures, and lead to the establishment of ways to handle different parts of the process.

8.2 The process of Industrialised house-building

8.2.1 Process structure

The industrialised house-building process requires a change of focus, from unique projects, to continuous processes. The level of uniqueness needs to be limited and considered for technical solutions, composition of the team, purchase and logistics patterns, etc.

The traditional house-building process is not designed with continuity as a foundation, it is rather focused on the uniqueness and the singularity of projects characterized by unique choices of technical solutions, scant use of platforms, uniquely combined teams and scarcely developed logistics and procurement strategies. This lack of continuity leads to a conception that the need and benefits of long-term activities such as knowledge management, use of advanced ICT tools, developed supplier and partner collaboration, are limited and require effort and resources that cannot be included in individual projects.

An industrialised house-building process should be based on continuity and be designed to facilitate a continuous documentation of new experience and knowledge, and for an on-going development of collaboration between the actors in the process. Technical systems, thorough planning, advanced logistics and procurement should be used continuously, based on strategies and process modules, supported by ICT tools, in the realization of specific projects. The purpose is to establish the most efficient and reliable structure for the specific project and give the customer satisfaction. In this context, specific projects are seen as crucial parts of a continuous house building process. This continuous process must be supported by a process in which technical solutions, as well as process solutions, are improved and developed continuously, based on experience gained in previous projects in the main process. This is illustrated in Figure 8.2.

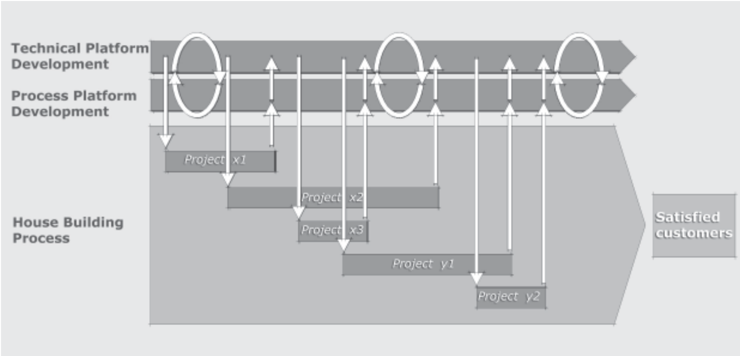

Figure 8.2 The Process Model for industrialised house-building, with supporting- and house-building process.

8.2.2 Process management

An industrialised house-building process requires a Process Owner who works continuously with the whole process, including the Process Platform, the Technology Platform, the specific housing projects and all required supporting processes. This role cuts across the traditional structure of the company and has the responsibility and authority to manage the whole process. Specific housing projects are managed by a project manager who handles all unique issues arising in the project and uses the Technology Platform and the Process Platform in the execution of the project.

Important tasks for the Process Owner are, to manage the development of the Technology Platform and the Process Platform and ensure a close integration of these, and that they are being used sufficiently in the process. The Process Owner should also ensure that projects, in which the platforms are used, are integrated with a continuous improvement process. Knowledge, experience and data from the projects need to be systematically processed and used as input for the further development and improvement of the platforms. The Process Owner's relation to the Technology Platform and the Process Platform is illustrated in Figure 8.3.

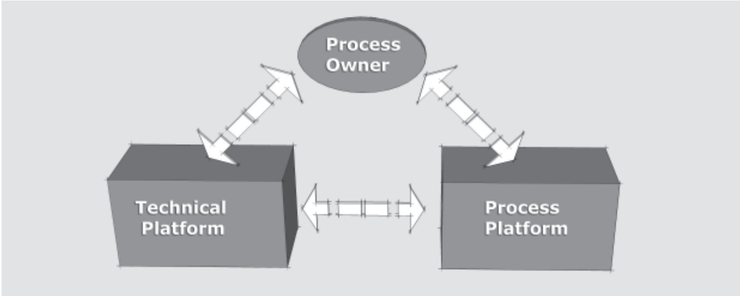

Figure 8.3 The Process Owner manages the Platforms.

The Project Manager is another important actor in an industrialised house-building process. This role is to manage all unique issues of a specific housing project, in which the Technology Platform and the Process Platform are used as tools for achieving an efficient house-building process.

The Process Owner's role is to develop, establish and maintain a process, including supporting processes and tools, together with technical solutions, which the Project Manager uses in the execution of the projects.

9 Discussion

In this chapter the research project and the field of industrialised house-building are discussed. Further research in the area is proposed and discussed.

9.1 Industrialised house-building

Industrialised house-building is an important issue for the construction industry in Sweden. It is presumably a key issue for the whole sector. A successful development of the house-building industry includes great opportunities for improved profitability. This insight may lead to increased investments in development and hence initiate a positive trend. The development of an industrialised house-building process will probably affect the traditional building process in a positive way. Principles, tools and sub-processes can be adjusted and used as means to improve also this part of the sector.

Many of the leading companies in the Swedish house-building industry, are working with industrialisation programmes, which possibly means that further development towards industrialised house-building, and other parts of the construction industry, will continue and more companies will follow. This movement also includes possibilities for new actors to be established in the field, not least through close partnerships between small and medium-sized companies which together can form interesting and competitive supply chains. The relatively well-developed part of the house-building industry, with companies focused on single-family houses, has great opportunities to develop and become actors in the field of multi-family houses. These companies have to develop their building systems and their processes, but with relatively little effort they can attain new positions on the market. Developed concepts and products, according to the concept of industrialised house-building described in this thesis, also include interesting possibilities for export and hence new business opportunities.

The movement towards industrialised house-building is not regarded as positive by everyone. One common argument is that industrialised house-building will lead to monotonous residential areas and buildings without local or regional adaptation. Hopefully they do not have to worry. Hopefully the development has only just begun and will lead to a large variety and numerous options for customers in all segments of the market. The expected benefits of a developed industrialised house-building process are, increased efficiency and quality combined with decreased costs. The working environment will probably be improved, which will facilitate the recruitment of staff. A more extensive use of automated machinery is one way of coping with the demographic change in age structure, which in the coming years will result in a considerably reduced work force.

Not only the production process and its participants are affected by the changes. Also the clients need to change their way of working and new knowledge is required. In an industrialised process the terms need to be defined and clarified at a certain point, whereafter changes are impossible, or at least very expensive. After this point the client must rely on the industrialised house-builder to deliver the ordered product of the right quality, at the right price and at the right time. Also suppliers have to develop in order to meet high demands from producers, for example, by developing components, improving logistics and contributing to product development processes.

Of vital importance for the further development of the construction industry, is the interest in and attitude to this development. There are numerous technological and process-related issues to be developed and implemented, which include great opportunities. However, it requires persistence and a deeply established will to develop, otherwise the benefits will be small. To achieve a shift from a project focused to a continuous, process-oriented business requires a great, but worth-while effort, from which many benefits can be expected.

One interesting approach is to take advantage of knowledge and experience from other industrial sectors, in order to develop the construction industry. The situation in Sweden is unique since there are many market-leading companies within the automotive and manufacturing industries with which fruitful and informative relations could be established.

9.2 Future research and development

The area of industrialised house-building requires further research since it is developing rapidly. The area is, as described in this thesis, based on several sub-areas that together constitute the concept and all these sub-areas need further development. However, it is crucial that further research is based on the fact that the sub-areas affect each other and that all areas are required for the concept to be powerful.

Research on the inter-relations between the different sub-areas would be fruitful for the further development of the concept. Some areas are closely related and obviously affect each other, while connections between other areas could be identified in a focused study. A study and analysis of this would lead to a better understanding of how action in one area affects others and hence be of great interest for companies developing their strategies for industrialised house-building.

Another important part of the concept which needs further research, is the development of Technology Platforms and Process Platforms. For Technology Platforms different product development strategies could be analysed together with various principles for modularization and technical interfaces. For Process Platforms different process modules need to be developed and analysed. Process modules must be developed to work together in a production system and supply chain and therefore the relations and interfaces between them need be investigated.

Industrialised house-building leads to changed processes and hence will affect the organizational structure in, and between companies. Therefore, it would be useful to further examine the changes required and related consequences. Also collaboration concepts, procurement and terms of contracts that support a development towards industrialised house-building, are important issues to be investigated.

Value chain investigations of companies which have developed their processes would show sources of waste and the generation of value. Such studies, which would require thorough measurements and analysis of statistical data, would be valuable in the examination of production methods and supply chain strategies.

Generally, it is appropriate to carry out research within the field of industrialised house-building in close relation to companies working in the field and in related industries from which knowledge can be transferred. Case studies are well suited since they allow the researcher to participate and interact with the environment being studied. Also action research would be fruitful, since the researcher is actively involved, with the aim to contribute to the development. Such research projects are fruitful for both the researcher and the company involved, but it requires a high degree of commitment of both parties to succeed.

References

Printed sources

Adler, P. (2001). "*Monteringsbyggda flerbostadshus*", Kungliga Tekniska Högskolan, Stockholm 2001.

Adler, P. (2005). "*Bygga industrialiserat*", Svensk Byggtjänst, Stockholm, Sweden.

Agapiou, A. et al. (1998). "The role of logistics in the materials flow control process" *Construction Management and Economics* 16, 131-137.

Ahrbom, N. (1983). "Arkitektur och samhälle – funderingar över 50 års svensk arkitektur" Arkitektur Förlag AB, Stockholm, Sweden.

Andréasson, I. (2005). "Behovet av industriellt byggande från byggherrens perspektiv" *Väg- och Vattenbyggaren*, No 2, 2005.

Apleberger, L. et al. (2003). "*ICT 2008 Informations och Kommunikationsteknologi för Bygg, Anläggning och Förvaltning - Ett Innovationsprogram*" ICT 2008, Stockholm, Sweden.

Arbnor, I., & Bjerke, B. (1994). "*Företagsekonomisk metodlära*" Studentlitteratur, Lund, Sweden.

Arnborg, S., Orrberg, L., & Edblom, A. (2005). Presentation at the seminar "*Design i det industrialiserade byggandet – processer och roller*" Vinnova, Stockholm 2005-05-18.

Ballard, G., & Howell, G. (1998). "What kind of production is construction?" *Proceedings IGLC-6*, 6th Annual Conference of the International Group for Lean Construction, Guarujá, Brazil, 1998.

Ballard, G. (2000). "Lean Project Delivery System" *LCI White Paper-8*, Lean Construction Institute.

Barlow, J. (1998). “From craft production to mass customization? Customer-focused approaches to housebuilding” *Proceedings IGLC-6*, 6th Annual Conference of the International Group for Lean Construction, Guarujá, Brazil, 1998.

Barlow, J. (1999). “From craft production to mass customisation: innovation requirements for the UK housebuilding industry” *Housing Studies* 14(1), 23-42.

Barlow, J. et al. (2003). “Choice and delivery in housebuilding: lessons from Japan for housebuilders” *Building Research and Information* 31(2), 134-145.

Bergström, M., & Stehn, L. (2005). “Ett effektivt stombyggande i trä” *Bygg & Teknik Nr 2*, 2005.

Bertelsen, S. (2004). “Lean Construction: Where are we and how to proceed?” *Lean Construction Journal* 2004, Vol 1 #1 2004.

Booth, R. (1996). “Agile manufacturing” *Engineering management journal*, April 1996.

Boverket, (2005). “*Bostadsmarknaden år 2005-2006 Slutsatser av Bostadsmarknadsenkäten 2005*” Boverket, Karlskrona, Sweden.

Boverket, (2005). “*Bostäder byggda med volymelement – En fallstudie av svenska bostadsprojekt*”, Boverket, Karlskrona, Sweden.

Boverkets Byggkostnadsforum, (2005). “*Forum, Magasin från Boverkets Byggkostnadsforum*”, No 1, 2005.

Brege, S. et al. (2004). “*Trämanufaktur – det systembärande innovationssystemet*”, Vinnova Analys 2004:02, Verket för Innovationsanalys.

Bunge, M. (1998). “*Philosophy of Science, Volume one – From problem to theory*” Transaction Publishers, New Brunswick, USA.

Byggkommisionen, (2002). “*Skärpning gubbar! Om konkurrensen, kvaliteten, kostnaderna och kompetensen i byggsektorn*”, Statens Offentliga Utredningar 2002:115, Fritzes Offentliga Publikationer, Stockholm, Sweden.

Byggkostnadsdelegationen, (2000). “*Från byggsekt till byggsektor*”, Statens Offentliga Utredningar 2000:44, Fritzes Offentliga Publikationer, Stockholm, Sweden.

Christopher, M. (2005). “*Logistics and Supply Chain Management - Creating value-adding networks*” 3rd Edition, Prentice Hall, UK.

Crowley, A. (1998). "Construction as a manufacturing process: Lessons from the automotive industry" *Computers and Structures* 67 (1998) 389-400.

Dalman, C. (2005). "*Visuell Planering*" Peab Projektrapport 2005, PEAB Sverige AB, Stockholm, Sweden.

Deeson, A. F. L. (1967). "*The Comprehensive Industrialised Building Systems Annual*" Product Journals Ltd, West Wickham, UK.

Dicander Alexandersson, M. et al. (1997). "*Att lyckas med processledning*" Liber Ekonomi, Malmö, Sweden.

Engström, D., & Claeson-Jonsson, C. (2005). "Industrialiserat byggande betyder inte nya betonggetton!" *Väg- och Vattenbyggaren*, No 2, 2005.

Fritzon, M. (2005). "Industrialiserat byggande i Skanskas tappning" *Väg- och Vattenbyggaren*, No 2, 2005.

Gann, D. (2000). "*Building Innovation: Complex Constructs in a changing world*" Thomas Thelford, London.

Gann, D.M. (1996). "Construction as a manufacturing process? Similarities and differences between industrialized housing and car production in Japan" *Construction Management and Economics* 14, 437-450.

Gibb, A. G. F. (2001). "Standardization and pre-assembly – distinguishing myth from reality using case study research" *Construction Management and Economics* (2001) 19, 307–315.

Hamrebjörk, L. (2005). "Ett industriellt byggande" *Väg- och Vattenbyggaren*, No 2, 2005.

Hellström, A. (2004). "Att bygga med industriella metoder" *Väg- och Vattenbyggaren*, No 5, 2004.

Hindersson, P. (2005). "Upprepning och samverkan är A och O" *Byggindustrin*, No 33, 2005

Ho, D.C.K. et al. (2002). "Empirical research on supply chain management: a critical review and recommendations" *International Journal of Production Research*, 2002, Vol 40, No 17, 4415-4430

Holme, I. M., & Solvang, B. K. (1996). "*Forskningsmetodik. Om kvalitativa och kvantitativa metoder*", Studentlitteratur, Lund, Sweden.

Hormozi, A. M. (2001). "Agile manufacturing: the next logical step". *Benchmarking: An International. Journal*, vol 8 No 2, 2001.

Howell, G. (1999). "What is lean construction -1999" *Proceedings IGLC-7*. Seventh Annual Conference of the International Group for Lean Construction, Berkely, California, USA 1999.

Hyll, H. (2005). "*Logistical principles in construction supply chains*" Dep. of Industrial Management and Logistics, Lund University, Lund, Sweden.

IGLC-13, (2005). "*Proceedings 13th International Group for Lean Construction Conference*", Sydney, Australia, 2005.

International Council for Building Research, Studies and Documentation – CIB (1965). "*Towards Industrialised Building*" Proceedings of the third CIB Congress, Copenhagen, 1965.

Jacobsson, M. (1965). *Byggandets industrialisering*, Byggnadsindustrins förlag, Stockholm, Sweden.

Johnson, T., & Bröms, A (2000). "*Profit beyond measure*" The Free Press, New York, USA.

Jones, D. et al. (1997). "Lean logistics" *International Journal of Physical Distribution & Logistics Management*, Vol 27 No 3/4, 1997, pp 153-173.

Josephsson, P-E. (1994)."*Orsaker till fel i byggandet*" Institutionen för Byggnadsekonomi och byggnadsorganisation, Chalmers Tekniska Högskola, Göteborg, Sweden.

Kadefors, A. (2002). "*Förtroende och samverkan i byggprocessen – Förutsättningar och erfarenheter*" Institutionen för service management, Centrum för management i byggsektorn, Chalmers Tekniska Högskola, Göteborg, Sweden.

Karlsson, C., & Åhlström, P. (1996). "Assessing changes towards lean production" *International Journal of Operations & Production Management* Vol 16 No 2 1996.

Lantz, A. (1993). "*Intervjumetodik*" Studentlitteratur, Lund, Sweden

Lessing, J. (2004). "*Industrial production of apartments with steel frame – A study of the Open House System*" The Swedish Institute of Steel Construction, Report 229:4, Stockholm, Sweden.

Lessing, J. et al. (2005). "Industriellt byggande är mer än bara prefabricering" *Bygg&Teknik*, No 2, 2005.

Lessing, J., Stehn, L., & Ekholm, A. (2005). "Industrialised housing – definition and categorization of the concept" *Proceedings IGLC-13*, 13th Annual Conference of the International Group for Lean Construction, Sydney, Australia, 2005.

Liker, J. (2004). "*The Toyota Way*" McGraw-Hill, New York, USA.

Linderman, K. et al. (2003). "Six Sigma: A goal-theoretic perspective" *Journal of Operations management*, 21 (2003) 193-203.

Ljungberg, A., & Larsson, E. (2001). "*Processbaserad verksamhetsutveckling*" Studentlitteratur, Lund, Sweden.

London, K.A., & Kenley, R. (2001). "An industrial organization economic supply chain approach for the construction industry: a review" *Construction Management and Economics* 19, 777-788.

Marmstål, M. (1992). "*Byggarna och maskinerna*" Byggförlaget, Stockholm, Sweden.

Mason-Jones, R. et al. (2000). "Lean, agile or leagile? Matching your supply chain to the marketplace" *International Journal of Production Research* 2000, vol 38, No17, 4061-4070.

Mentzer, J. et al (2001). "Defining Supply chain management" *Journal of business logistics*, Vol 22, No, 2001.

Merriam, S. B. (1988). "*Fallstudien som forskningsmetod*" Studentlitteratur, Lund, Sweden.

Meyer, M. H., & Lehnerd, A. P. (1997). "*The power of Product Platforms – Building value and cost leadership*" The free press, New York, USA.

Mikkelsen, M. et al. (2005). "*Systemleverancer i byggeriet – en udredning til arbejdsbrug*" Institut for Produktion og Ledelse, Denmark Technological University, Lyngby, Denmark.

Myrdal, G. (1965). "*Towards Industrialised Building*" Proceedings of the third CIB Congress, Copenhagen, 1965, International Council for Building Research, Studies and Documentation – CIB.

Naim, M., & Barlow, J. (2003). "An innovative supply chain strategy for customized housing" *Construction Management and Economics*, 21, 593-602.

Naylor, B. J. et al. (1999). " Leagility: Integrating the lean and agile manufacturing paradigms in the total supply chain" *International Journal of Production Economics* 62 (1999) 107-118.

NCC, (2004). "*Annual report 2004*", NCC.

Ohno, T. (1988). "*Toyota Production System- Beyond Large-Scale Production*" Productivity Press, New York, USA.

Olofsson, T. et al. (2004). "*Produktmodeller i ett flexibelt industriellt byggande*" Teknisk rapport 2004:06, Institutionen för Samhällsbyggnad, Avdelningen för Konstruktionsteknik, Luleå Tekniska Universitet.

Olofsson, T. et al. (2004) "Industriellt byggande byggbranschens nya patentlösning?" *Väg- och Vattenbyggaren,* No 5, 2004

Olsson, F. (2000). "*Supply chain management in the construction industry -Opportunity or utopia*?" Dep. of Design Sciences, Logistics, Lund University, Lund, Sweden.

Rentzhog, O. (1997). "*Processorientering – En grund för morgondagens organisationer*" Studentlitteratur, Lund, Sweden.

Roy, R., Brown, J., & Gaze, C. (2003). "Re-engineering the construction process in the speculative house building sector" *Construction Management and Economics* 21(2), 137-146.

Sahin, F. (2000). "Manufacturing competitiveness: different systems to achieve the same results" *Production and Inventory Management Journal* 41(1), 56-65.

Senge, P. M. (1990). "*The fifth discipline – the art & practice of the learning organization*" Random House business books, London, UK.

Skarne, A. (1987). "*Med kran och krok*" Byggförlaget, Stockholm, Sweden.

Stake, R. (1995). "*The art of case study research*" SAGE Publications, Thousand Oaks, USA.

Statens råd för byggnadsforskning, (1969). "*Elementbyggnad – problem och forskningsbehov*" Programskrift Nr 10, 1969, Svensk Byggtjänst, Stockholm, Sweden.

Statens råd för byggnadsforskning, (1970). "*40 sätt att bygga småhus*", Svensk byggtjänst, Stockholm, Sweden.

Statens råd för byggnadsforskning, Moby-kommitén (1975). "*Monteringsbyggda flerfamiljshus*".

Statistics Sweden, (2005). "*Yearbook of Housing and Building Statistics 2005*" Official Statistics of Sweden, Örebro, Sweden.

Strand, P. (2005). "Strukturerad projektering ger ett industrialiserat byggande" *Väg- och Vattenbyggaren*, No 2, 2005.

Sörqvist, L. (2004). "*Ständiga förbättringar*" Studentlitteratur, Lund, Sweden.

Tan, K. et al. (2002). "Supply chain management: a strategic perspective" *International Journal of Operations & Production Management*, Vol 22 No. 6, pp 614-631.

Tarandi, V. (2005). "IT-stöd för ett industriellt byggande – ett gemensamt språk" *Väg- och Vattenbyggaren*, No 2, 2005.

The Construction Task Force, (1998). "*Rethinking Construction*" Department of Trade and Industry, London, UK.

Thurén, T. (1991). "*Vetenskapsteori för nybörjare*" Liber, Stockholm, Sweden.

Tyrén, S., & Åkerblad, H. (1965). "The rationalisation of drawings – Carrying on of rationalisation work" *Proceedings of the third CIB Congress*, Copenhagen, 1965, International Council for Building Research, Studies and Documentation – CIB.

Wallén, G. (1996). "*Vetenskapsteori och forskningsmetodik*" Studentlitteratur, Lund, Sweden.

Winch, G. (2003). Models of manufacturing and the construction process: the genesis of re-engineering construction. *Building Research & Information* 2003, 31(2), 107-118.

Womack, J., & Jones, D. (1996). "Lean Thinking – Banish waste and create wealth in your corporation" Free Press, New York.

Womack, J., Jones, D., & Roos, D. (1990). "*The machine that changed the world – The story of Lean Production*" Harper Perennial, New York, USA.

Vriejhoef, R., & Koskela, L. (2000). The four roles of Supply Chain Management in Construction, *European Journal of Purchasing & Supply Management*, Vol 6, pp. 169-178.

Yin, R. (2003). "*Case study research - Design and methods*" Sage Publications, London, UK.

Åberg, U. (2004). "En industrialiserad byggprocess – möjlighet eller myt?" *Väg- och Vattenbyggaren*, No 5, 2004.

Electronic sources

http://www.cscmp.org, *Council of Supply Chain Management Professionals,* visited February 15, 2006.

http://www.iglc.net, *International Group for Lean Construction*, visited 2006-03-15.

http://www.leanconstruction.dk, *Lean Construction DK*, visited 2006-03-15.

http://www.leanconstruction.org, *The Lean Construction Institute*, visited 2006-03-15.

http://www.leanforumbygg.se, *Lean Forum Bygg*, visited 2006-03-15.

http://www.ncc.se, *NCC AB*, visited 2005-04-25.

http://www.ne.se, *Nationalencyklopedin* (2006), visited 2006-05-18.

LUNDS UNIVERSITET

Lunds Tekniska Högskola

ISBN 978-91-631-9254-8